On the Development of an Undergraduate Research Training Program in Geophysics[1]

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1. Introduction

The purpose of this paper is to present an ongoing effort to develop an undergraduate research training program in geophysics at North Carolina A&T State University. Being an extremely broad and important field of science, geophysics entails the study and exploration of the earth and its atmosphere and waters by means of physical measurements, and requires its practitioners to utilize a combination of mathematics, physics, geology, and computer science to analyze these measurements to infer properties and processes of the complex earth system. By its nature of interdisciplinarity, geophysics makes research and development projects ideal for education and research training of science, technology, engineering, and mathematics (STEM) students. Education and training have become lifelong pursuits for our workforce, as new jobs requiring new skills are created, and older jobs and skills become obsolete. Career broadening through interdisciplinary experiences is particularly important in preparing underrepresented students for the opportunities in geophysical sciences. North Carolina A&T State University, the Nation's top producer of minority baccalaureate degrees in STEM disciplines, is well positioned to take the lead role in preparing underrepresented students to pursue academic studies and career opportunities in geophysical sciences.

The National Science Foundation HBCU Undergraduate Program (HBCU-UP) funded the University's ***TALENT-21: Gateway for Advancing Science and Mathematics Talent*** program in 1999. The TALENT-21 Program began the effort of developing an undergraduate research training program in geophysics. The development of such a research training program includes

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building up research infrastructure in geosciences, defining a unified and coherent research program, engaging undergraduate students into faculty research projects, and integrating research and STEM education. This paper will report the progress that we have made so far in all four areas.

Through the TALENT-21 Program, a facility has been established for undergraduate research training in the geophysical and environmental sciences. The facility includes a Seismic Physical Modeling Laboratory for earth subsurface modeling and simulated measurements, and a Seismic Data Processing Laboratory for data analysis and visualization. Planned for the research training program is a three-pronged approach of generating (1) real-world seismic data by seismic field surveys, (2) physical modeled data through the Seismic Physical Modeling Laboratories, and (3) computer simulated data through mathematical modeling and numerical simulation. The proposed approach facilitates a mutually refined understanding of site, the data, and the methods selected for testing; the results will be used to build models that simulate earth subsurface structures. This research training program aims to expose students to theory via topical seminars and workshops, and to practice via hands-on experience in field geophysical surveying, comparative field data analysis, computational modeling and numerical simulation of synthetic seismic data. It offers structured education and training activities that guide experiences in geophysical techniques and research. The goal is to integrate research into education by linking the creation of new knowledge with the transfer of that knowledge to students, and to increase students' interest and participation in geophysical science as an option for STEM career development. Students normally begin the program with preparatory academic year research training, and then proceed to undertake research projects and write project reports through an intensive summer REU program. Students are encouraged to present their research results at regional and national undergraduate research conferences. Currently, there are six undergraduate students and one graduate student participating in our geophysical research training program. The program is expected to grow.

The paper is organized as follows. We discuss some of pedagogical issues and challenges related to the development of such a program in Section 2. Section 3 describes the development of the geophysical research facility and program. Section 4 is devoted to the description of some recent student research projects. We summarize the paper in Section 5.

2. Integration of research and education

As noted by Anne Peterson [6] in an editorial when she served as the deputy director of the National Science Foundation, "…the integration of research and education deserves a higher priority on federal and university agendas. Today's students will spend their careers in a 21st-century workplace that presents complex and open-ended challenges. Those who will thrive in this setting are those who have been educated in a discovery-rich environment." Integration of research and education offers undergraduate students the opportunity of investigating the unknown as well as acquiring critical-thinking and problem-solving skills through discovery-based learning experiences. While traditional lectures and instructional laboratory sessions help students master what is known, they are not substantial enough experiences to help students truly develop the skills such as solving complex problems, dealing with uncertainty, and probing the unknown. Engaging undergraduate students into investigative research projects can remediate the limitation of conventional lecture and lab sessions, and help students comprehend that research is an ongoing and complex endeavor which requires persistence.

Recognizing the importance of integration of research and education, an undergraduate research training component was defined in the Talent-21 Program. Our student research training program offers structured education and training activities that guide experiences in geophysical topics and techniques, and research for students to increase interest and participation in geophysical science with STEM career development.

The challenges we faced in developing a meaningful undergraduate research training program include building up research infrastructure such as research facility, research faculty and support staff, ensuring student participation and support, and engaging undergraduate students into faculty research projects. We will discuss in detail the development of research infrastructure in Section 3, and describe how we involve students into faculty research projects in Section 4.

Student participants of the geophysical research training program are generally recruited through the on-campus advertisements by the Talent-21 Program and personal invitations by research faculty involved with the research training program. Financial support for students to participate in our research training program is primarily provided by the TALENT-21 project. However, besides the TALENT-21 project, several existing and new sponsored programs at the University also provide scholarship and other student financial support to STEM students, specifically, NSF CSEMS, NSF GeoEd, NSF LS-AMP, NASA PAIR, and Sloan Physics Scholars programs. We have collaborated with these programs to gain access to and link geophysical science education and research training options for the students they fund. The real incentives for student participation in the geophysical research training program are: hands-on experience with sophisticated equipment and instrumentation, seminars and workshops on geosciences, field experiences in geophysical data collection, opportunities to develop and apply scientific, technical, and computer skills, and opportunities to earn certificates and achievement titles. Currently, we have six undergraduate students and one graduate student working with our geophysical research workgroup. The program is expected to grow.

As implied by its name, our research training program includes two components: training of undergraduate researchers and production of quality research. The training part of the program is handled through topical seminars and workshops. Students participating receive training in the theory and practice of reflection and refraction seismology, wave propagation and derivation of acoustic and elastic wave equations, finite difference method and numerical solutions of wave equations, Fortran and Maple programming through a series of workshops or seminars. In the workshops, students will walk through the steps of seismic survey design, data acquisition, basic data processing, and interpretation, and forward finite-difference modeling of seismic wave propagation. Each step will consist of didactic teaching and hands-on exercises. Training on the use of seismic data processing software and visualization tools are also incorporated into the workshops and some of the exercises will include processing data using the software packages or tools. The production of quality research component is managed via engaging students into investigative research projects to explore uncharted intellectual terrain. Participating in faculty research projects as a team player, students will have the opportunity to design or implement research experiments with the geophysical research facility, and choose an individual or group research project closely related to our defined research program. A faculty or an industry mentor will provide direction, supervision, and encouragement to students on relevant research projects. Students participating, at both the undergraduate and graduate level, will be provided opportunities to learn the fundamentals of applied seismology and pursue research projects in applied seismology. The students will collect the data, process the data, draw conclusions, and produce a written paper or poster presentation. Students are encouraged to present their research results at regional and national undergraduate research conferences.

While students working on research projects normally receive one-on-one attention from and interaction with faculty researcher, topical seminars and workshops are conducted in a group for all participating students. Due to different course and work schedules among student participants, it has been very challenging to schedule seminars or workshops at a time convenient to all students. To address this problem, we have developed two geophysics course sequence: *PHYS 600-Selected Topics in Geophysics*, and *PHYS 601-Introduction to Geophysical Research*. The twin courses have gained approval from the Physics Department as part of its Engineering Physics curriculum offering, and have been submitted by the Physics Department to the College of Arts and Sciences, and the University for approval. Once approved by the University, PHYS 600 will be offered in Fall and/or Summer while PHYS 601 will be offered in Spring with PHYS 600 as a prerequisite. The development of the geophysics course sequence is part of our effort to institutionalize our undergraduate research training program, and to attract a more broad range of STEM students to undergraduate research in geophysics. Students can take each course twice to earn up to six credit hour points.

3. Geophysical research facility and program

The geophysical research facility includes a seismic physical modeling laboratory for earth subsurface modeling and simulated measurements, a computational laboratory for data processing, analysis and visualization, and a physical acoustics sensor testing laboratory. With NSF funds through the TALENT-21 Project, the seismic physical modeling system was built by the Allied Geophysical Laboratory (AGL) at the University of Houston. This physical modeling system is used to acquire 2-D seismic data automatically, and 3-D seismic data manually.

Seismic data generated from the Seismic Physical Modeling Lab can be processed in the Seismic Data Processing Laboratory. Acquired seismic data need to be processed by sophisticated data processing software to enhance the signal with respect to the noise, extract significant earth reflectivity information, and display it for geological interpretation. Seismic data processing results depend on the techniques used for processing. The data processing laboratory was configured for this purpose. It consists of powerful Sun Enterprise server and workstations running the state-of-the-art seismic processing software, OMEGA®, awarded by WesternGeco. The system is installed on a SUN Enterprise application server, and is accessible through a cluster of SUN Ultra 60 workstations and X-terminals emulated on Dell Pentium III or IV PCs running EXCEED software in the lab. Additional data processing and visualization software packages were installed in Sun, Linux or MS Windows workstations.

A sensor testing laboratory for theoretical and experimental physical acoustics, recently funded by the U.S. Department of Education Minority Science and Engineering Improvement Program

(MSEIP), is under construction. This facility will enhance our developed seismic physical modeling and data processing facility to include critical test equipment for the ultrasonic transducers, which are the sensitive probes for the system, enabling us to build capacity in physical acoustics with theoretical and experimental competencies in ultrasonic wave propagation in solid and liquid media. The facility will also be utilized for the characterization of the ultrasonic system as a physical system to test mathematical and computational models. All three laboratories are housed in a big lab space contributed by the University.

The development of our geophysical research facility is further enhanced and expanded by a recent NSF funded Geosciences Education project entitled, "Development of a geophysical field research training program." This project will broaden the geophysical research training facility to include field equipment for geophysical surveying. Geophysical field research and training will produce data and analysis that can be used as resources for both research and innovative course/curriculum development.

A research program driven by physics and mathematics faculty is already under development, which utilizes the new seismic physical modeling and seismic data processing laboratories. Additionally, studies involving mathematical and computational modeling of acoustic waves in solid and liquid media are taking place as well. Dr. Caesar Jackson of the Physics Department, Drs. Guoqing Tang and Dominic Clemence of the Mathematics Department, Dr. Van Burbach, an industry consultant in environmental and engineering geophysics and a visiting senior research scientist in the Physics Department, and some interested graduate and undergraduate students formed a geosciences workgroup two years ago. Two recent doctorates from the College of Engineering, Dr. Mark Kithcart of Mechanical and Chemical Engineering, and Dr. Legunchim Emmanwori of Center for Composite Materials Research, joined the group last year, further enhancing the group's range of expertise and capabilities. This workgroup has sponsored a series of lectures and discussion groups on applied seismology over the past two years, and successfully directed a summer undergraduate research program in geosciences in the past summer. The workgroup also has worked on several cooperative research proposals that combined Dr. Clemence's expertise in differential equations and wave propagation, Dr. Tang's expertise in computational modeling of physical systems and digital signal processing, Dr. Jackson's expertise in physical modeling and experiment design and implementation, and Dr. Burbach's expertise in applied seismology. Besides securing funding for two research projects from the NSF Geosciences Education Program and the U.S. Department of Education MSEIP Program mentioned above, an NSF Interdisciplinary Grants In Mathematical Sciences (IGMS) grant was awarded to Dr. Guoqing Tang last spring, enabling him to spend a full year in the Physics Department to conduct research in applied seismology.

The workgroup has finalized a focused geophysical research program with the establishment of a Geophysical Research Facility. Planned for our geophysical research program is a three-pronged approach of generating (i) real-world seismic data by seismic field surveys, (ii) physical modeled data through the Seismic Physical Modeling Laboratories, and (iii) computer modeled data through mathematical modeling and numerical simulation to mutually refine understanding of site, the data, and the methods selected for testing. The physical and computational modeling and simulation of seismic waves through a complex Earth model is a major focus of geophysical research. The current forefront is solving the elastic wave equations in complex 2-D or 3-D geometries. Our primary research focus is on understanding the mathematical and physical differences between high-frequency seismic waves induced by piezoelectric transducers and propagating through laboratory materials in the seismic physical modeling laboratory, and seismic waves generated by a sledgehammer source propagating through earth materials in a field survey. Another research focus is to obtain detailed imaging of acoustic or elastic media via seismic experiments. This task will require accurate representations of the point sources and reflectivity. The third research focus is on the use of seismic tomography to image the Earth's interior structure. Seismic tomographic images of the Earth's interior are obtained by using an unstructured grid to solve a linear system that includes enormous seismic wave travel time observations and waveform databases.

4. Examples of some recent student research projects

Students normally begin the program with preparatory academic year research training, and then proceed to undertake research projects and write project reports through an intensive summer REU program. Once they go through a full year circle of research training, most students continue their participation in our research training program, refining and expanding their research work, and making presentations at undergraduate research conferences. Following are examples of some recent student research training projects.

Geophysical Investigation of the North State Goldmine in the summer 2001

An off-campus field research project was designed for and implemented by students in the summer 2001 to conduct a geophysical investigation of an abandoned gold mine, the North State Goldmine. This was a cooperative venture between North Carolina A&T State University and Pyramid Environmental, Inc., a local consulting firm specializing in environmental geophysics. Three NC A&T students, Clifton Townes, Andrew Kong, and Mookesh Dhanasar, participated in a detailed resistivity survey of an abandoned gold mine site under the supervision of Dr. Van Burbach from Pyramid. The scientific purpose of the project was to determine whether the resistivity profiling method could be used to detect voids associated with old mine workings. The voids could be both geotechnical and environmental safety hazards.

The summer project consisted of approximately two weeks of seminar-style instruction and assigned readings to familiarize the students with geophysical surveying in general and with resistivity surveying in particular. The instruction focused both on theory and practical preparation for the fieldwork. The field equipment, an AGI Sting/Swift resistivity surveying unit, was rented and was available for only 6 days, consequently the actual field work had to be well planned and was intensive. In those six days, often working 10-12 hours per day, the students gathered thirteen resistivity profiles totaling 956 meters of data and covering approximately 2.75 acres. Over the several weeks that followed, the students worked with the data, learned to process those data and produced resistivity pseudo-sections using resistivity inversion software called RES2DINV. Dr. Burbach continued to work with the students on a part-time basis to guide their work and to help them get the most out of the research experience. At the end of the summer, the students produced a written report of their findings. The results of the survey not only indicated several possible voids, but also delineated the geologic structure that the mine shafts were following (cf. Figure 1). Later, in February 2002, two of the students, Clifton

Townes and Andrew Kong, presented their work [7] as a poster session at the 2002 NSF HBCU-UP National Research Conference at Albany State University in Albany, Georgia. They won the first place award for best poster at the conference.

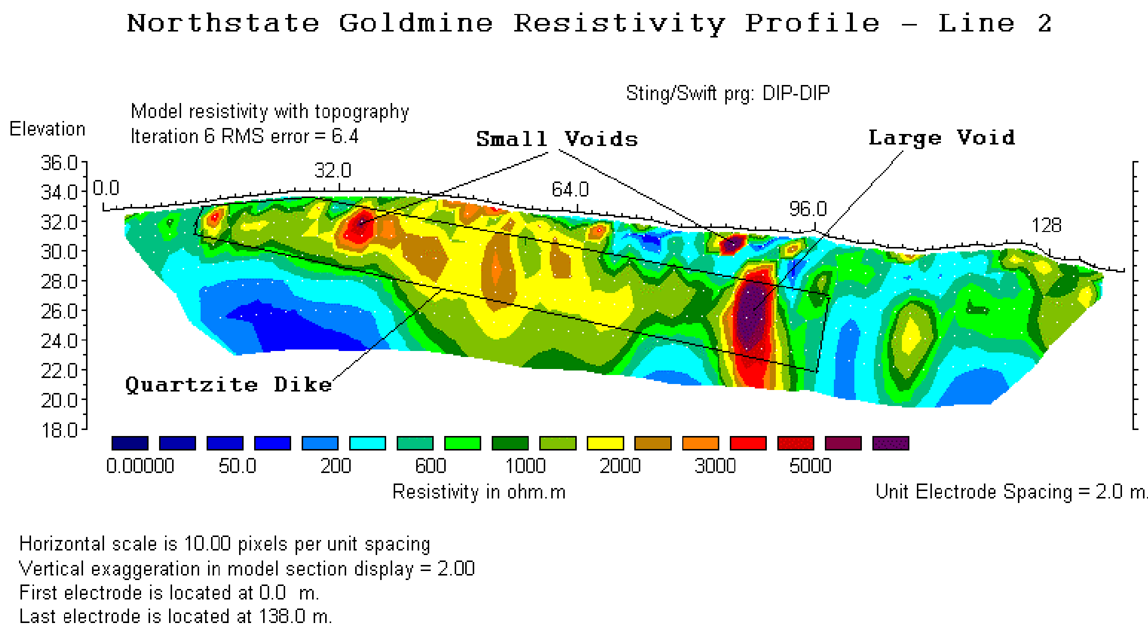

Figure 1: Resistivity Pseudosection from the Summer 2001 Student Research Project

Labview Code Development for Motion Control and Data Acquisition for the SPMS

We involved two students, Clifton Townes and Mookesh Dhanasar, in the code development project for both motion control and data acquisition parts of our seismic physical modeling facility from the spring 2002 until the summer 2002.

They started the project with the development of independent motion control and data acquisition subsystems. Clifton Townes worked on the development of a motor-control software code using Labview as part of his senior research project. Mookesh Dhanasar was involved in developing a Labview software code to control the data acquisition as part of his master's research project. They were successful in this endeavor. Using their independently developed motion control and data acquisition subsystems, some bench-top tests with the ultrasonic transducers, pulser/receiver and associated electronics were performed, and seismic signals transmitted through blocks of Plexiglas and other materials were captured. Therefore we can make direct measurement of seismic velocities and other physical parameters for various materials (plastic, latex, rubber, metal, etc.) and build a catalog of physical properties of these materials. Mr. Dhanasar presented a poster of his work [2] at the Seventh Annual Life and Physical Science Research Symposium at NC A&T on February 22, 2002, and completed his MS program by the summer 2002.

They then attempted to incorporate both control modules into a single software code that would systematically move the source and receiver transducers across a model, collecting data after each step, and producing a seismic profile. The data would then be recorded in standard SEG (Society of Exploration Geophysicists) format, SEGY or SEGD, so that it can be processed in the Seismic Data Processing Laboratory (SDPL). The integration of the motion control and data acquisition subsystems was carried out after they completed their individual subsystems. Some partial results were obtained, and major technical obstacles were identified. With the assistance from the AGL of the University of Houston, these technical difficulties were eventually overcome in the Fall 2002, and a fully automated seismic physical modeling system has been functioning.

2002 Summer Collaborative REU Program

The 2002 Summer Research Program, directed by Drs. Caesar Jackson, Guoqing Tang, Van Burbach and Dominic Clemence, was a collaborative effort with the UNC-Chapel Hill's Summer Pre-Graduate Research Experience (SPGRE) Program. Six students, Forpu Njikam and Judia Park from NC A&T, Kori Brown and Jodie McCullough from Texas Southern University, Sam White from Norfolk State University in Virginia, and Nelson Veale from Elizabeth City State University in North Carolina participated in the ten-week intensive geophysical science research training program. The 2002 Summer RUE Program involved students in field geophysical surveying, comparative field data analysis, computational modeling and numerical simulation of synthetic seismic data.

Geophysical fieldworks were conducted on the NC A&T Environmental Research Site consisting of an intermittent creek, a pond, twenty-two water sampling/observation wells, and a weather station in the University Farm and the North State Goldmine. The geophysical techniques used to conduct field surveys included electromagnetic methods (EM), geoprobe soil borings, ground penetrating radar (GPR), and seismic refraction. The objective of geophysical surveying on the University Environmental Research Site was to determine the geologic structure of the subsurface in the Site. The data obtained from GPR and seismic refraction surveys were analyzed and the images of the sub-surface along each profile were produced.

Geoprobe soil borings were taken from the same site. The borings were visually examined to determine the type of soil in the different horizons. Another important aspect of the soil seen from the borings was the refusal depth for the Geoprobe, indicating subsurface impenetrable material (assumed to be bedrock). The soil boring cores were also processed to determine the soil densities (cf. Figure 2).

The results of the two geophysical surveys were compared to each other and to Geoprobe boring data collected along the profiles. The relative accuracies of the techniques/methods, especially for terrain-related shortcomings, were also discussed. Based on actual subsurface structure findings obtained from geophysical surveys at North Carolina A&T State University Environmental Study Site, a simplistic "best-fit" two-layer model was considered to simulate shallow seismic data in an attempt to mimic actual data collected in the field. The model used in this study consists of two distinct layers with different velocities. Both velocity and density in each layer are assumed to be constant. The values of p-wave velocities in the two layers are obtained from the seismic refraction survey data analysis, and the values of the soil bulk densities in the two layers are gathered and calculated from the Geoprobe soil borings samples.
The study of this numerical modeling problem focused on determination of appropriate boundary conditions and a reasonable source function that resembles the actual source wavelet generated

in the field, and simulation and interpretation of synthetic seismic data. All simulations were created using Maple 7, a computer algebra system by the Waterloo Maple, Inc.

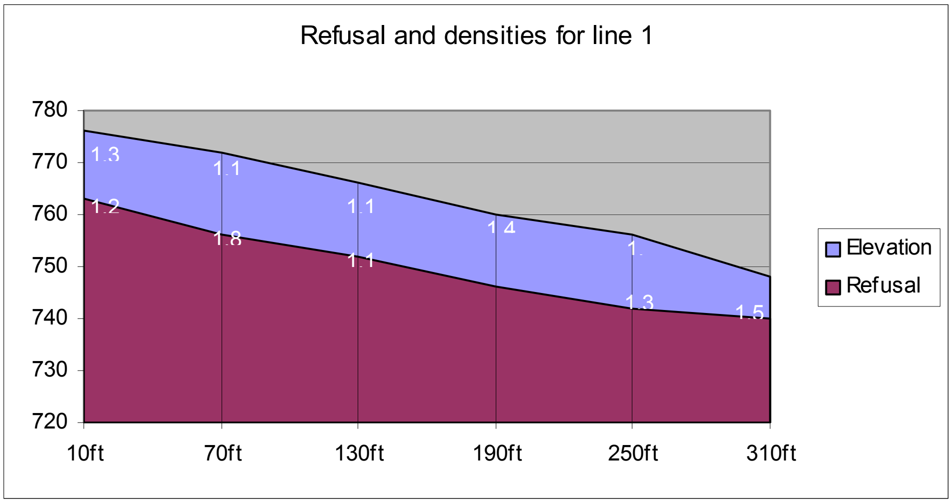

Figure 2: Refusal and Densities for One Survey Line

The students also undertook another project of simulating acoustic waves propagating through a solid using the Mindlin Plate Theory (MPT). In this study, a material (specifically, aluminum) was used to study the effects that occur when the material receives an initial acoustic/vibration stimulation. When a finite plate is perturbed physically, a unique wave pattern occurs. An algorithm was developed and coded in FORTRAN to numerically simulate wave propagation through the solid medium. Graphs of simulated data were obtained using Matlab.

Students prepared three project reports and submitted them to the UNC-CH's SPGRE Program [1,4,5]. They also presented three post presentations at UNC-Chapel Hill and three oral presentations at North Carolina A&T State University in the last week of their summer research program. Their presentations were highly regarded by the SPGRE program staff at UNC-Chapel Hill. Two NC A&T students, Forpu Njikam and Judia Park, continue to be involved in the geophysical science research program at NC A&T in the current academic year. Forpu gave an oral presentation based on the work of one of the projects at the Joint 3rd Annual Undergraduate Science and Engineering Conference, and NSF HBCU-UP National Research Conference on November 22-24 in Tuskegee, Alabama. Judia Park's abstract based on the project of simulating acoustic waves propagating through a solid using the Mindlin Plate Theory (MPT) was accepted for an oral presentation at the 2003 National Conference on Undergraduate Research to be held on March 13-15, 2003 at the University of Utah.

Geophysical Characterization of the North State Goldmine in the Fall 2002

As part of the 2002 Summer REU Program in geophysical sciences, six students went back to the North State Goldmine site in June 2002 to conduct two different geophysical surveys: ground-penetrating radar (GPR) survey, and seismic refraction survey. The GPR and seismic refraction data were collected along some of the same lines used in an earlier resistivity survey in June 2001. With the support from the TALENT-21 Project and under the supervision of Dr. Van Burbach, two students, Andrew Kong and Forpu Njikam, undertook a new research project of comparing the three different types of geophysical data gathered from the resistivity survey in 2001 and the GPR and seismic refraction surveys in 2002. In the very beginning they discovered that the seismic refraction survey data was not very useful. Hence they decided to focus their study on the comparison of the resistivity data with GPR data. Their comparative analysis (cf. Figure 3) found that the resistivity profiles proved to be more effective for identifying potential voids on this site. The resistivity survey data was very successful in identifying what we believe to be a former mineshaft in at least one location. GPR identified some apparent fill areas that may have been related to old mine workings. Their work also identified a number of potential voids, which were later confirmed by drilling.

The results of this study was presented by Andrew Kong as an oral presentation at the Joint 3rd Annual Undergraduate Science and Engineering Conference, and NSF HBCU-UP National Research Conference on November 22-24 in Tuskegee, Alabama, and the presentation won the second place in the agriculture and environmental sciences division. In addition, these two students prepared a paper of this research project which has been accepted for presentation at the Symposium on the Application of Geophysics to Environmental and Engineering Problems (SAGEEP) in San Antonio, Texas in April 2003 [3].

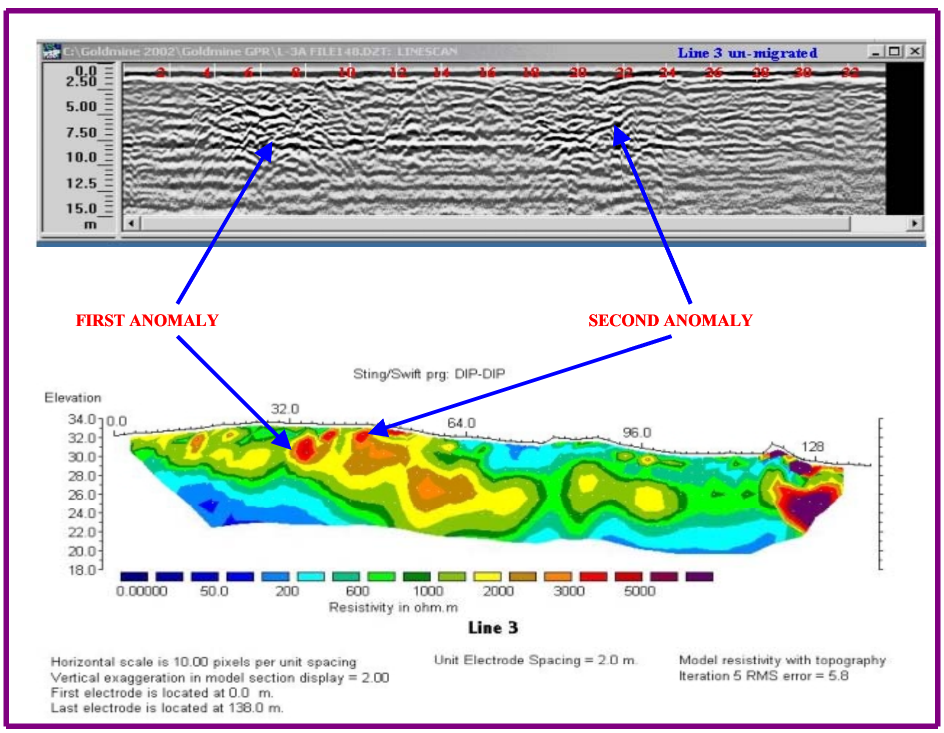

Figure 3: Comparison of Resistivity Data with GPR Date

5. Summary

This paper has described our ongoing effort of developing an undergraduate research training program in geophysics. The development of such a program enabled us to build up our geophysical research infrastructure and faculty research team, define a focused research program, and provide students with training and research experience. Although we are still evolving and refining this program, we have directed several successful student research projects in the past two years, and have laid a good foundation for further development of the program.

We believe that our program has been successful in drawing students into geophysical research and training, and impacting them on their professional and career development. With the structured research projects and close faculty supervision, student trainees have gained research experience and skills that can be transferred to research in geophysics or other STEM disciplines. Such positive research experience has motivated and encouraged them to pursue graduate studies involving geophysical research. Three of our former research trainees have continued into graduate studies, and one of them has already completed his masters program in applied physics. Two of our current undergraduate trainees plan to go to graduate school after graduation. In addition, working collaboratively in research projects has enabled them to gain team working experience, communication, negotiation and consensus building skills. Preparing project reports and presenting their research results at conferences have developed and nurtured their writing and presentation skills.

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