Using Geophysical methods for determining the unknown extents of the abandoned Blackhawk gypsum mine, Blackhawk, SD

by

Mohammadhossein Sadeghiamirshahidi, Ph.D., A.M. ASCE.
Assistant Professor, Geological Engineering

Affiliation
Montana Technological University

A proposal prepared for the

Fitzgerald Law Firm
343 Quincy Street; Ste 101
Rapid City, SD 57701

12/11/2020

TABLE OF CONTENTS

List of Tables iii
List of Figures iv
Problem Statement 1
Background Summary 3
Research Plan 6
Schedule 8
Budget 9
References 10
Curriculum Vitae 11

LIST OF TABLES

Table 1. Annual gypsum production (Aberdeen 1928) 3
Table 2. Project Time Schedule 8
Table 3. Detailed Project Budget 9

LIST OF FIGURES

Figure 1. April 27th, 2020 Sinkhole, Hideaway Hills Subdivision, Blackhawk, SD 1

Figure 2. Approximate extent of the underground mine developed by Paha Sapa Grotto cavers (Anderson et al. 2020) overlaid on the subdivision by Patric Ealy, Fitzgerald Law Firm (Zionts 2020).. 2

Figure 3. Approximate location of known mining activities in the area 4

Figure 4. Gypsum bearing Spearfish Formation outcrops in the area 4

Figure 5. Contours of the depth to the groundwater table (in ft.) in the area 5

Figure 6. Proposed area (green polygon) for SP and FDEM Analyses 6

Figure 7. Proposed Electrical Resistivity Tomography survey lines.. 7

PROBLEM STATEMENT

Abandoned mines are spread all across the United States. According to the Bureau of Land Management's official government website, there are as many as 500,000 abandoned mines in the US. Many of the historic abandoned underground mines have very little, if any, long term stability measures which pose serious effects on the construction projects on the surface (NC-DEQ). Around 278 abandoned mine related fatalities were reported from 2001 to 2017 in the United States (King 2017).

On April 27th, 2020, a sudden ground collapse (sinkhole) appeared in the Hideaway Hills Subdivision located in Blackhawk, South Dakota (Figure 1). After a group of cavers from Paha Sapa Grotto (an internal organization of the National Speleological Society located in the Black Hills of South Dakota) investigated the sinkhole, it was determined that the sinkhole was related to a shallow (10 ft. deep) abandoned gypsum mine. About half a dozen families were forced to evacuate the premises while many others have voluntarily evacuated their houses out of fear. It is worth mentioning that, apart from this recent sinkhole, there are other possible indicators of subsidence throughout the subdivision, e.g., growing cracks on the roads and sidewalks.

Figure 1. April 27th, 2020 Sinkhole, Hideaway Hills Subdivision, Blackhawk, SD

In order to develop a hazard map for the area that can be used for issuing proper evacuation notices, the exact extent of the abandoned mine needs to be known. There is limited information available about this mine, from which the exact extent of the mine can not be determined with a desired degree of certainty. Although an approximate map of the underground mine extent was produced by the cavers (see Figure 2), the exact extent could not be determined due to some obstacles. The eastern part of the underground mine was filled with water which made it impossible to access and map the extent of the mine beyond that point. Also, what appeared to be collapsed zones according to the cavers, restricted access to the northern, southern, and western boundaries of the underground mine.

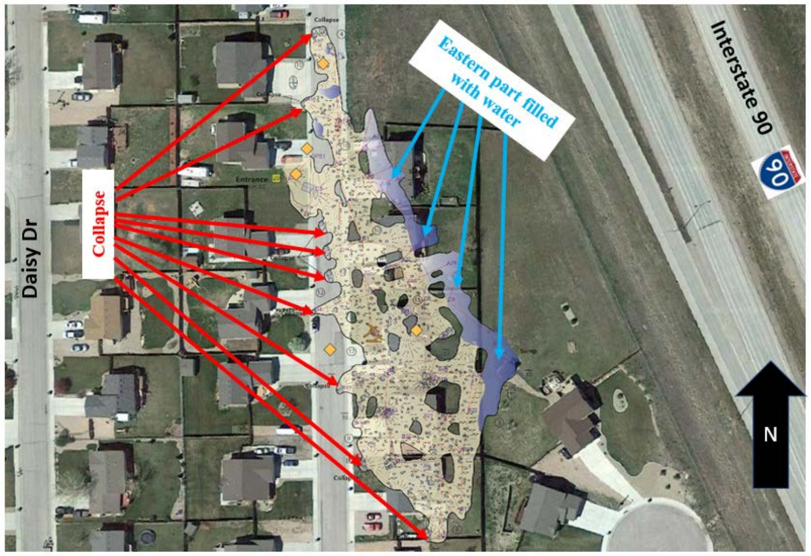

Figure 2. Approximate extent of the underground mine developed by Paha Sapa Grotto cavers (Anderson et al. 2020) overlaid on the subdivision by Patric Ealy, Fitzgerald Law Firm (Zionts 2020)

The main purpose of this project is to use geophysical methods to determine the extent of the abandoned mine.

BACKGROUND SUMMARY

The underground Blackhawk mine was operated by the Dakota Plaster company starting from 1912. The first report on the Blackhawk Mine, that the author could find, was from the South Dakota state mine inspector in 1912 (Aberdeen 1928). There is not enough data from the first year but it seems that the mine only produced gypsum part of the first year. Also, from 1919-1921, the underground mine did not produce gypsum, as the Dakota Plaster Company was taking gypsum from the surface. It is, however, unclear if the gypsum was mined from an outcrop of the Spearfish Formation (the gypsum bearing formation), or if it was taken from the gypsum that was already mined from the underground mine and stockpiled on the surface. In 1924, the Dakota Plaster Company secured a contract to supply gypsum for the state cement plant for the next year. No mining information could be found for the underground mine after 1926. It is speculated that the lack of accurate mining history for the area is because, prior to 1983, the state of South Dakota did not require a license to mine gypsum, sand, gravel, and other materials used to produce cement. Table 1 summarizes the annual gypsum production from the Blackhawk mine from 1912-1926 (Aberdeen 1928).

Table 1. Annual gypsum production (Aberdeen 1928)

Year	Tons of Gypsum Produced
1912	No data
1913	10,760
1914	10,000
1915	9,105
1916	4,070 (mill destroyed by fire)
1917	3,915
1918	3,000
1919	3,956 (No underground mining, gypsum was taken from the surface)
1920	1,495 (No underground mining, gypsum was taken from the surface)
1921	3,933 (No underground mining, gypsum was taken from the surface)
1922	2,127+1488
1923	3,327
1924	1,707
1925	5,035
1926	1,877 (last yearly mine inspection found)
1912-1926 total	66,095

Figure 3 shows the approximate locations of the past and present known mining activities in the Blackhawk area. The locations identified by the blue polygons are reclaimed surface gypsum mines. The location identified by the red polygons 1 is an active surface gypsum mine, and the location identified by the red polygons 2 is an active surface sand and gravel mine. The approximate location of the underground Blackhawk mine is identified with the yellow polygon.

Figure 3. Approximate location of known mining activities in the area

The Blackhawk underground mine was targeting a gypsum bed in the Spearfish Formation. The Spearfish Formation is a 402 - 497 ft (122 - 151 m) thick rose to red mudstone and siltstone formation containing gypsum beds of up to 20 ft (6 m) thick. The gypsum beds occur near the middle and near the top of the formation. Also, veins of gypsum occur throughout the formation (Lisenbee and Hargrave 2005).

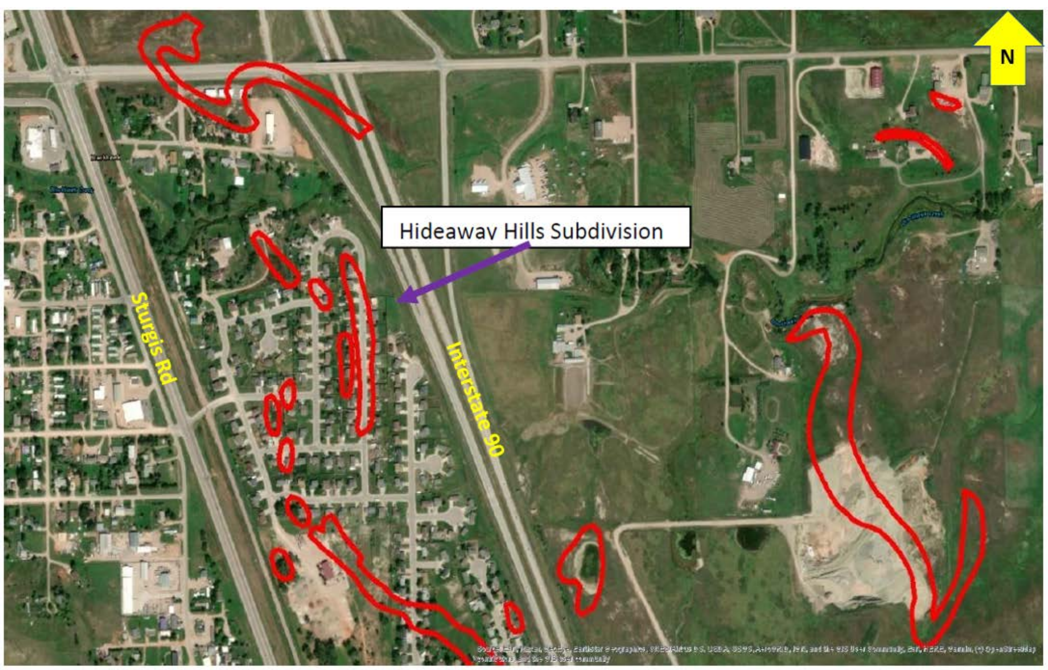

Figure 4. Gypsum bearing Spearfish Formation outcrops in the area

Figure 4 shows the gypsum bearing Spearfish Formation outcrops in the area. As it can be seen, the gypsum bearing layers are very shallow in the area and even has outcrops in the vicinity to the west of the Blackhawk underground mine. Based on a cross-section presented in the 1:24,000 Geologic map of the Blackhawk quadrangle, South Dakota (Lisenbee and Hargrave 2005), the Spearfish Formation dips down to the northeast. This implies that the underground mine is unlikely to extend much farther to the west and determining the extent of the mine to the north, south, and east are more crucial.

Figure 5 shows the contours of the depth to the groundwater table in the area. The contours were developed based on the reported groundwater depths in the well-logs obtained from the South Dakota Department of Environment and Natural Resources.

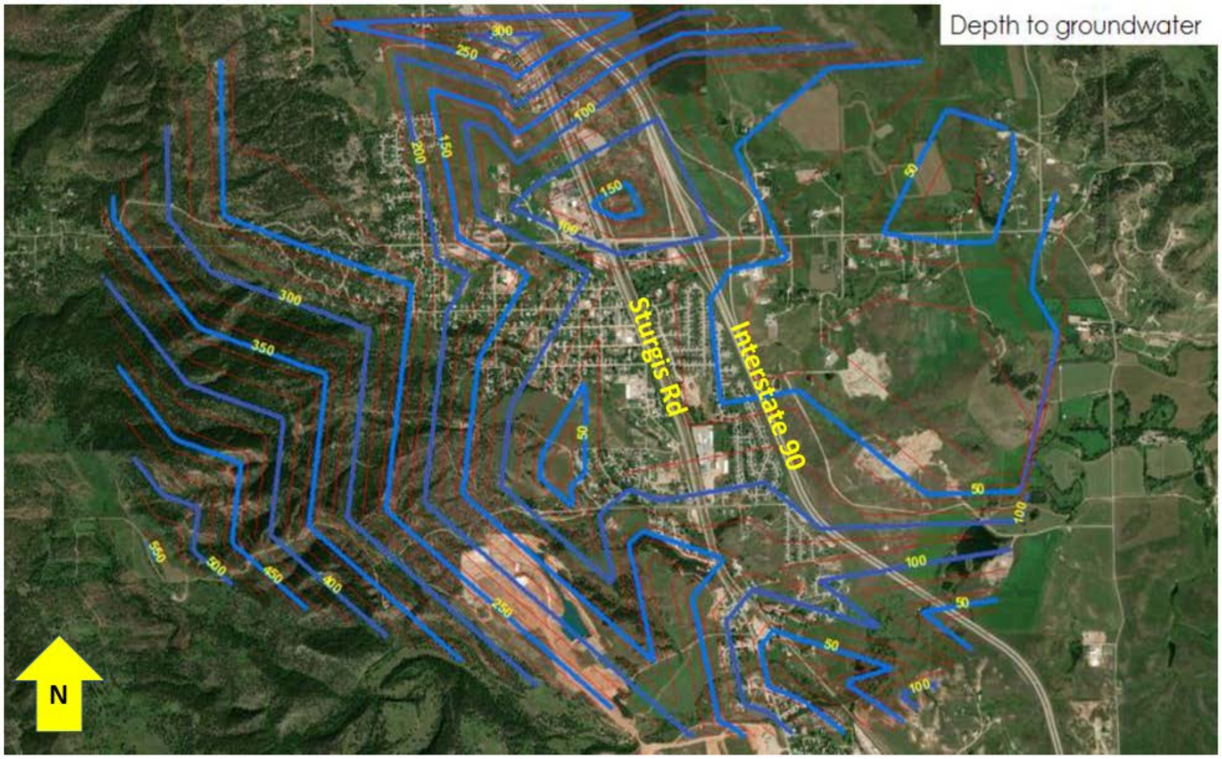

Figure 5. Contours of the depth to the groundwater table (in ft.) in the area

As can be seen from Figure 5, the groundwater table in the area is about 50 ft deep while the abandoned Blackhawk mine is only 10 to 20 ft deep. This implies that the water flooding the mine on the eastern boundaries are most likely surface water accumulation in the mine. It is worth mentioning, however, that some of the groundwater data used in developing the contours of the groundwater table (collected from the South Dakota Department of Environment and Natural Resources) were very old and might not accurately represent the current location of the groundwater table. It is, therefore, important to at least attempt to also estimate the groundwater table depth using the geophysical methods.

The main purpose of this project is therefore to use nondestructive geophysical methods to better determine the extent of the underground mine (especially to the north, east, and south of the currently known working areas) and estimate the depth and flow of the underground water.

RESEARCH PLAN

In this research, a geophysical investigation program will be conducted in the Hideaway Hills Subdivision, Blackhawk, SD. The goal is to determine the extent of the underground mine under the subdivision and estimate the depth of groundwater and possible groundwater flow.

In order to map the horizontal distribution of sinkholes and the inferred tunnels and cavities, three non-destructive geophysical methods will be conducted; (1) Frequency Domain Electromagnetic (FDEM) method, (2) Self-Potential (also known as Spontaneous Potential, SP) method, and (3) Electrical Resistivity Tomography (ERT). The three methods will be conducted by the PI (Mohammad Sadeghi) with the help of an experienced consultant (Mohamed Kahlil, Assistant Professor of geophysics) using Montana Tech's geophysical engineering department's equipment. The consultant has extensive experience in conducting such surveys (Khalil et al. 2013, 2018; Prudhomme et al. 2019).

In Self-Potential (SP) method, naturally occurring electric potential difference in the ground is measured between two electrodes. The Frequency Domain Electromagnetic (FDEM) method is a type of electromagnetic or magnetic induction and involves measuring voltages induced in the earth when exposed to a varying frequency domain magnetic field. The Electrical Resistivity Tomography (ERT) method utilizes differences and contrasts in electrical resistivity to identify the subsurface geo-material, including voids.

Implementation of the FDEM and SP methods:

Figure 6 shows a proposed polygon of approximately 120m width and 420 m length. This area will be covered by SP and FDEM grides (5 X5 m) to have more than 2000 data points. These data sets will be processed to have an SP distribution map, that shows water flow directions and two FDEM maps at 10ft (~3m) and 20ft (~6m) depths. FDEM maps will show the conductivity or resistivity distribution at two depths as mentioned. It is worth mentioning that FDEM will be affected by any high-power lines in the area. To the best of the author's knowledge, there are not any high-power lines nearby the proposed area.

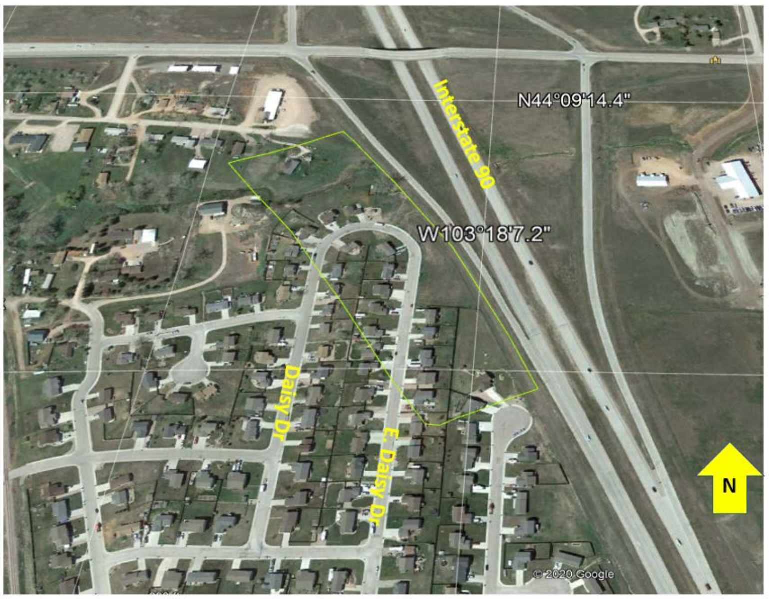

Figure 6. Proposed area (green polygon) for SP and FDEM Analyses

Implementation of the ER methods:

Figure 7 shows the proposed resistivity sections. Based on the observations in the field when conducting the survey, some more sections might be needed on the western side. An electrode spacing of 1.5 m will be used for the ERT method to achieve the highest resolution for the targeted depth (10 to 20 ft). The survey is designed to start with line 1, which potentially covers three possible areas of interest. The far east portion of the line probably extends over areas with no underground mine, while towards the middle, the line passes over the known underground workings that are currently flooded. Finally, towards the west end of the line, it covers the known working areas that are not flooded. This line would be used to calibrate the readings with more confidence and will be used to interpret the data collected from other survey lines (lines 2-10, see Figure 7). The distribution of the survey lines was designed to be practical (avoid hard surfaces like pavements) while still able to be used to better determine the extent of the mine.

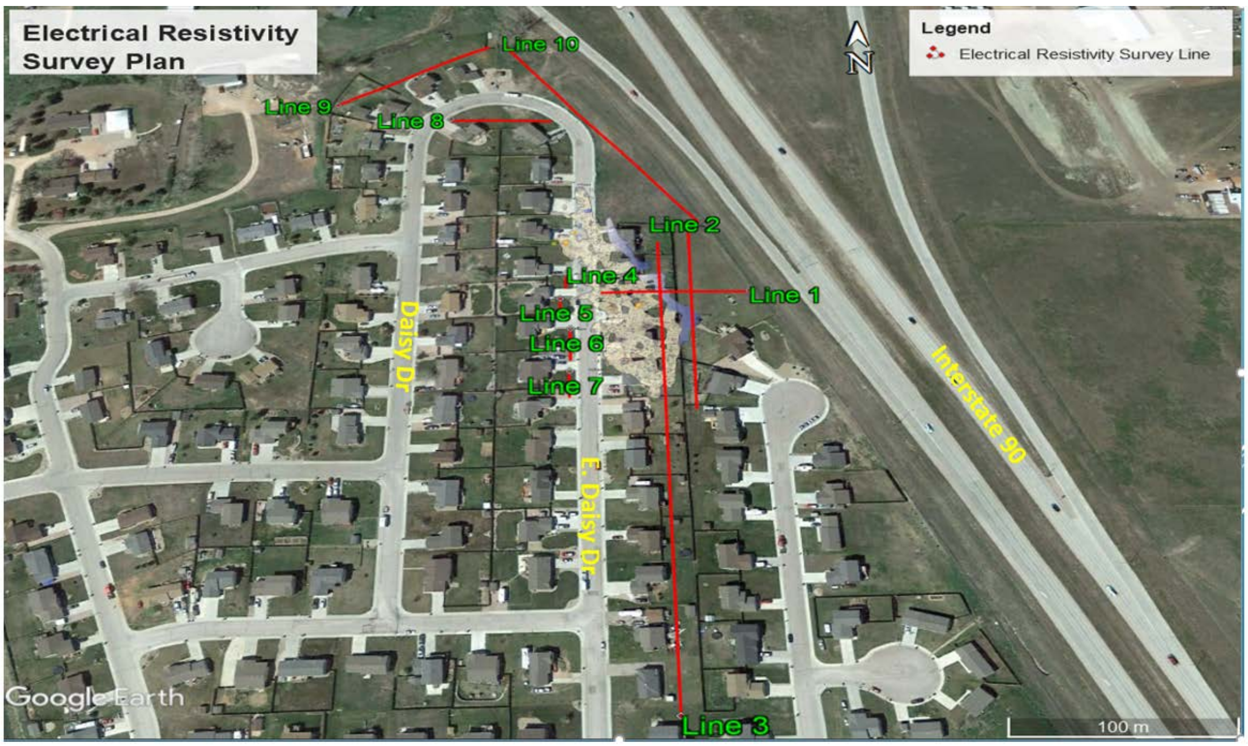

Figure 7. Proposed Electrical Resistivity Tomography survey lines

It is worth mentioning that some of the survey lines and grid areas (for all three methods) extend over the private properties and that author has made no attempt to obtain permission from the owners. It is assumed that the Fitzgerald Law Firm has, or can obtain, permission from the residents for the survey to be conducted.

REFERENCES

Aberdeen SD. Annual report of the state mine inspector of the state of South Dakota [Internet]. 1928. Available from: https://books.googleusercontent.com/books/content?req=AKW5Qae-zYQjBoEWnLrpttRPELKQ47N08M_fdV-vVLdOu4NyH3NAxQP0XeaIMRSbvXPyXTqQB-O3Z0IAujd2e2bKEWW1eLkTB6QxFSFK3VEyfRQe_HLUALzxE-jg4eZJCutvIcztZzJ0vafx_KlMxOLy7VDIc_7PGGPjH6cHPJqLdlT61XRq1b7_fuZZc89Z0-MbB8ovg

Anderson N, Austin D, Ohms R, Pelczarski C, Springhetti D, Weaver A, et al. Hideaway Mine, Meade County, SD. Paha Sapa Grotto [Internet]. 2020. Available from: https://www.pahasapagrotto.org/

Khalil M, Orubu A, Rutherford B, Speece M, Santos F, Farzamian M. Integrated application of 2D resistivity and electromagnetic methods to investigate a metallic-sulfide deposit in Soap Gulch, Montana. A case study. Arab J Geosci [Internet]. 2018 Dec 1 [cited 2020 Dec 11];11(23):1–9. Available from: https://doi.org/10.1007/s12517-018-4130-1

Khalil MA, Santos FM, Cachão M, Fonseca PE, Mata J. 2D and 3D resistivity tomography of the Suímo garnet-bearing dyke, Lisbon Volcanic Complex, Portugal: A case study. J Geophys Eng [Internet]. 2013 Jun 1 [cited 2020 Dec 11];10(3):035013. Available from: https://academic.oup.com/jge/article/5110827

King M. Abandoned Mine & Quarry Accidents Claim 20-30 Lives Per Year [Internet]. 2017 [cited 2020 Dec 10]. Available from: https://geology.com/articles/abandoned-mines.shtml

Lisenbee AL, Hargrave RG. Geologic map of the Blackhawk quadrangle, South Dakota (Map Scale: 1:24,000) [Internet]. 2005. Available from: https://ngmdb.usgs.gov/Prodesc/proddesc_96362.htm

NC-DEQ. Ground Collapse: Old mines and prospects and sinkholes [Internet]. [cited 2020 Dec 10]. Available from: https://deq.nc.gov/about/divisions/energy-mineral-land-resources/north-carolina-geological-survey/geologic-hazards/ground-collapse-old-mines-and-prospects-and-sinkholes

Prudhomme KD, Khalil MA, Shaw GD, Speece MA, Zodrow KR, Malloy TM. Integrated geophysical methods to characterize urban subsidence in Butte, Montana, U.S.A. J Appl Geophys. 2019 May 1;164:87–105.

Zionts A. Meade County Planning Board knew Hideaway Hills was built over mine as early as 2000 | Local | rapidcityjournal.com [Internet]. Rapid City Journal. 2020 [cited 2020 Dec 10]. Available from: https://rapidcityjournal.com/news/local/meade-county-planning-board-knew-hideaway-hills-was-built-over-mine-as-early-as-2000/article_dc405d7c-bd07-5bc6-8837-32a2216b9c07.html

Curriculum Vitae

Mohammadhossein Sadeghiamirshahidi, Ph.D., A.M. ASCE.

- **Education**

Ph.D. Civil (Geotechnical) Engineering, Michigan Technological University, MI, USA
M.S. Mining Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran
B.S. Mining Engineering, Yazd Univerity, Yazd, Iran

- **Academic Experience**

August 2019-Present:
Assistant Professor: Department of Geological Engineering, Montana Technological University, Butte, MT.

Summer, 2016
Lecturer: Department of Civil and Environmental Engineering, Michigan Technological University, Houghton, MI.

Spring, 2015 - Spring 2019 (nine semesters):
Graduate Teaching Assistant: Soil mechanics Laboratory, Michigan Technological University, Houghton, MI.

Spring, 2011- Summer, 2014:
Lab Supervisor: Petrology Laboratory, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran.

Fall, 2009 – Spring, 2011:
Graduate Teaching Assistant: Petrology Lab., Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

- **Non-Academic Experience (consulting)**

August, 2018 - September, 2018:
Signature Research, Inc., Calumet, MI, Soil analysis (grain size distribution, mechanical sieve and hydrometer), thermal conductivity, Munsell color, soil density) for thermal determination of disturbed ground for rapid runway constructions.

July, 2018 - August, 2018:
Keweenaw Research Center (KRC), Houghton, MI, NATO mobility summit soil database for vehicle mobility test track. Soil analysis included triaxial compression, direct shear, proctor compaction, grain size distribution (sieve and hydrometer), and Atterberg limits.

July, 2017 - September, 2017:
Highland Copper Company, Longueuil, Quebec Canada, Oversaw geotechnical exploration drilling program for the proposed Copperwood Mine site facilities located in Gogebic County, western Upper Peninsula of Michigan. Collection of rotary sonic samples, selection and packaging of soil samples for laboratory testing, analysis of laboratory test results and conducting borehole logging. Conducted bearing capacity and settlement calculations for the design of the mine facilities on

both lacustrine and glacial till clay soil. Report preparation and submittal to G-Mining, Montreal Canada.

June, 2016-September, 2016:

Highland Copper Company, Longueuil, Quebec Canada, Mechanical rock testing of the main ore zone of the Copperwood Mine for mine design and investigating the potential for mechanical mining of the Precambrian age Nonesuch Shale Formation. Conducted uniaxial compressive strength (UCS), Brazilian splitting tensile strength (BTS), and point load index tests. Analysis and compilation of the final report.

June, 2015-September, 2015:

Golder Associates, Lansing, MI, Location and stability assessment of historic 1853 to 1893 underground coal mining, which was discovered to be beneath and adjacent to Interstate I-94 in Jackson, MI. Conducted stability analysis of mine roof spans based on extraction ratios and estimated the rock's RMR and GSI values. Assisted in the preparation and submittal of the final report to Golder.

September, 2013- June, 2014:

Cavosh Madan Consulting Engineers, Tehran, Iran, Economical assessment and feasibility studies of a prospective Iron seam near Sangan Mine during exploration stages.

September, 2011- August, 2013:

Alborz Sharghi Coal Washing Company, Shahrood, Iran, Investigation of the extent of pyrite oxidation at different locations and depths in waste dumps of the Alborz Sharghi Coal Washing Company (with an annual production of 300,000 tons of washed coal) and the environmental consequences of possible Acid Mine Drainage (AMD) production due to the pyrite oxidation.

September, 2007- September, 2009:

Zafar Construction Company, Tehran, Iran, Oversaw the construction of a 10 story (20 units) skyscraper in the business district of Zafar Street, Tehran, Iran.

- **Publications:**
  https://scholar.google.com/citations?user=1rrhWq4AAAAJ&hl=en