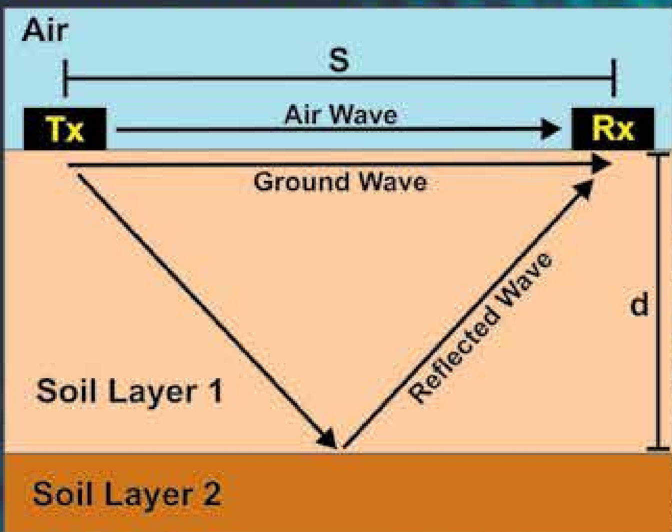
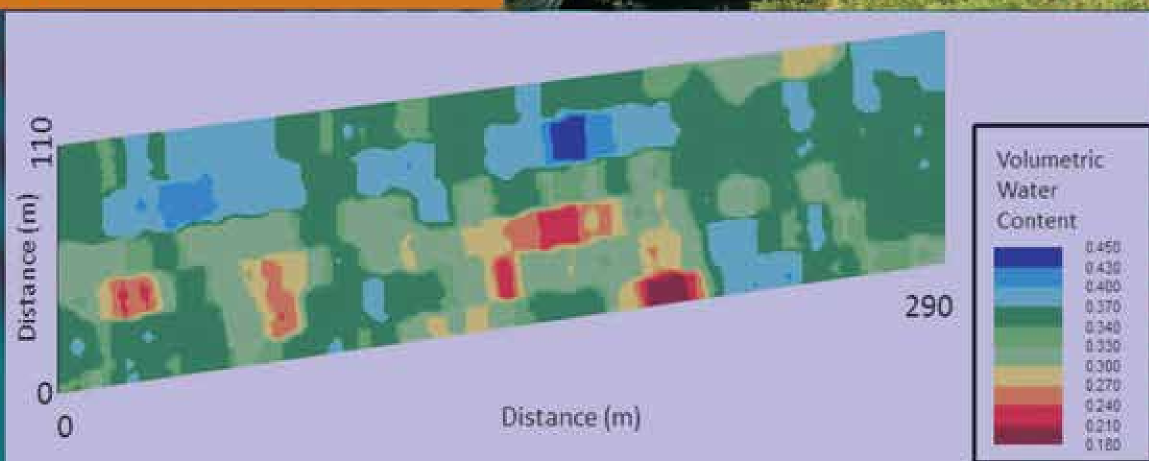
FastTIMES

GPR Soil Water Content Measurement





Also:

Seismic Refraction Surveying for Roadway Site Evaluation

and

Information on Joint Special Issue by JEEG and NSG

September 2013

Volume 18, Number 3

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Ground penetrating radar techniques are applied to soil water content measurement.

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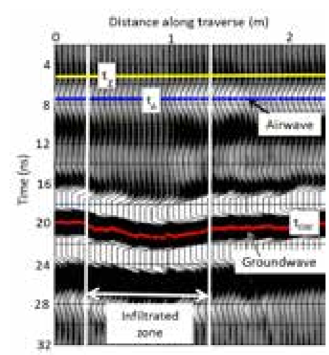

FastTIMES

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ABOUT EEGS

The Environmental and Engineering Geophysical Society (EEGS) is an applied scientific organization founded in 1992. Our mission:

"To promote the science of geophysics especially as it is applied to environmental and engineering problems; to foster common scientific interests of geophysicists and their colleagues in other related sciences and engineering; to maintain a high professional standing among its members; and to promote fellowship and cooperation among persons interested in the science."

We strive to accomplish our mission in many ways, including (1) holding the annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP); (2) publishing the Journal of Environmental & Engineering Geophysics (JEEG), a peer-reviewed journal devoted to near-surface geophysics; (3) publishing FastTIMES, a magazine for the near-surface community, and (4) maintaining relationships with other professional societies relevant to near-surface geophysics.

JOINING EEGS

EEGS welcomes membership applications from individuals (including students) and businesses. Annual dues are $90 for an individual membership, $50 for introductory membership; $50 for a retired member, complimentary membership for students, $50 developing world membership, and $650 to $4000 for various levels of corporate membership. All membership categories include free online access to JEEG. The membership application is available at the back of this issue, or online at www.eegs.org.

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FastTIMES is published electronically four times a year. Please send articles to any member of the editorial team by December 8, 2013. Advertisements are due to Jackie Jacoby by December 8, 2013.


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CALENDAR

2013

December 8	Deadline for submission of articles, advertisements, and contributions to the December issue of *Fast*TIMES http://www.eegs.org/Publications-Merchandise/FASTTIMES
December 9-13	American Geophysical Union Fall Meeting San Francisco, California, USA http://meetings.agu.org/

2014

March 16-20	SAGEEP 2014 Boston, Massachusetts, USA http://www.eegs.org/Annual-Meeting-SAGEEP/SAGEEP-2014
April 6-9	3rd International Workshop on Induced Polarization (IP) Ile d'Oleron, Charente-Maritime, France http://ip.geosciences.mines-paristech.fr/
June 20-23	6th International Conference on Environmental and Engineering Geophysics Xi'an, China http://tdem.org/iceeg2014/en (Note: Antonio Menghini, antonio.menghini@aarhusgeo.com, a JEEG Associate Editor, will be co-chairing a session on airborne geophysics.)
August 24-30	22nd EM Induction Workshop Weimar, Germany http://www.emiw2014.de
October 26-31	Society of Exploration Geophysicists International Exposition and 84th Annual Meeting Denver, Colorado, USA http://www.seg.org

Please send event listings, corrections or omitted events to any member of the *Fast*TIMES editorial team.

NOTES FROM EEGS

PRESIDENTS MESSAGE

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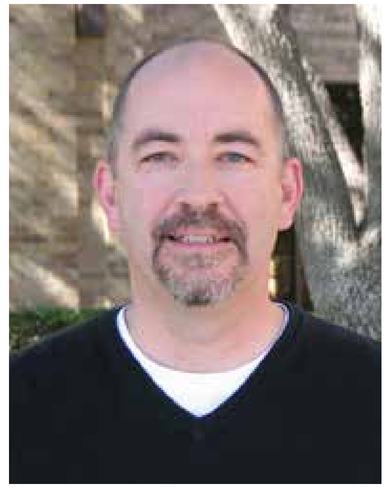
(cskokan@mines.edu)



Doug Laymon, Past President
(doug.laymon@tetratech.com)

Update on the EEGS/SEG Joint Task Force Discussions

As you know, a committee referred to as the "EEGS/SEG Joint Task Force" has been meeting for over a year to consider changes in societal structure for the near surface geophysics community. This is an issue that is of the utmost importance to you as a near-surface geophysicist, engineer, or practitioner. The decision regarding a realignment of your professional society could affect your personal professional growth and day-to-day activities, and is worthy of your attention. Thanks to all to who have given their thoughtful comments and responses to the Task Force questionnaires. We appreciate the time you have taken to guide our discussions, as we all have a significant stake in the decisions that could be made in the coming year. With that in mind, we set aside time during the SAGEEP 2013 meeting in Denver to allow the membership to hear the latest update on the Task Force deliberations and to provide input into the process. Your input was needed and was crucial to this process. In the mean time, anyone who would like to ask questions, voice opinions or offer suggestions should contact any of the Task Force members listed below.

The EEGS /SEG Joint Task Force is continuing to evaluate options for further cooperation between the two organizations for the benefit of our society members and the greater near-surface geophysical community. The Task Force has had many conference calls and has conducted three face-to-face meetings since December 2011. As previously communicated, the Task Force is currently evaluating the possibility of combining EEGS and the SEG Near-Surface Geophysics Section (NSGS) into a new organization that would be structured as a subsidiary of SEG. The new organization would need to retain an appropriate amount of autonomy of the near surface community, the strengths of the existing EEGS culture, and the essence of the SAGEEP spring meeting while working with SEG for sustained growth in the next few decades and beyond, when near-surface geophysics is expected to play a more important role in our society.

NOTES FROM EEGS

PRESIDENTS MESSAGE

The key components of a potential new society that are currently being discussed by the Task Force include details of governance, publications, annual meeting, membership dues and benefits. The Task Force is working out the details of how these components could be implemented and has made significant progress. Key information was gathered from both organizations' memberships from the two online surveys that were recently distributed regarding the formation of a potential new organization and related publications. The surveys and Task Force discussions clearly supported continuation and strengthening of a near surface journal as well as an e-magazine (like FastTimes). The annual spring near-surface conference (e.g. SAGEEP) would also continue. A subsidiary structure, as currently envisioned, allows for a relatively high level of autonomy. A "frequently asked questions" (FAQ) page has been prepared to answer some of the questions that you may have and to provide you with additional details regarding the potential new organization. Please take some time to visit this FAQ page and consider what is being proposed, it will be updated as additional information is ready.

The changes that are being considered carry potential benefits and compromises that must be weighed carefully by the Task Force and by the members of each organization. Ultimately, the EEGS membership will decide for EEGS whether to form a new organization with SEG and the NSGS. Therefore, it is important that the Joint Task Force and EEGS Board receive continued input from you on this important issue.

Doug Laymon
EEGS Past-President 2012-2013

Catherine Skokan
EEGS President 2013-2014

EEGS and SEG Joint Task Force Committee

EEGS:
William Doll, Battelle
Mark Dunscomb, Schnabel Engineering
Doug Laymon, Tetra-Tech
John Stowell, Mount Sopris
John Nicholl, URS
Bruce Smith, USGS
Cathy Skokan, Colorado School of Mines

SEG:
Peter Annan, Sensors & Software
John Bradford, Boise State University
Rick Miller, Kansas Geological Survey
Peter Pangman, SEG

EEGS Foundation makes great strides in its first years.

Since the launch of the EEGS Foundation, there are numerous accomplishments for which we can all be proud: Establishing and organizing a structure that serves the needs of EEGS; underwriting the legal process, achieving tax-exempt status; and soliciting and receiving support for SAGEEP. In addition, the Foundation helped underwrite the SAGEEP conference held this spring in Keystone.

These are only a few of the tangible results your donations to the Foundation have enabled. We would therefore like to recognize and gratefully thank the following individuals and companies for their generous contributions:

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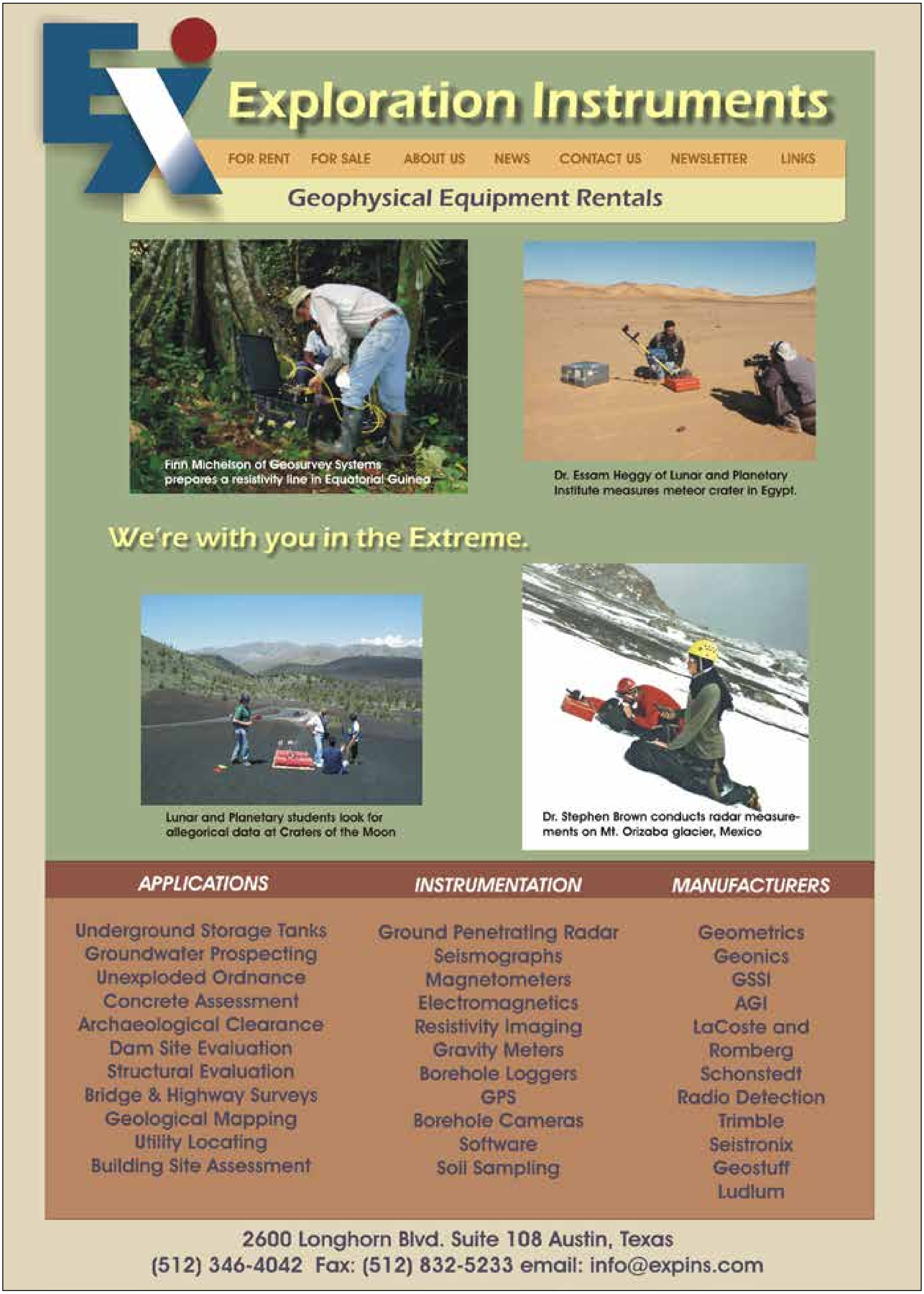

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Renew your EEGS Membership for 2014

Be sure to renew your EEGS membership for 2014! In addition to the more tangible member benefits (including the option of receiving a print or electronic subscription to JEEG, *Fast*TIMES delivered to your email box quarterly, discounts on EEGS publications and SAGEEP registration, and benefits from associated societies), your dues help support EEGS's major initiatives such as producing our annual meeting (SAGEEP), publishing JEEG, making our publications available electronically, expanding the awareness of near-surface geophysics outside our discipline, and enhancing our web site to enable desired capabilities such as membership services, publication ordering, and search and delivery of SAGEEP papers. You will also have the opportunity to donate to the EEGS Foundation during the renewal process. Members can renew by mail, fax, or online at www.eegs.org.

Sponsorship Opportunities

There are always sponsorship opportunities available for government agencies, corporations, and individuals who wish to help support EEGS's activities. Specific opportunities include development and maintenance of an online system for accessing SAGEEP papers from the EEGS web site and support for our next SAGEEP conference, to be held in Boston, Massachusetts in 2014. Make this the year your company gets involved! Contact Catherine Skokan (cskokan@mines.edu) for more information.

FROM THE *FAST*TIMES EDITORIAL TEAM

*Fast*TIMES is distributed as an electronic document (pdf) to all EEGS members, sent by web link to several related professional societies, and is available to all for download from the EEGS web site at http://www.eegs.org. Past issues of *Fast*TIMES continually rank among the top downloads from the EEGS web site. Your articles, advertisements, and announcements receive a wide audience, both within and outside the geophysics community.

To keep the content of *Fast*TIMES fresh, the editorial team strongly encourages submissions from researchers, instrument makers, software designers, practitioners, researchers, and consumers of geophysics—in short, everyone with an interest in near-surface geophysics, whether you are an EEGS member or not. We welcome short research articles or descriptions of geophysical successes and challenges, summaries of recent conferences, notices of upcoming events, descriptions of new hardware or software developments, professional opportunities, problems needing solutions, and advertisements for hardware, software, or staff positions.

The *Fast*TIMES presence on the EEGS web site has been redesigned. At http://www.eegs.org/Publications-Merchandise/FASTTIMES you'll now find calls for articles, author guidelines, current and past issues, and advertising information.

Submissions

The *Fast*TIMES editorial team welcomes contributions of any subject touching upon geophysics. *Fast*TIMES also accepts photographs and brief non-commercial descriptions of new instruments with possible environmental or engineering applications, news from geophysical or earth-science societies, conference notices, and brief reports from recent conferences. Please submit your items to a member of the *Fast*TIMES editorial team by December 8 to ensure inclusion in the next issue. We look forward to seeing your work in our pages.

JEEG NEWS AND INFO

The Journal of Environmental & Engineering Geophysics (JEEG), published four times each year, is the EEGS peer-reviewed and Science Citation Index (SCI®)-listed journal dedicated to near-surface geophysics. It is available in print by subscription, and is one of a select group of journals available through GeoScienceWorld (www.geoscienceworld.org). JEEG is one of the major benefits of an EEGS membership. Information regarding preparing and submitting JEEG articles is available at http://jeeg.allentrack.net.

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Journal of Environmental & Engineering Geophysics
v. 18, no. 3, September 2013

Editor's Note

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The Journal of Environmental and Engineering Geophysics (JEEG) is the flagship publication of the Environmental and Engineering Geophysical Society (EEGS). All topics related to geophysics are viable candidates for publication in JEEG, although its primary emphasis is on the theory and application of geophysical techniques for environmental, engineering, and mining applications. There is no page limit, and no page charges for the first ten journal pages of an article. The review process is relatively quick; articles are often published within a year of submission. Articles published in JEEG are available electronically through GeoScienceWorld and the SEG's Digital Library in the EEGS Research Collection. Manuscripts can be submitted online at www.eegs.org/Publications-Merchandise/JEEG.

Special Issue

Geotechnical Assessment and Geo-environmental Engineering Geophysics

The past decade has seen a distinct change in the way that geophysical methods are utilized in solving geotechnical and geo-environmental problems. Advances in instrumentation design, computer hardware and data processing software, and availability of new data have all led to novel and highly sophisticated geophysical techniques being routinely applied to geotechnical and geo-environmental problems.

Experts say that the near-surface geophysics community will witness a rapid growth over the next decade. The recent surge in the development of new technologies and analysis tools lends weight to that theory, and today we have numerous means to solve many of the complex engineering problems associated with the natural and built environments. Assessing the stability and integrity of structures such as buildings, bridges, dams, roads, water ways, foundations, underground excavations, mines, landfills, and sinkholes often requires a multi-disciplinary approach and collaboration between experts in geophysics, hydrology, geotechnical and environmental engineering, and geology. A trend to objectify the information about the condition of a structure is beginning to emerge: the development of tools to appraise and integrate data from sources of similar and dissimilar nature.

In response to the rapid and exciting expansion of research, the *Journal of Environmental & Engineering Geophysics and Near Surface Geophysics* have produced a collaborative *"Special Issue on Geotechnical Assessment and Geo-environmental Engineering"* to showcase the state-of-the-art and most pertinent research currently being undertaken in the discipline. Chief Editors, Janet Simms of *JEEG* and Ugur Yaramanci of *NSG*, are delighted to present a jointly worked special issue addressing an active topic in both research and practice, i.e., the application of geophysics for geotechnical and geo-environmental issues. Increasing demand and efforts to meet the needs of activities for environmental issues need a platform to communicate the achievements of science and technology and bring communities together working and doing science in the same subject area.

Special Issue

Geotechnical Assessment and Geo-environmental Engineering Geophysics

Well known individuals in the professional community for their scientific and technical work are brought together to serve as Guest Editors for this special issue: Moe Momayez and Fred Boadu from the U.S. and Nigel Cassidy and Denis Jongmans from Europe. Their efforts shaped the content and quality of the contributions.

The unique feature of this special issue is that it is produced jointly by the two journals, with each journal addressing different geophysical methods that are complementary. Subscribers of each journal will receive both the *NSG* and *JEEG* issues of the special issue as on-line access and hard copy (if given). Using this approach, a large community can be addressed and informed about the newest developments, and allows authors to get their work to the attention of a much larger audience and producing more impact.

The Special Joint-Issue of the *JEEG* and *NSG* is a selection of original contributions organized under two themes. *Near Surface Geophysics* presents eight articles on the application of the electrical resistivity techniques to determine the geotechnical properties of the ground, and the integration of geophysical and geotechnical data. The *Journal of Environmental and Engineering Geophysics* contains seven papers that investigate the stability of structures using seismic techniques.

In the paper *"Seismic surface-wave prospecting methods for sinkhole hazard assessment along the Dead Sea shoreline"*, **Ezersky et al.** present the results of a surface-wave investigation into evaporite karsts which are caused by slow salt dissolution, and are linked to the mechanism of sinkhole formation along the Dead Sea coastal areas. Vs mapping allowed soft zones associated with karstified salt to be characterized, while roll along acquisition, dispersion stacking, and inverted pseudo-2-D Vs sections made it possible to detect decompacted sediments associated with potential sinkholes occurrences. **Walter et al.** employ passive seismic to monitor landslides at three soft-rock sites in the Austrian and French Alps and in the San Juan Mountains of Colorado, U.S. Their paper *"Slidequake generation versus viscous creep at soft rock landslides: Synopsis of three different scenarios at Slumgullion landslide, Heumoes slope, and Super-Sauze mudslide"* discusses the origin of the process and how it might be directly influenced by the boundary surfaces causing seismic and aseismic modes. Geotechnical and mine planning engineers will be interested in the work presented in *"Seismic reflection for hard rock mineral exploration: Lessons from numerical modeling"* by **Greenhalgh and Manukyan**. The authors show that where there is enough density contrast through the presence of metallic ore, or fractured zones, it is possible to probe ahead of the mining face – a useful tool in the context of narrow vein mining that would help reduce dilution. They propose that numerical modeling of elastic scatterers can help in the design of the field survey and effectively avoid spatial aliasing problems caused by the shape and location of the orebody and the restricted range of view angles. The potential for the ground to liquefy is omnipresent in earthquake-prone regions. **Nobes et al.** employ several near-surface geophysical methods in the article *"Geophysical imaging of subsurface earthquake-induced liquefaction features at Christchurch Boys High School, Christchurch, New Zealand"* to better understand the characteristics of liquefaction in the subsurface and interpret paleoliquefaction features. Monitoring microseismic activity in underground mining operations is mandated by law to warn of potential slope/pillar failures or rockbursts. The average magnitude of mining induced seismic events is between 1 and 3 on the Richter scale. Nanoseismic monitoring (NM) focuses on the detection, location and characterization of extremely low-energy (ML > -4.0) source processes and has been applied by **Wust-Bloch and Tsesarsky** to study pre-failure microcracking in concrete beams and marble plates. Their paper *"Structural health monitoring in natural environments: Pre-failure event location and full-waveform characterization by nanoseismic monitoring"* discusses how the nanoseismic technique can be adapted to monitor unstable archaeological caves excavated in natural chalk, and highlights NM potential for analyzing pre-failure microcracking processes in the broader geological media. **James and Ferreira** use 3-D modeling to compute and compare the response of various cavity targets from a range of techniques such as gravity, gravity gradient, magnetic, magnetic gradient and GPR in their paper entitled *"Geophysical modeling of typical cavity shapes to calculate detection probability and inform survey design"*. This objective approach should resonate with engineers: it aids in assessing the probability of target detection, hence, discriminate the choice of technique(s), improve survey design, and increase the likelihood of success. The analysis of seismic noise recorded from extremely low frequency seismometers (0.2 to 2 Hz) to identify precursors to rock-falls is the topic of the article *"Spectral analysis of prone-to-fall rock compartments using ambient vibrations"* by **Bottelin et al.** They show that the correlation between the primary natural frequency of the rock mass and meteorological parameters can be used to identify the natural frequencies of the unstable rocks and to monitor their evolution through time.

Arjwech and Everett carry out 2-D and 3-D resistivity surveys at three roadway bridges and one railway bridge, and one geotechnical test site, and report their research findings in the paper *"Electrical resistivity imaging of unknown bridge foundations"*. They show that the 2-D electrical resistivity imaging technique used on the ground and underwater is a cost-effective geophysical method, and relatively straightforward for bridge foundation investigations. To infer site-specific engineering parameters (that affect the mechanical behavior of soil) from electrical measurements, **Boadu** uses multivariate regression models to validate the output from neural networks in his paper *"Artificial neural network and statistical models for predicting the basic geotechnical properties of soils from electrical measurements"*. Spectral electrical parameters, including conductivity, phase shift, and loss tangent are related to engineering properties such as fines content, specific surface area and pore size which are essential properties used in site characterization. In the paper *"Towards geophysical and geotechnical integration for quick-clay mapping in Norway"*, **Sauvin et al.** present an integrated approach to characterize hazardous quick-clay sites. The authors emphasize that because of the inherent complexities in integrated approaches, high resolution data, in-depth imaging, and site-specific data calibration would provide the essential parameters for stability analyses. Geotechnical properties of the subsurface material are needed for the expansion of the Panama Canal to be completed in 2015. Limited core, lithographic and stratigraphic data are available from the previous expansion phase that took place over 60 years ago. The paper *"Using marine resistivity to map geotechnical properties: A case study in support of dredging the Panama Canal"* by **Rucker and Noonan** shares the results of an investigation that helped reduce the uncertainty in interpolating material properties between boreholes, by conducting a spatially continuous electrical conductivity survey. Few studies have offered an objective comparison between the powers of various electrical resistivity tomography (ERT) algorithms/tools. **Caterina et al.** propose in their paper *"A comparison study of different image appraisal tools for electrical resistivity tomography"*, a quantitative methodology to appraise the performance of the most commonly used ERT tools such as model resolution matrix, the cumulative sensitivity matrix, and the depth of investigation index. This work paves the way to develop additional appraisal indicators suitable for more comprehensive analyses. A second contribution in this collection on the topic of quick-clays is *"Mapping of quick-clay using geoelectrical imaging and CPTU-resistivity"* by **Dahlin et al.** The authors conducted an integrated 2-D resistivity-IP survey with a combined cone penetration test and resistivity measurement (CPTu-R). The approach has been successful in segregating leached soils from soils with a high salt water content, thus providing an efficient screening tool when used in the early stages of the investigation process. **O'Driscoll et al.** investigate the integration of refraction, multichannel surface waves and resistivity data to determine the spatial variability of aggregate quality in a quarry. Data integration in their paper *"Assessment of aggregate resources: An integrated geophysical approach"* is carried out by linking measured elastic and electrical parameters through regression analysis of cross-plots and using established petrophysical relationships to set up guided inversions of the refraction and resistivity data. **Bitri et al.** present an alternative method to the cone penetration test to determine the mechanical properties of soil in their paper *"Assessment of ground compaction using multi-channel analysis of surface-wave data and cone penetration tests"*. These authors formulate that the shear wave profiles of a site offer the potential to characterize the soil at a higher spatial resolution and a fraction of the time.

SUCCESS WITH GEOPHYSICS

FastTIMES welcomes short articles on applications of geophysics to the near surface in many disciplines, including engineering and environmental problems, geology, hydrology, agriculture, archaeology, and astronomy. In the articles that follow, the authors present examples of soil water content measurement using ground penetrating radar and a roadway site evaluation based on geologic studies and seismic refraction surveys.

A SUMMARY OF GROUND PENETRATING RADAR TECHNIQUES FOR SOIL WATER CONTENT MONITORING

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Introduction

The vadose zone is a dynamic environment where pore water is retained, released to the surface, and infiltrated into the saturated zone. The availability and movement of water within the vadose zone influences large-scale processes such as global energy redistribution and precipitation (Entekhabi and others, 1996) and is a controlling factor for agriculture, groundwater recharge and water supply, geotechnical engineering, and flooding (Robinson and others, 2008; Vereecken and others, 2008). Several techniques are available to monitor soil water content, including gravimetric sampling, time-domain reflectometry (TDR), neutron probes, and capacitance sensors. Although these techniques may provide accurate estimates of water content, they are all point measurements and are time-consuming to acquire (Hillel, 1997; Vischel and others, 2008). Thus, these techniques are not usually suitable for monitoring soil water content at the field scale. Remote sensing techniques can provide estimates of water content over large areas, but usually with low resolution and a very shallow sampling depth; these techniques are also limited by vegetation (Famiglietti and others, 2008; Vischel and others, 2008). Ground Penetrating Radar (GPR) is a geophysical technique that can be used to obtain rapid, high-resolution, non-invasive soil water content estimates over large areas, and so offers considerable promise for water content monitoring at the field scale.

Different GPR techniques can be used to estimate soil water content at a variety of sampling depths and measurement volumes. GPR techniques for water content estimation include ground-coupled reflections, groundwaves, guided waves, air-launched reflections, and borehole direct waves. These techniques employ different GPR data acquisition or processing strategies to provide an estimate of the electromagnetic velocity or dielectric permittivity of the soil, which can be converted to soil water content using a petrophysical relationship.

Relating Dielectric Permittivity to Water Content

Several petrophysical relationships are available to convert GPR measurements to water content estimates. These relationships use dielectric permittivity to estimate water content, while most GPR techniques measure electromagnetic velocity. For the low-loss conditions common in many near-surface environments, electromagnetic velocity (v) can be converted to dielectric permittivity (κ) using the follow approximation:

$$\kappa \approx \left(\frac{c}{v}\right)^2 \quad , \tag{1}$$

where c is the velocity of an electromagnetic wave in free space (0.3 m/ns). Soil water content is the most important factor influencing the electromagnetic velocity, although soil density and mineralogy can have some effect. Wetter soils have slower velocities (and thus higher permittivities) than drier soils. The permittivity of air and water are 1 and ~80, respectively, while the permittivity of soil ranges from ~3 to 40, depending on soil water content.

The two types of petrophysical relationships most often used to convert permittivity to volumetric water content (θ_v) are empirical relationships and volumetric mixing models. Empirical relationships do not require any additional information about soil properties, and so are easily applied to sites with significant soil heterogeneity or limited soil characterization. The most commonly used empirical relationship was developed by Topp and others (1980) using a range of agricultural soil textures:

$$\theta_v = -5.3 \times 10^{-2} + 2.92 \times 10^{-2}\kappa - 5.5 \times 10^{-4}\kappa^2 + 4.3 \times 10^{-6}\kappa^3 \quad . \tag{2}$$

Several other empirical relationships have been developed for soils with differing textures, densities, and organic components (Roth and others, 1992; Jacobsen and Schjønning, 1993; Curtis, 2001; Steelman and Endres, 2011). For the most accurate water content estimates, site-specific empirical relationships can be developed using TDR or GPR data acquired over an appropriate range of water contents.

The second most common type of petrophysical relationship, volumetric mixing models, relates the measured (bulk) permittivity to the permittivity and volume fraction of each soil component. Near-surface soil is usually a three-way system composed of soil solids, water, and air. The volumetric mixing model for a three-way system is given by:

$$\theta_v = \frac{\kappa^\alpha - (1-n)\kappa_s^\alpha - n\kappa_a^\alpha}{\kappa_w^\alpha - \kappa_a^\alpha} \quad , \tag{3}$$

where n is the porosity, κ_s, κ_a, and κ_w are the permittivities of the soil solids, air, and water, respectively, and α is a geometrical mixing factor. The geometric factor is most often assumed to be 0.5, although other values have been suggested for differing mineralogies or pore fluids (Roth and others, 1990; Brovelli and Cassiani, 2008).

Ground-Coupled Reflection Methods

Ground-coupled GPR reflection data can be acquired in either variable- or common-offset modes. Both modes are suitable for water content estimation, although with different advantages and limitations. One characteristic shared by both modes is that the measurement volume extends from the ground surface to the reflective interface. Vertical resolution is limited to the depth of the reflector, but the potential sampling depth is greater than for any other non-invasive

GPR technique. If water content estimates are required for depths greater than ~0.5 m, reflection methods are probably the only suitable non-invasive GPR technique.

Variable-Offset Reflections

Variable-offset data are obtained using either common-midpoint or wide-angle reflection and refraction surveys. A reflective interface will produce a hyperbola on a time vs. antenna separation plot for a variable-offset survey (Figure 1), and most GPR data processing software allows the user to manually fit a curve to this hyperbola to determine the velocity. To reduce human error, more sophisticated data analysis techniques such as semblance analysis (Yilmaz, 1987) can be used. If reflections are observed from multiple interfaces, the velocity of each layer can be obtained using the Dix formula (Dix, 1955; Yilmaz, 1987).

Scientists have used variable-offset reflections to measure the velocity to an interface, then converted this velocity to volumetric water content (Greaves and others, 1996; van Overmeeren and others, 1997; Nakashima and others, 2001; Garambois and others, 2002; Turesson, 2006). The primary advantage to variable-offset surveys is that they do not require a known depth to the reflective interface to calculate velocity. The main disadvantages are that a reflective interface is required and that data are time-consuming to collect, so variable-offset surveys are not practical for mapping large areas with standard GPR antennas.

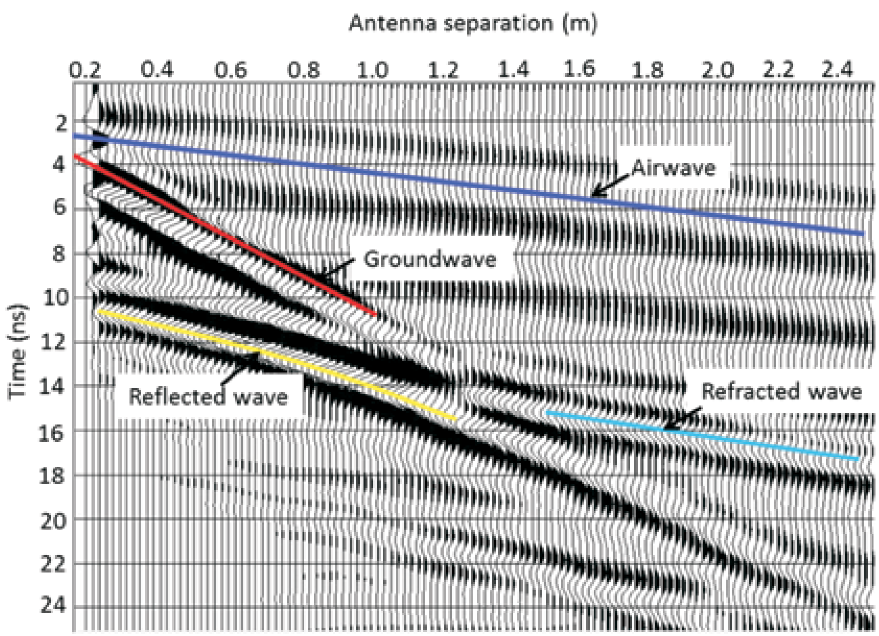

Figure 1: Variable-offset, 500 MHz GPR data were acquired over a continuous reflector. The reflected energy is shown by the hyperbola arriving after the direct wave events (the airwave and groundwave). At longer antenna offsets, the reflection wavelet may be superimposed with refraction events.

Common-Offset Reflections

Common-offset reflection data can be used for water content estimation when the depth to a subsurface reflector is known independently of the GPR data. Common-offset data can be acquired more quickly and with simpler processing than variable-offset data, so common-offset data are useful for estimating water content over large areas, if a continuous reflector is present. If the reflector depth (d) is known, the velocity is calculated using the two-way travel time of the reflected energy (t_r) and the antenna separation (S):

$$v = \frac{2\sqrt{d^2 + (0.5S)^2}}{t_r} \quad (4)$$

The antenna separation is known, and the depth to the reflector can be determined using borehole logs for natural (stratigraphic) interfaces or construction records for engineered soils or manufactured reflectors such as pipes. The two-way travel time is calculated by subtracting the zero time (the time at which the energy leaves the GPR transmitter) from the arrival time of the reflected energy (Figure 2). A simple method for estimating the zero time (t_z) uses the airwave arrival time (t_a):

$$t_z = t_a - \frac{S}{c} \quad , \tag{5}$$

where the second term in Equation 5 accounts for the time needed for the airwave to travel between antennas. Other procedures for correcting for the zero time are given in Huisman and others, 2003. Care must be taken to pick the same point on the wavelet (i.e., leading edge, maximum amplitude, etc.) for the airwave (if used to find t_z) and the reflection. Picking the same point on the wavelet is especially important if the subsurface reflector is shallow and small changes in travel time might cause significant changes in velocity.

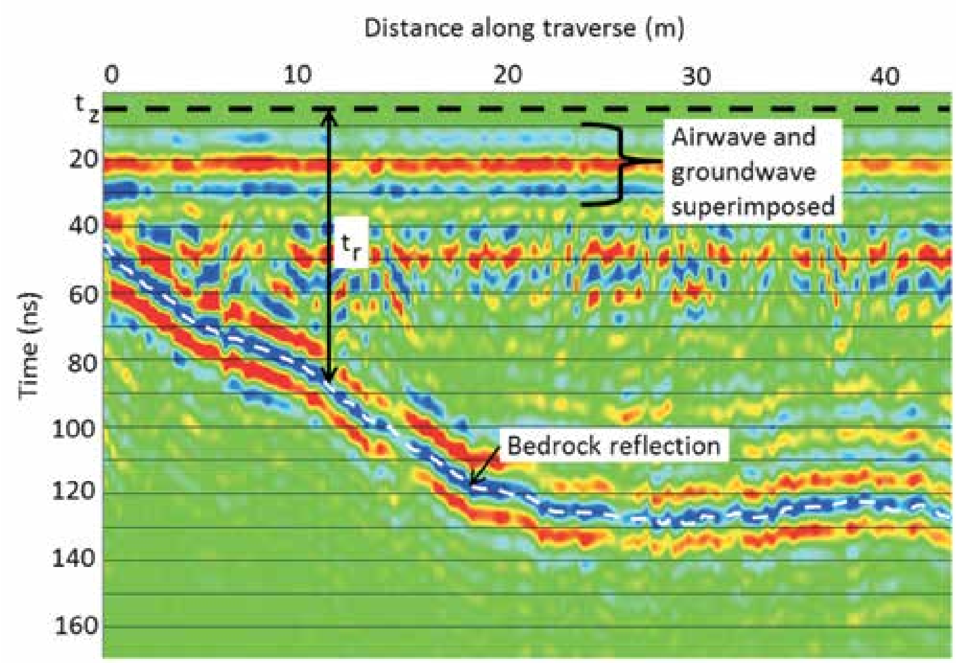

Figure 2: Continous interfaces, such as the bedrock reflection shown in this 100 MHz common-offset data, can be used to estimate soil water content. The two way travel time (t_r) can be found using the reflected wave arrival time and the calculated time zero (t_z).

While a continuous reflective interface is useful for calculating water content along a traverse or over large areas, a point reflector, such as buried pipe, can be used to estimate water content at one location without knowing the depth of the reflector. For point reflectors, the limbs of the reflection hyperbola can be used to determine the velocity, and most GPR data processing software includes this functionality. However, care should be taken during the survey to align the traverse perpendicularly to the reflector, as approaching the reflector obliquely can affect the accuracy of velocity estimates from hyperbola analysis.

Several researchers have used common-offset GPR data for water content estimation. Grote and others (2002) used reflections from metal plates within a sandy test pit, while Stoffregen and others (2002) used reflections from the base of a lysimeter to calculate seasonal water content; GPR-derived estimates of water content in both experiments agreed with conventional water content measurements to 0.01 m^3/m^3. Weilor and others (1998) and Lunt and others (2005) measured seasonal changes in water content in fields using natural soil interfaces as reflectors and borehole logs to determine the depth to the soil interfaces, and the estimates of water content obtained with GPR correlated well with those from TDR or neutron probes. Wollschläger and Roth (2005) used a natural soil horizon at an estimated depth in conjunction with time-lapse GPR measurements to estimate changes in water content. Grote and others (2005) used the known thicknesses of engineered soil layers in pavements to monitor the water content distribution in three layers during infiltration.

Groundwaves

GPR groundwaves are generated by the energy that travels through the ground directly from the transmitter to the receiver. The travel path is the distance separating the transmitter and receiver, and the velocity can be determined using this distance and the groundwave travel time. Groundwave data can be acquired in either variable- or common-offset modes. For variable-offset data, the groundwave appears as a straight line in time vs. antenna separation plots (Figure 1); the inverse slope of the groundwave is the groundwave velocity. As with reflection data, variable-offset data are easy to interpret and do not require a zero-time correction, but these data have a large sample size (lower resolution) and are not practical for monitoring water content over large areas due to the cumbersome data acquisition procedure. Common-offset data, which can be acquired and processed quickly and with higher resolution, are more useful for field-scale water content monitoring. For common-offset surveys (Figure 3), the groundwave velocity can be calculated using the arrival time of the groundwave (t_{gw}):

$$v = \frac{S}{t_{gw} - t_a + \frac{S}{c}} \qquad (6)$$

Figure 4 shows water content estimates from common-offset groundwave data acquired over a large field, part of which was irrigated with a pivot sprinkler system. Other examples of using groundwaves for monitoring water content at the plot scale (van Overmeeren and others, 1997; Huisman and others, 2001; Galagedara and others, 2003a; Steelman and Endres, 2010; Pallavi and others, 2011) and field scale (Du and Rummel, 1994; Grote and others, 2003; Galagedara and others, 2005; Weihermüller and others, 2007) are available.

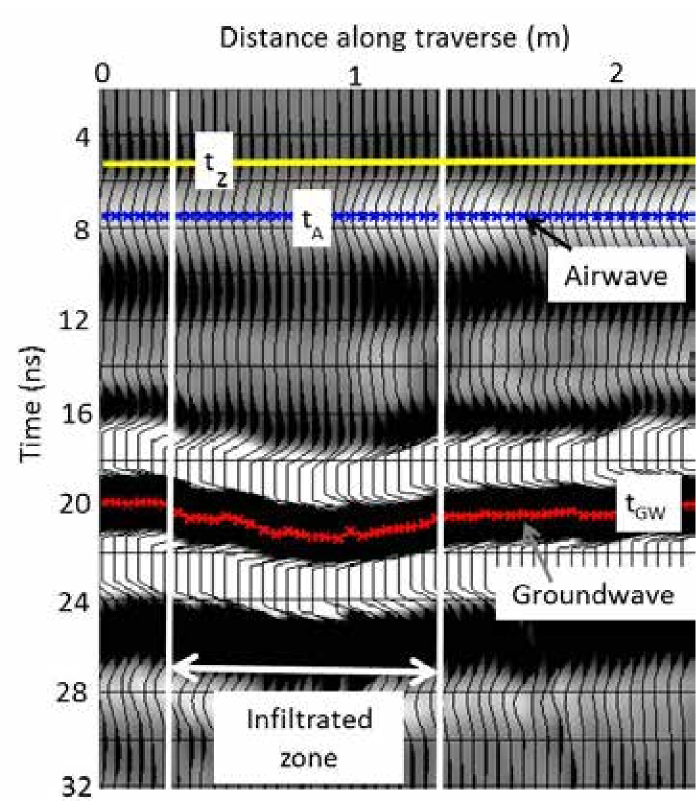

Figure 3: Common-offset, 250 MHz groundwave data were acquired during an infiltration experiment. The airwave was used to find the zero time (t_z). The wetter soils beneath the infiltrated zone have lower velocities, so the groundwave arrives later in these soils.

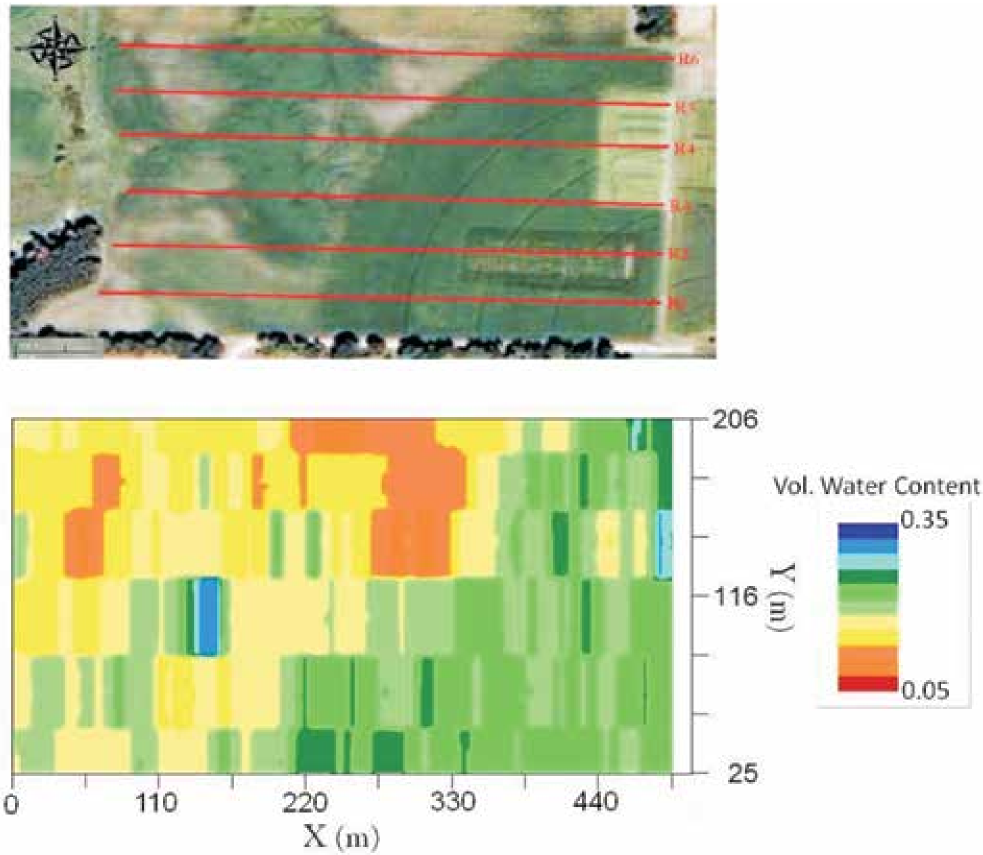

Figure 4: Common-offset, 250 MHz groundwave data were acquired over a field after pivot irrigation. The top photo shows the GPR traverses and the extent of irrigation in the southeast corner of the field. The bottom image shows the volumetric water content estimates from GPR, where the irrigated portion of the field is much wetter than the non-irrigated portion.

Although groundwave data are relatively straightforward to interpret, care must be taken during data acquisition to ensure that a clear groundwave is recorded. Groundwaves are evanescent, so can only be measured when the antennas are coupled to the ground; very rough ground (i.e., boulders or cobbles) may lead to poor coupling and preclude a reliable groundwave. Also, the antenna spacing must be chosen carefully so the groundwave and airwave are clearly separated; if the antenna separation is too small, the airwave and groundwave will be superimposed, and it will not be possible to accurately pick the arrival times of these waves (i.e., antenna separations of less than ~0.5 m in Figure 1). If the antenna separation is too large, the groundwave energy may be too attenuated or refracted energy may arrive before the groundwave, so the groundwave cannot be clearly identified (i.e., offsets larger than ~1.0 m in Figure 1). Before conducting a common-offset groundwave survey, it is essential to first perform a variable-offset survey to determine the optimal antenna separation and to help interpret different radar events.

The primary advantage of GPR groundwaves for water content estimation is that groundwave data can be collected quickly at a variety of field sites, and no subsurface reflector is required. The main limitations of groundwave data are the relatively shallow sampling depth and possible interference from reflections or refractions from shallow subsurface interfaces. The sampling depth for GPR groundwaves is a topic of active research; several of the previously cited experiments have yielded sampling depth estimates that range from just a few centimeters to 3 m, although most estimates are in the range of 10 – 30 cm. Some researchers have found that the sampling depth is frequency dependent (van Overmeeren and others, 1997; Galagedara and others, 2005; Grote and others, 2010), suggesting that multi-frequency groundwave data might be used to determine the shallow vertical water content distribution at the field scale.

Guided Waves

If a thin surficial layer overlies a deeper layer with either a lower permittivity or a much higher permittivity, both reflection and groundwave methods may be unsuitable for water content estimation. Electromagnetic waves may be trapped and internally reflected within the thin layer (the wave guide), resulting in dispersive wave propagation (Figure 5). The formation of dispersive (or guided) waves is also influenced by frequency, so the same subsurface conditions will not always result in guided waves if different frequencies are used. Examples of possible wave guides are unfrozen soil overlying permafrost, a thin soil layer over bedrock, ice over water, or a sharp infiltration front resulting from precipitation or irrigation.

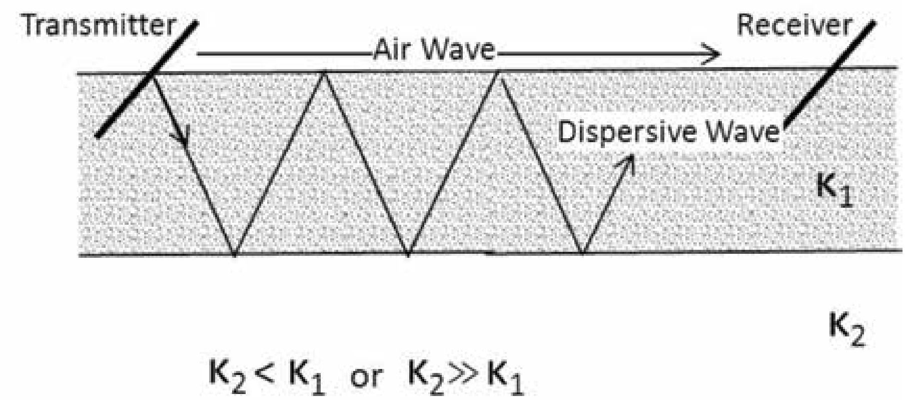

Figure 5: Dispersive waves may occur when a thin surficial layer acts as a wave guide, creating a series of GPR reflections within that layer.

Guided waves can usually be distinguished from reflections or groundwaves in variable-offset data. Guided waves attenuate more slowly than reflected waves, and instead of one wavelet representing an event (typical for reflected waves or groundwaves), guided waves often appear as a "shingled" event on a time vs. antenna separation plot, where the phase velocities of individual wavelets are different from the group velocity. Guided waves also differ from groundwaves in that the groundwave and airwave arrival times can be extrapolated to the same "zero time" representing no separation between antennas, while guided waves extrapolate to a later starting time at zero antenna separation.

Researchers have developed inversion codes that use dispersive waves to estimate the permittivity (and thus the water content) of the wave guide and the underlying layer, as well as the thickness of the wave guide (Strobbia and Cassiani, 2007; van der Kruk and others, 2009; Haney and others, 2010). These inversion codes are not yet readily available, and guided wave analysis is not often performed. Also, the conditions which create guided waves are often transient, limiting the effectiveness of this technique for measuring water content at different times. Although guided waves have been shown to be effective at estimating soil water content under certain conditions, one of the most important reasons for recognizing guided waves may currently be to avoid erroneously processing them as reflections or groundwaves.

Air-launched Reflections

Proximal air-launched GPR reflection data are obtained by holding the antennas a short distance off the ground (usually less than 2 m), and the antennas are often attached to a frame mounted on a vehicle. Conventionally, the permittivity of the near-surface soil is measured using the amplitude of the reflection from the air-soil interface (A_s), normalized by the amplitude of a perfect reflector (such as a metal plate) (A_m):

$$\kappa = \left(\frac{1 + \frac{A_s}{A_m}}{1 - \frac{A_s}{A_m}} \right)^2 . \tag{7}$$

The height of the antenna above the ground must be the same for reflections from the soil surface and the metal plate. Also, the metal plate must be larger than the footprint of the radar signal; the first Fresnel zone is often used to approximate the radar footprint (Redman and others, 2002). The radar footprint is inversely related to frequency, so higher frequency GPR systems require smaller calibration plates and are more commonly used for air-launched reflection surveys than lower frequency systems.

The advantages of air-launched reflection data are that they can be acquired quickly, conventional data processing is straightforward, and air-launched reflections are not usually compromised by reflections or refractions from shallow soil layers, which can be a problem for groundwaves. One significant disadvantage is that the sampling depth for air-launched reflections is uncertain, but current research suggests that it is very shallow (<5 cm) (Serbin and Or, 2003; Escorihuela and others, 2010), while many applications require deeper water content estimates. Additionally, the accuracy of air-launched data is significantly diminished by vertical changes in water content and by surface roughness. (For a 1-GHz antenna, surface roughness needs to be less than ~4 cm for accurate air-launched data to be acquired (Huisman and others, 2003).) Also, vegetation can decrease the accuracy of air-launched reflections, so a vegetation-appropriate correction must be applied if surveys are not performed over bare ground (Serbin and Or, 2005).

Recent advances in data processing techniques, especially full-waveform inversion, have increased the accuracy of air-launched GPR data, and several researchers have used air-launched techniques to map water content at the field scale (Lambot and others, 2006; Jadoon and others, 2010; Slob and others, 2010; Jonard and others, 2011; Ardekani, 2013). However, even though full-waveform inversion is more accurate than conventional data processing techniques, factors such as variable water content profiles and surface roughness can still limit air-launched methods (Jonard and others, 2012). Also, full-waveform inversion is, at present, a relatively complicated data interpretation technique which has many times more computational cost than other GPR techniques (Ardekani, 2013), and the inversion codes are not yet commonly available. Thus, air-launch reflections are a promising technique with some advantages over ground-coupled methods, but continued research is needed to overcome some of the limitations in site suitability and to simplify advanced forms of data processing.

Borehole Methods

Borehole GPR methods are not suitable as a reconnaissance tool, but are useful for providing detailed subsurface information at strategic locations. Borehole data have been used for applications such as mapping the soil water content distribution (Alumbaugh and others, 2002; Galagedara and others, 2003b), imaging water-filled fractures or permeable pathways (Hubbard and others, 1997), and monitoring infiltration from trenches (Parkin and others, 2000). Borehole data are commonly used to characterize the subsurface between two boreholes, but can also be acquired when one antenna is in a borehole while the other antenna is on the ground surface or in a mining tunnel. Data are typically acquired with vertical antennas, but horizontally-oriented profiling has also been performed.

Borehole data can be collected in either zero-offset profiling (ZOP) or multiple-offset profiling (MOP) modes. In the ZOP mode, the transmitting and receiving antennas are simultaneously lowered into two boreholes, and measurements are acquired at vertical intervals within the borehole (Figure 6). ZOP data can be acquired fairly quickly, and data processing is straightforward, but the horizontal resolution is limited to the distance between the boreholes. In MOP, one antenna is held stationary within the first borehole, and measurements are taken at several elevations as the other antenna is lowered into the second borehole; this process is repeated with the first antenna positioned at a variety of elevations along the length of the first borehole (Figure 6). MOP allows construction of a tomographic profile of water content between the boreholes (Figure 7, used with permission from Truex and others, 2013), but requires much more time to perform, and thus is not suitable for measuring rapid changes in water content. Also, it is very important that MOP data be processed carefully, with adequate attention paid to time-zero shifts due to changes in the transmission characteristics or acquisition procedures (Peterson, 2001).

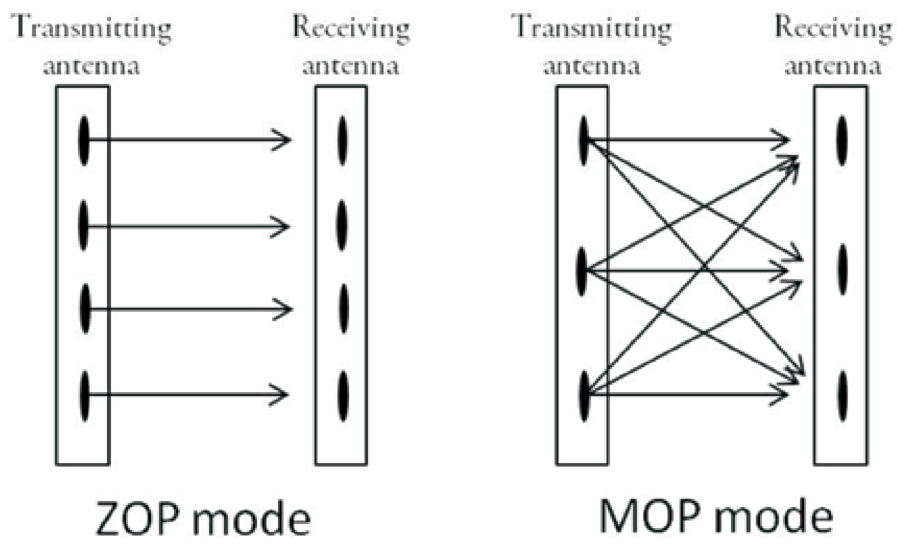

Figure 6: In zero-offset profiling (ZOP), one measurement is acquired for each transmitter station (elevation of the transmitting antenna). For multiple-offset profiling (MOP), multiple measurements are acquired along the length of the second borehole for each transmitter station.

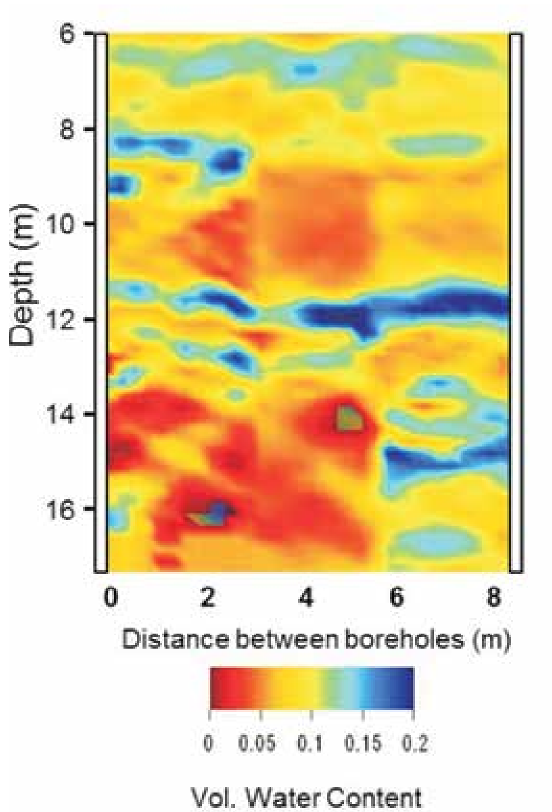

Figure 7: Tomographic water content distribution between two boreholes obtained from MOP (from Truex and others, 2013).

Borehole data can provide a high-resolution, two-dimensional image of the water content distribution between boreholes, but borehole data are not always accurate over the entire depth of the survey. The shallowest borehole data may be problematic, as refractions through the air along the surface between boreholes may arrive before the wave traveling through the soil. At greater depths, energy may refract through dry layers in the subsurface, causing errors in the velocity estimation if the refractions are not considered during processing (Slob and others, 2010). An additional limitation of borehole data is that the resolution is determined by the distance between antennas, the antenna frequency, and the length of the antenna, so it is not always possible to image smaller-scale variations in water content.

Summary and Conclusions

GPR techniques can be used to estimate soil water content over a range of depths and resolution scales. The most useful GPR technique will depend on the application and the site conditions. Air-launched GPR can estimate water content in very shallow soils, if the soil surface is sufficiently smooth and the water content does not change too greatly with depth. GPR groundwaves estimate water content over a somewhat greater depth, and can be used at most field sites, although shallow reflective layers may limit site suitability. Reflection techniques can only be used when a reflective subsurface interface is present, but this method is the best option for deeper water content estimates, since the measurement extends to the depth to the reflector. A combination of GPR techniques could be useful for estimating the water content at different depths, providing a method for monitoring the vertical water content distribution at the field scale.

GPR techniques for water content estimation continue to evolve, and advances in data processing may expand the efficacy of these techniques. As software for full-waveform inversion of air-launched reflections or guided wave analysis becomes more readily available, these techniques may become more widely used. Additionally, as uncertainty regarding the sampling depth of air-launched and groundwave data is reduced, the utility of these methods will increase. Continued research into GPR techniques and innovation in utilizing the existing techniques will increase the effectiveness of GPR as a tool for monitoring soil water content.

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GEOLOGICAL AND SHALLOW SEISMIC REFRACTION STUDIES FOR DELINEATION AND CONSTRUCTION OF ASSIUT-HURGHADA DESERT ROAD, MIDDLE EGYPT

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Abstract

The existence of a road network in any part of the world is a clear indication of progress in urban, social, and economic development. Due to the lack of a highway in Middle Egypt joining the Nile River with the Red Sea coast, a technical economic study was conducted in 1987 for road construction evaluation. An integrated study analyzing several types of data was carried out in an effort to identify the best route for this proposed road. Analyzed data include geological and geographical maps from a period between 1930s into the 1980s. Furthermore, satellite images and photogeological maps were used in this study, along with field trips organized to evaluate and follow the potential routes for the road. A shallow seismic refraction survey was done across different locations of the proposed road to show the nature and structure of the bedrock.

Two possible routes (A and B) for this road were defined based on the interpreted geological/geophysical data which include topographic, structural, stratigraphic, surface, near-surface, type of soil, and geoseismic cross sections. The distance of route A is about 275 km and was excluded due to the existence of high mountains with hard bedrock that the route crosses for a long distance. The length of route B is nearly 300 km, but is less expensive because it does not encounter mountains with hard bedrock. The B route can be divided into four segments, and it includes natural tracks and secondary desert roads. Consequently, the B route was selected as the best course for the road, which saves about 50% of the distance south of Assiut and 70% of the distance north of Assiut. Advanced technology and standard specifications for road design were recommended by this study to secure the road against natural hazards.

Keywords: Seismic Refraction, Eastern Egyptian Desert, Seismic Interpretation.

Introduction

In this integrated study, geological and geophysical data were used for delineating and exploring the route of Assiut-Hurghada desert road. This data includes geological and geographical maps with different scales published by different Egyptian authorities during the period from the 1930's into the 1980's. Satellite images and photogeological maps were also used in this study for selecting the best route for the road. In addition, several field trips were organized along the proposed route of the road to study geological structural features, type of soil, surface rocks, and produce field stratigraphic cross-sections. Furthermore, a shallow seismic refraction survey was conducted at different locations on both sides of the road to better identify the nature and structure of the bedrock. Interpretation of geoseismic cross sections in turn helped with the design and construction of the road.

Purpose of Study

The goal of this study is to help delineate, design, and construct the Assiut- Hurghada desert road. This study was important for the following reasons.

1) Assiut city lies at the same latitude (27 12′) with Hurghada city, the capital of the Red Sea governorate, which is about 275 km distant from Assiut.

2) This road can be considered as a means of communication between the governorates of Middle Egypt (Assiut, Minya, Sohag, and New Valley) and the Red Sea towns.

3) The road will promote development of new urban, agricultural, and industrial communities and lead to more construction projects, especially in the area of Wadi EL-Assiuty, east of Assiut city. Wadi El-Assiuty is regarded as the gateway for this road, and in general, it is rich in groundwater resources and mineral deposits.

4) This road will help with prospecting for natural earth resources and mineral deposits in the Eastern Egyptian Desert, which is necessary for housing and industrial construction projects.

Analysis of Available Data

From the analysis of all available data, it was clearly evident that the direct distance of the road is nearly 260 km, which is different from the actual distance of about 275 km. Naturally, the actual distance of the road along its route increases with a certain amount according to the nature of soil and existence of several deviations around hills and mountains. Investigation of geographical maps published since the 1940's up until present show that there are natural tracks and secondary desert roads present in the area, some with widths that can exceed 10 m. The routes of these natural/secondary tracks/roads start from Assiut and Hurghada but are missing at the middle part of the road over distance of about 50 km. The existence of these natural tracks and secondary desert roads, which are fit for light transport is important for construction of the road and can decrease its costs.

As a result of this study, it was generally noticed that two possible routes for this road (A and B) can be delineated, based on geological and topographical factors previously mentioned in this article (Figure 1). The distance of the A route is 275 km and was excluded because of the existence of mountain chains with hard bedrock crossing this route (Figure 2). Hard bedrock mountain chains requires blasting to install the roadway, which results in higher construction costs. The B route, which includes natural tracks and secondary desert roads, can therefore be considered the best route for the road, and it is divided into 4 segments.

Figure 1: Two delineated routes for the Assiut–Hurghada desert road (route A is black and route B is green).

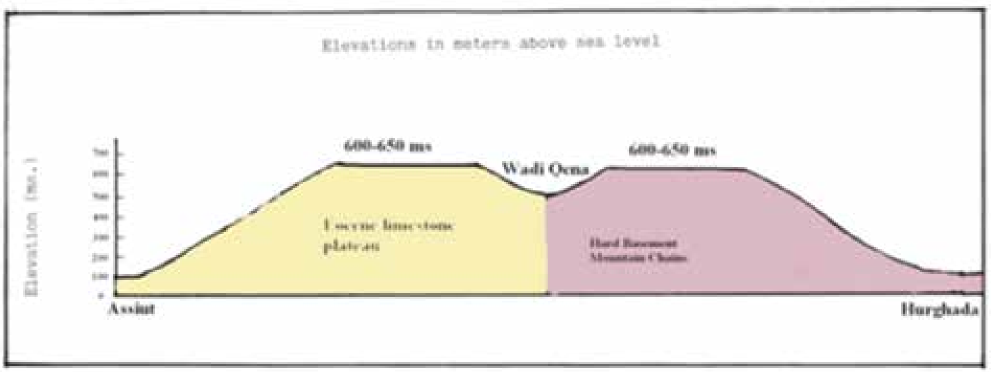

Figure 2: Diagrammatic cross-section of the delineated trend of Assiut-Hurghada desert road.

Geology of Selected Route B

First Segment

The distance of this segment is about 110 km and starts from the entrance of Wadi El-Assiuty and follows approximately parallel to the Wadi El-Assiuty in the Eastern Desert. Rocks along this segment belong to the Cenozoic Era. The first 30 km of this segment are covered by Quaternary and Pliocene rocks, which are sand wadi deposits (Figure 3), and this part of the segment was later macadamized and paved by asphaltic layer. The eastern 80 km of this segment have Eocene age rocks comprised of limestones with chert and silica (Figures 4 and 5). At the end of this segment are hills and an Eocene plateau with an elevation over 600 m above sea level. At the beginning of this segment near Assiut, there is some gentle topography (100 m), which is affected by a series of a few simple faults.

Second Segment

This segment is 50 km in length and is not defined by natural tracks and secondary desert roads. This segment begins before Wadi Qena at an elevation ranging from 600 to 700 m, and then decreases gradually until it reaches the bottom of Wadi Qona at 400 m above sea level.

Third Segment

The distance of the third segment is about 80 km and begins with a natural secondary desert road through Wadi Abu Had connecting Wadi Qena with Ras Gemsa on the Red Sea coast. This segment is not crossed by hard bedrock mountain chains with igneous, metamorphic, or volcanic rocks.

Fourth Segment

Its distance is 60 km beginning at Ras Gemsa and ending in Hurghada city along the Red Sea coast. This stage is well-macadamized and paved by an asphaltic layer and is considered as part of the high road connecting Quseir with Suez city along coasts of the Red Sea and the Gulf of Suez.

Figure 3: The final stop during the field trip on the first part of the road which crosses sand wadi deposits.

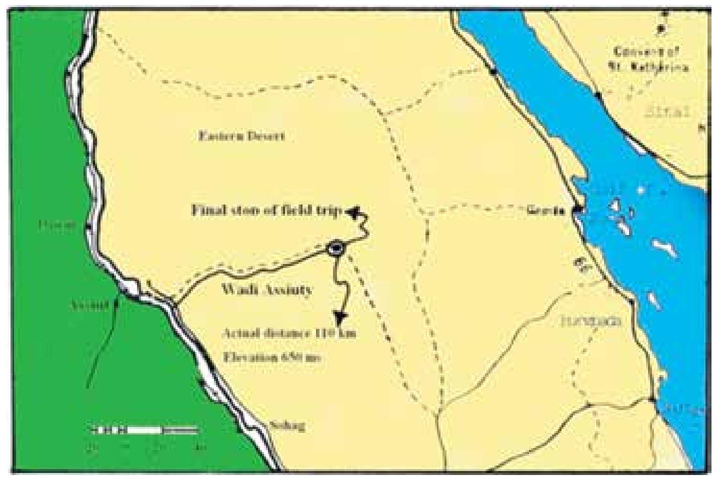

Figure 4: Route B of the field trip along the delineated Assiut–Hurghada desert road.

Figure 5: The Eocene age limestone and silica surface layer of the second part of the first segment of the road (observed during the field trip).

Field Work

Field trips were organized along the delineated B route of the road. One of the longest field trips was conducted with a team under the author's supervision, with 3 cars to transport members representing the General Authority for Roads and Bridges, Military Forces, Assiut Governorate, and Assiut University. The first segment of the B route was covered by a field trip along its entire length of 110 km. Field observations with respect to distances, topography, geology, stratigraphy, structures, and type of soil were completely consistent with prior information obtained from geologic and geographic maps.

The beginning part (30 km) of first segment starts from the entrance of Wadi El-Assiuty and travels over Quaternary and Pliocene wadi deposits (Figure 3). The elevations of this beginning part of the first segment start at 100 m above sea level near Assiut and ends at 200 m above sea level. This part has already been macadamized and paved by an asphaltic layer. The second part of the first segment (80 km) starts to the east from the narrow strip of the Wadi El-Assiuty and terminates at Wadi Gurdi El-Sagheer near Wadi Gena.

The route of this field trip (Figure 4) is approximately parallel to the trend of Wadi El-Assiuty. The second part of this first segment is distinguished by the existence of obstructions appearing at different distances. Sometimes, some small hills and plateaus can be found on both sides of the road. Also, some small sand dunes are present on the northern side of the road. These minor sand dunes have no effect on the road, because there are many natural plants and trees that anchor these sand dunes in place. Rocks along this part of the first segment of the B route belong to the Eocene age and formed of limestones with chert and silica (Figure 5). The Eocene plateau (elevation - 650 m) was the final stop on this field trip. The soil along this segment was determined to be suitable for construction of Assiut – Hurghada desert road. The abundance of natural tracks and secondary desert roads present have widths that sometimes exceed 10 m along this segment of the B route (Figure 6), which does not include hard bedrock mountain chains. All these factors can easily decrease construction costs. Also, the slope of this first segment is regular, gentle and not steep through its entire distance until Wadi Qena. It was recommended to remove material from the Eocene plateau by excavation and then fill Wadi Qena with material extracted from excavation. On the other hand, it may be required to raise the bottom of Wadi Qena and lower the relief or level of the Eocene plateau.

Figure 6: The final stop of the second part of the first segment of the road during the field trip.

Interpretation of Shallow Seismic Refraction Data

A shallow seismic refraction survey using a 12-channel exploration seismograph (Geometrics model 1225) was conducted at various locations on both sides of the B route to identify the nature and structure of the bedrock (Figure 7). For this geophysical investigation, the seismic survey was designed with 14 shot points distributed along 4 continuous seismic profiles with both normal and reverse shot directions with a total length of 500 m for each profile. Each spread is 240 m with two spreads for each profile. Vertical geophones were used and spaced 20 m apart. The locations of the seismic refraction profiles are shown in Figure 8. Four geoseismic cross sections have been constructed along these profiles (Figure 9). Interpretation of these geoseismic cross-sections has resulted in the identification of two layers, a sand overlying a clay. The thickness of sand layer ranges between 8 and 50 m, and the depth to the clay layer ranges from 10 to 60 m. Faulting, which is not common, was clearly observed and interpreted in geoseismic cross section of profile 2. These two seismically interpreted layers are observed in an outcrop near the B route of the road (Figure 10). Also, these interpreted layers are found in a lithological log of water well drilled in Wadi El-Assiuty, also near the B route (Figure 11).

Figure 7: Equipment used for refraction seismic survey - 12 channel exploration seismograph (Geometrics model 1225).

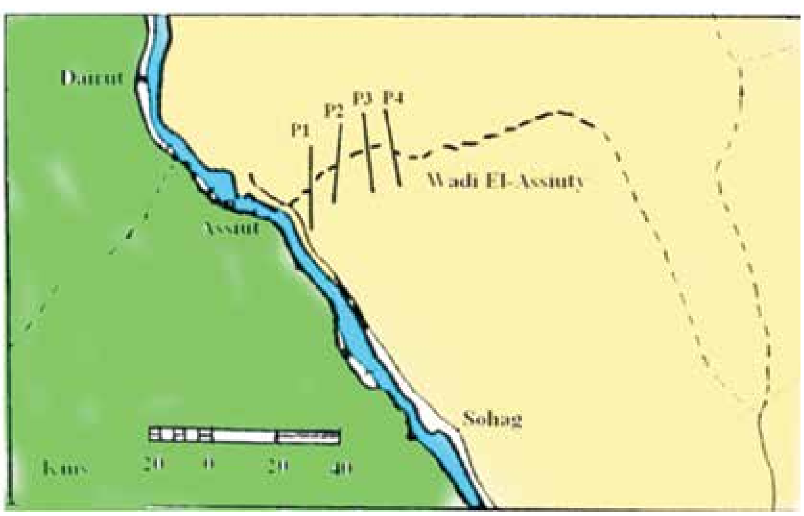

Figure 8: Location of seismic refraction profiles along the delineated B route of the Assiut–Hurghda desert road.

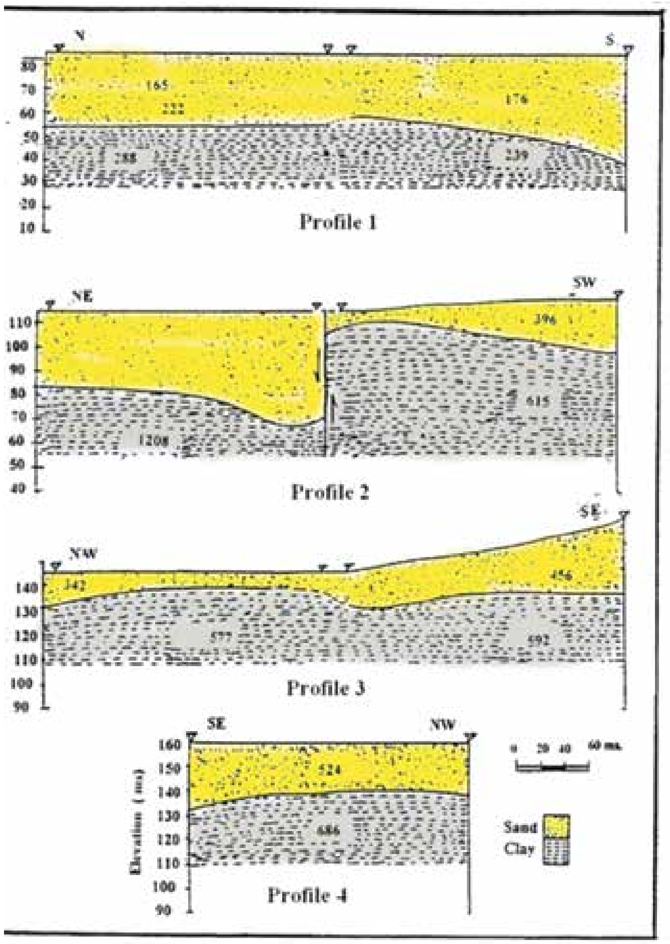

Figure 9: Interpretation of geoseismic subsurface cross-sections along seismic refraction profiles.

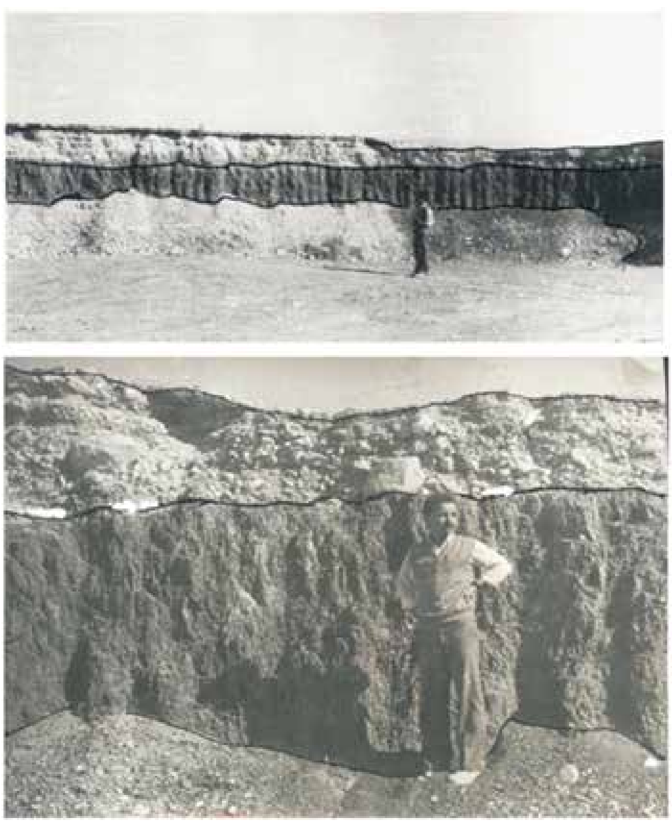

Figure 10: Field outcrop indicating the bedrock formed of two layers, sand (upper) and clay (lower).

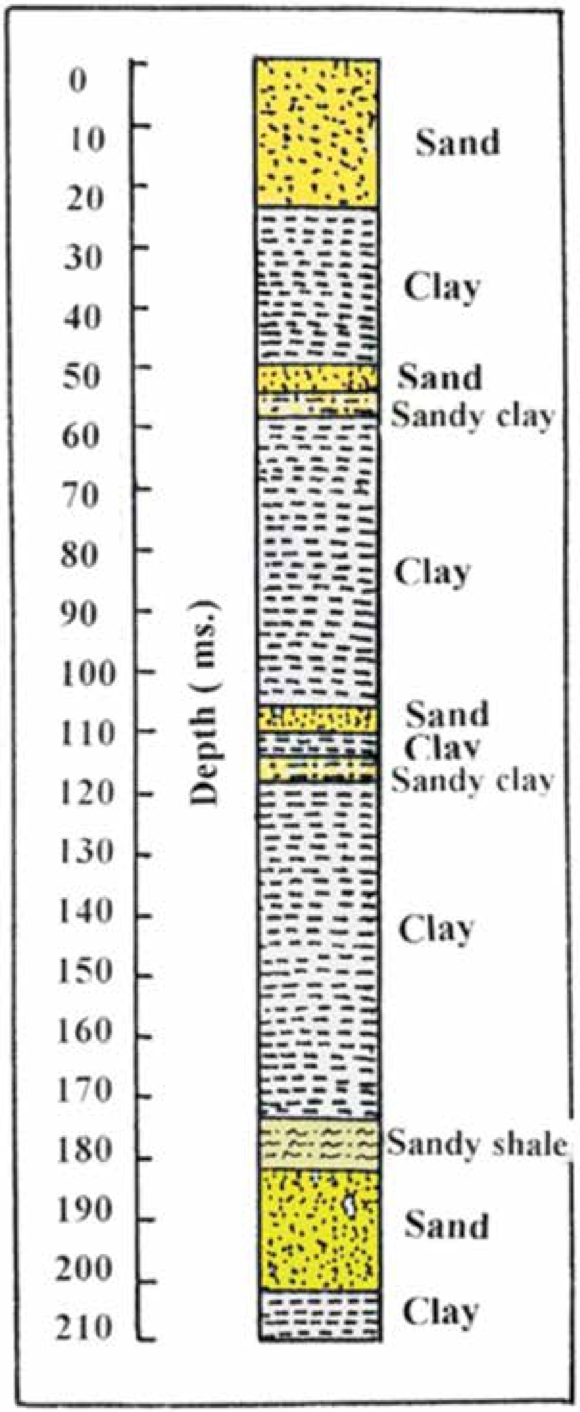

Figure 11: Lithological log of Wadi El-Assiuty water well.

Conclusions

It is clear that shallow seismic refraction is a powerful engineering tool, which can be used for determining soil/rock layer velocities and thicknesses, rock quality, depths to the bedrock, and the presence of structural features, thereby providing important information for construction of buildings, bridges, tunnels, dams, highways, and other projects. From this study, that was focused on the delineation and construction of the Assiut- Hurghada desert road, the following conclusions were reached:

1) From interpretation and analysis of geological and shallow seismic refraction data, two routes were defined (A and B) of which the B route with distance of about 300 km can be considered the best suited for the road, because it includes many natural tracks and secondary desert roads, and is not crossed by any hard bedrock igneous and volcanic mountain chains as is the case for the A route.
2) The existence of these natural tracks and secondary desert roads could easily decrease construction costs.
3) The slope of this B route is regular, gentle and not steep through its total distance. Also, the nature and structure of the bedrock identified from the analysis of geological and shallow seismic refraction data support indications that the quality of the bedrock is favorable for the construction of the road .
4) The interpretation of shallow seismic refraction data has resulted in identification of two layers, a sand overlain by clay layer, and this finding is consistent with observations at an outcrop near the B route and also with the lithologic log results from water well drilled in Wadi El-Assiuty.
5) The road saves about 50% of the distance between south of Assiut and Hurghada and about 70% of the distance between north of Assiut and Hurghada.
6) For safety, and to reduce future risks resulting from natural hazards, particularly flash floods, it is clear that rigorous specifications need to be defined and then followed during road construction.
7) The road can be hydrologically isolated by dykes on both sides, which will reduce risks of flooding and the associated damage on the macadamized asphaltic layer of the road. Also, it is recommended to construct concrete tunnels under the road bridges adjacent to the wadies.
8) A pipeline for water supply can be extended parallel to this road across the Eastern Desert to serve the urban, agricultural, and industrial projects which are expected to be established in the future on both sides of the road.

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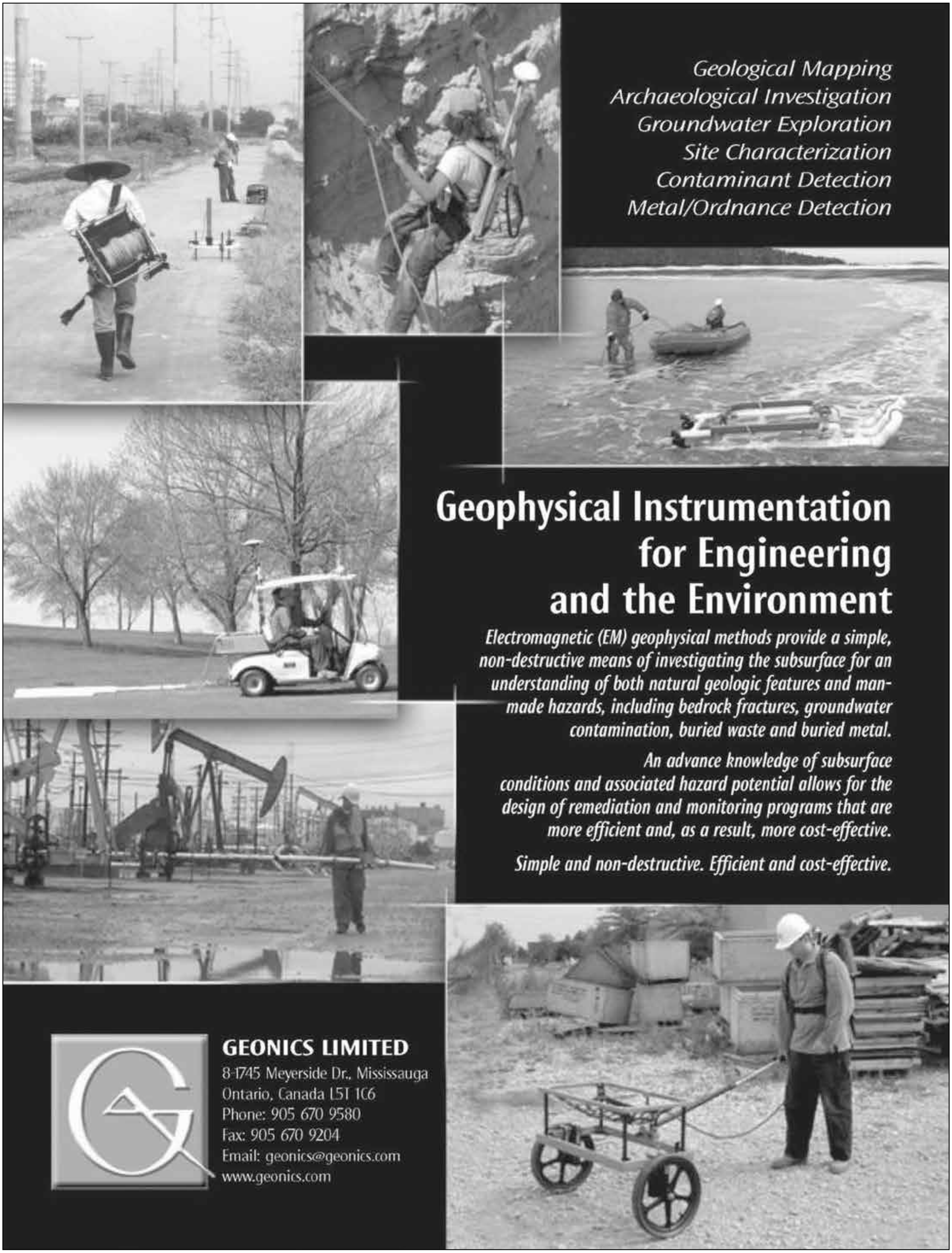
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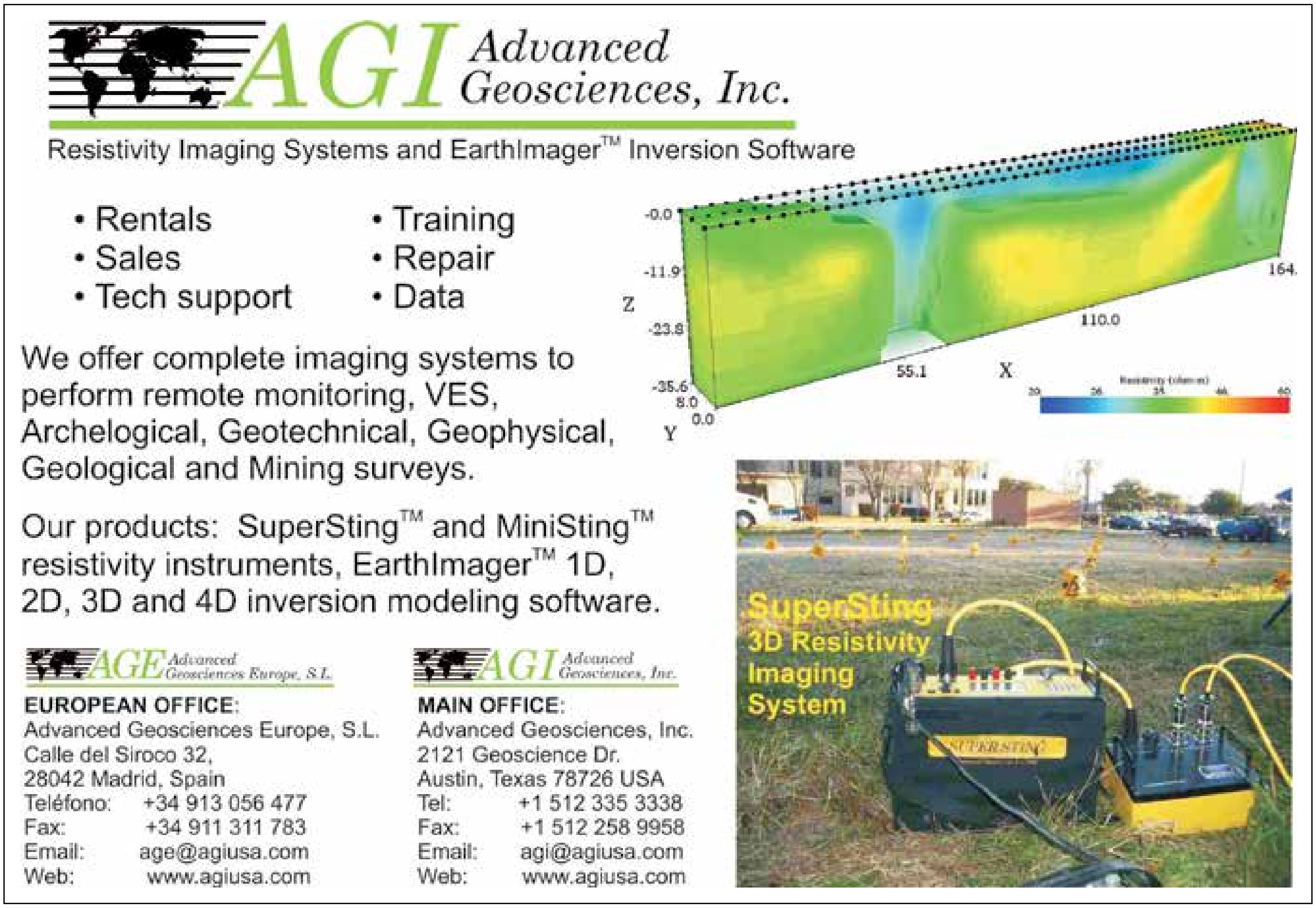
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NEW! **Student**	No Cost (Membership is paid by Corporate Sponsor)	$60

Corporate Members

Corporate members enjoy all the benefits of individual membership, a corporate link on the EEGS website, a company profile in *FastTIMES*, recognition at SAGEEP and a 10% discount on advertising in *JEEG* and *FastTIMES*. Additional benefits are listed for each corporate level.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
NEW! **Corporate Student Sponsor** *Includes one (1) individual membership to EEGS and sponsors 10 student memberships*	$300	$310
Corporate Donor *Includes one (1) individual membership to EEGS and one (1) full conference registration to SAGEEP*	$650	$660
Corporate Associate *Includes two (2) individual memberships to EEGS, an exhibit booth and registration at SAGEEP, and the ability to insert marketing materials in the SAGEEP delegate packets*	$2400	$2410
Corporate Benefactor *Includes two (2) individual memberships to EEGS, two (2) exhibit booths and registration at SAGEEP, and the ability to insert marketing materials in the SAGEEP delegate packets*	$4000	$4010

Membership Renewal
Developing World Category Qualification

If you reside in one of the countries listed below, you are eligible for EEGS's Developing World membership category rate of $50.00 (or $100.00 if you would like the printed, quarterly *Journal of Environmental & Engineering Geophysics* (*JEEG*) mailed to you). To receive a printed *JEEG* as a benefit of membership, select the Developing World Printed membership category on the membership application form.

Afghanistan
Albania
Algeria
Angola
Armenia
Azerbaijan
Bangladesh
Belize
Benin
Bhutan
Bolivia
Burkina Faso
Burundi
Cambodia
Cameroon
Cape Verde
Central African Republic
Chad
China
Comoros
Congo, Dem. Rep.
Congo, Rep.
Djibouti
Ecuador
Egypt
El Salvador
Eritrea
Ethiopia
Gambia
Georgia
Ghana
Guatemala
Guinea-Bissau
GuyanaHaiti
Honduras
India
Indonesia
Iran
Iraq
Ivory Coast
Jordan
Kenya
Kiribati
Kosovo
Kyrgyz Republic
Lao PDR
Lesotho
Liberia
Madagascar
Malawi
Maldives
Mali
Marshall Islands
Mauritania
Micronesia
Moldova
Mongolia
Morocco
Mozambique
Myanmar
Nepal
Nicaragua
Niger
Nigeria
North Korea
Pakistan
Papua New Guinea
Paraguay
Philippines
Rwanda
Samoa
Sao Tome and Principe
Senegal
Sierra Leone
Solomon Islands
Somalia
Sri Lanka
Sudan
Suriname
Swaziland
Syria
Taiwan
Tajikistan
Tanzania
Thailand
Timor-Leste
Togo
Tonga
Tunisia
Turkmenistan
Uganda
Ukraine
Uzbekistan
Vanuatu
Vietnam
West Bank and Gaza
Yemen
Zambia
Zimbabwe

1720 South Bellaire Street | Suite 110 | Denver, CO 80222-4303
(p) 001.1.303.531.7517 | (f) 001.1.303.820.3844 | staff@eegs.org | www.eegs.org

Environmental and Engineering Geophysical Society	Renew or Join Online at www.EEGS.org
2013 Membership Application	

CONTACT INFORMATION

Salutation	First Name	Middle Initial	Last Name

Company/Organization	Title

Street Address	City	State/Province	Zip Code	Country

Direct Phone	Mobile Phone	Fax

Email	Website

ABOUT ME: INTERESTS & EXPERTISE

In order to identify your areas of specific interests and expertise, please check all that apply:

Classify Association	Classify Interest or Focus	Specific Areas of Involvement	Professional/ Scientific Societies	Willing to Serve on a Committee?
☐ Consultant	☐ Archaeology	☐ Borehole Geophysical	☐ AAPG	☐ Publications
☐ User of Geophysical Svcs.	☐ Engineering	☐ Electrical Methods	☐ AEG	☐ Web Site
☐ Student	☐ Environmental	☐ Electromagnetics	☐ ASCE	☐ Membership
☐ Geophysical Contractor	☐ Geotechnical	☐ Gravity	☐ AWWA	☐ Student
☐ Equipment Manufacturer	☐ Geo. Infrastructure	☐ Ground Penetrating	☐ AGU	
☐ Software Manufacturer	☐ Groundwater	☐ Magnetics	☐ EAGE	
☐ Research/Academia	☐ Hazardous Waste	☐ Seismic	☐ EER1	
☐ Government Agency	☐ Humanitarian Geo.	☐ Other	☐ GeoInstitute	
☐ Other	☐ Mining		☐ GSA	
	☐ Shallow Oil & Gas		☐ MGLS	
	☐ UXO		☐ NGWA	
	☐ Other		☐ NSG	
			☐ SEG	
			☐ SSA	
			☐ SPWLA	

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FOUNDATION CONTRIBUTIONS

FOUNDERS FUND

The Founders Fund has been established to support costs associated with the establishment and maintenance of the EEGS Foundation as we solicit support from larger sponsors. These will support business office expenses, necessary travel, and similar expenses. It is expected that the operating capital for the foundation will eventually be derived from outside sources, but the Founder's Fund will provide an operation budget to "jump start" the work. Donations of $50.00 or more are greatly appreciated. For additional information about the EEGS Foundation (an IRS status 501(c)(3) tax exempt public charity), visit the website at http://www.EEGSFoundation.org.

Foundation Fund Total: $ ________________

STUDENT SUPPORT ENDOWMENT

This Endowed Fund will be used to support travel and reduced membership fees so that we can attract greater involvement from our student members. Student members are the lifeblood of our society, and our support can lead to a lifetime of involvement and leadership in the near-surface geophysics community. Donations of $50.00 or more are greatly appreciated. For additional information about the EEGS Foundation (a tax exempt public charity), visit the website at http://www.EEGSFoundation.org.

Student Support Endowment Total: $ ________________

CORPORATE CONTRIBUTIONS

The EEGS Foundation is designed to solicit support from individuals and corporate entities that are not currently corporate members (as listed above). We recognize that most of our corporate members are small businesses with limited resources, and that their contributions to professional societies are distributed among several organizations. The Corporate Founder's Fund has been developed to allow our corporate members to support the establishment of the Foundation as we solicit support from new contributors.

Corporate Contribution Total: $ ________________

Foundation Total: $ ________________

PAYMENT INFORMATION

☐ **Check/Money Order** ☐ **VISA** ☐ **MasterCard**

☐ **AmEx** ☐ **Discover**

Subtotals

Membership: $ ________________

Foundation Contributions: $ ________________

Grand Total: $ ________________

Card Number **Exp. Date**

Name on Card

Signature

Make your check or money order in US dollars payable to: EEGS. Checks from Canadian bank accounts must be drawn on banks with US affiliations (example: checks from Canadian Credit Suisse banks are payable through Credit Suisse New York, USA). Checks must be drawn on US banks.

Payments are not tax deductible as charitable contributions although they may be deductible as a business expense. Consult your tax advisor.

Return this form with payment to: EEGS, 1720 South Bellaire Street, Suite 110, Denver, CO 80222 USA
Credit card payments can be faxed to EEGS at 001.1.303.820.3844

Corporate dues payments, once paid, are non-refundable. Individual dues are non-refundable except in cases of extreme hardship and will be considered on a case-by-case basis by the EEGS Board of Directors. Requests for refunds must be submitted in writing to the EEGS business office.

QUESTIONS? CALL 001.1.303.531.7517

EEGS CORPORATE MEMBERS

Corporate Benefactor

Your Company Here!

Corporate Associate

Advanced Geosciences, Inc.
www.agiusa.com

Allied Associates Geophysical Ltd.
www.allied-associates.co.uk

CGG Canada Services Ltd.
www.fugroairborne.com

Exploration Instruments LLC
www.expins.com

Geogiga Technology Corporation
www.geogiga.com

Geomar Software Inc.
www.geomar.com

Geometrics, Inc.
www.geometrics.com

Geonics Ltd.
www.geonics.com

Geophysical Survey Systems, Inc.
www.geophysical.com

Interpex Ltd.
www.interpex.com

Mount Sopris Instruments
www.mountsopris.com

Petros Eikon Incorporated
www.petroseikon.com

R. T. Clark Co. Inc.
www.rtclarck.com

Vista Clara Inc.
www.vista-clara.com

Zonge international, Inc
www.zonge.com

Corporate Donor

Geomatrix Earth Science Ltd.
www.geomatrix.co.uk

Northwest Geophysics
www.northwestgeophysics.com

Spotlight Geophysical Services
www.spotlightgeo.com

Corporate Student Sponsor

Geo Solutions Limited, Inc.
www.geosolutionsltd.com

Spotlight Geophysical Services
www.spotlightgeo.com

EEGS STORE

Environmental and Engineering Geophysical Society

2012 Publications Order Form

ALL ORDERS ARE PREPAY

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Phone: 303.531.7517; Fax: 303.820.3844
E-mail: staff@eegs.org; Web Site: www.eegs.org

Sold To:
Name: ______________________________
Company: ______________________________
Address: ______________________________
City/State/Zip: ______________________________
Country: ____________________ Phone: ____________
E-mail: ____________________ Fax: ____________

Ship To (If different from "Sold To":
Name: ______________________________
Company: ______________________________
Address: ______________________________
City/State/Zip: ______________________________
Country: ____________________ Phone: ____________
E-mail: ____________________ Fax: ____________

Instructions: Please complete both pages of this order form and fax or mail the form to the EEGS office listed above. Payment must accompany the form or materials will not be shipped. Faxing a copy of a check does not constitute payment and the order will be held until payment is received. Purchase orders will be held until payment is received. If you have questions regarding any of the items, please contact the EEGS Office. Thank you for your order!

SAGEEP PROCEEDINGS

Member/Non-Member

	0029	2010 (CD-ROM) ****NEW****	$75	$100
	0026	2009 (CD-ROM)	$75	$100
	0025	2008 (CD-ROM)	$75	$100
	0023	2007 (CD-ROM)	$75	$100
	0020	2006 (CD-ROM)	$75	$100
	0018	2005 (CD-ROM)	$75	$100

	0016	2004 (CD-ROM)	$75	$100
	0015	2003 (CD-ROM)	$75	$100
	0014	2002 (CD-ROM)	$75	$100
	0013	2001 (CD-ROM)	$75	$100
	0012	1988-2000 (CD-ROM)	$150	$225
		SUBTOTAL—PROCEEDINGS ORDERED:		

SAGEEP Short Course Handbooks

	0027	Principles and Applications of Seismic Refraction Tomography (Printed Course Notes & CD-ROM) - William Doll	$125	$150
	0028	Principles and Applications of Seismic Refraction Tomography (CD-ROM including PDF format Course Notes) - William Doll	$70	$90
	0007	2002 - UXO 101 - An Introduction to Unexploded Ordnance - (Dwain Butler, Roger Young, William Veith)	$15	$25
	0009	2001 - Applications of Geophysics in Geotechnical and Environmental Engineering (HANDBOOK ONLY) - John Greenhouse	$25	$35
	0011	2001 - Applications of Geophysics in Environmental Investigations (CD-ROM ONLY) - John Greenhouse	$80	$105
	0010	2001- Applications of Geophysics in Geotechnical and Environmental Engineering (HANDBOOK) & Applications of Geophysics in Environmental Investigations (CD-ROM) - John Greenhouse	$100	$125
	0004	1998 - Global Positioning System (GPS): Theory and Practice - John D. Bossler & Dorota A. Brzezinska	$10	$15
	0003	1998 - Introduction to Environmental & Engineering Geophysics - Roelof Versteeg	$10	$15
	0002	1998 - Near Surface Seismology - Don Steeples	$10	$15
	0001	1998 - Nondestructive Testing (NDT) - Larry Olson	$10	$15
	0005	1997 - An Introduction to Near-Surface and Environmental Geophysical Methods and Applications - Roelof Versteeg	$10	$15
	0006	1996 - Introduction to Geophysical Techniques and their Applications for Engineers and Project Managers - Richard Benson & Lynn Yuhr	$10	$15

Miscellaneous Items

	0021	Geophysics Applied to Contaminant Studies: Papers Presented at SAGEEP from 1988-2006 (CD-ROM)	$50	$75
	0022	Application of Geophysical Methods to Engineering and Environmental Problems - Produced by SEGJ	$35	$45
	0019	Near Surface Geophysics - 2005 Dwain K. Butler, Ed.; Hardcover Special student rate - 71.20	$89	$139
	0024	Ultimate Periodic Chart - Produced by Mineral Information Institute	$20	$25
	0008	MATLAB Made Easy - Limited Availability	$70	$95
		EEGS T-shirt (X-Large) Please circle: white/gray	$10	$10
		EEGS Lapel Pin	$3	$3
		SUBTOTAL—SHORT COURSE/MISC. ORDERED ITEMS:		

Publications Order Form (Page Two)

***Journal of Environmental and Engineering Geophysics* (JEEG) Back Issue Order Information:**

Member Rate: $15

Non-Member Rate: $25

Qt.	Year	Issue	Qt.	Year	Issue	Qt.	Year	Issue
	1995			**2001**			**2006**	
		JEEG 0/1 - July			JEEG 6/1 - March			JEEG 11/1 - March
	1996				JEEG 6/3 - September			JEEG 11/2 - June
		JEEG 0/2 - January			JEEG 6/4 - December			JEEG 11/3 - September
		JEEG 1/1 - April		**2003**				JEEG 11/4 - December
		JEEG 1/2 - August			JEEG 8/1- March		**2007**	
		JEEG 1/3 - December			JEEG 8/2 - June			JEEG 12/1 - March
	1998				JEEG 8/3 - September			JEEG 12/2 - June
		JEEG 3/2 - June			JEEG 8/4 - December			JEEG 12/3 - September
		JEEG 3/3 - September		**2004**				JEEG 12/4 - December
		JEEG 3/4 - December			JEEG 9/1- March		**2008**	
	1999				JEEG 9/2 - June			JEEG 13/1 - March
		JEEG 4/1 – March			JEEG 9/3 - September			JEEG 13/2 - June
		JEEG 4/2 - June			JEEG 9/4 - December			JEEG 13/3 - September
		JEEG 4/3 - September		**2005**				JEEG 13/4 - December
		JEEG 4/4 - December			JEEG 10/1 - March		**2009**	
	2000				JEEG 10/2 - June			JEEG 14/1 - March
		JEEG 5/3 - September			JEEG 10/3 - September			JEEG 14/2 - Available June
		JEEG 5/4 - December			JEEG 10/4 - December			JEEG 14/3 - Available September
								JEEG 14/4 - Available December

SUBTOTAL—JEEG ISSUES ORDERED	

SUBTOTAL - SAGEEP PROCEEDINGS ORDERED	
SUBTOTAL - SHORT COURSE / MISCELLANEOUS ITEMS ORDERED	
SUBTOTAL - JEEG ISSUES ORDERED	
CITY SALES TAX (If order will be delivered in the City of Denver—add an additional 3.5%)	
STATE SALES TAX (If order will be delivered in Colorado—add an additional 3.7%)	
SHIPPING & HANDLING (US—$10; Canada/Mexico—$20; All other countries: $45)	
GRAND TOTAL:	

Order Return Policy: Returns for credit must be accompanied by invoice or invoice information (invoice number, date, and purchase price). Materials must be in saleable condition. Out-of-print titles are not accepted 180 days after order. No returns will be accepted for credit that were not purchased directly from EEGS. Return shipment costs will be borne by the shipper. Returned orders carry a 10% restocking fee to cover administrative costs unless waived by EEGS.

Payment Information:

☐ Check #: ________________________________ (Payable to EEGS)

☐ Purchase Order: ________________________________
(Shipment will be made upon receipt of payment.)

☐ Visa ☐ MasterCard ☐ AMEX ☐ Discover

Environmental and Engineering Geophysical Society

1720 S. Bellaire Street, Suite 110
Denver, CO 80222-4303
Phone: 303.531.7517
Fax: 303.820.3844
E-mail: staff@eegs.org
Web Site: www.eegs.org

2012 Merchandise Order Form

ALL ORDERS ARE PREPAY

Sold To:

Name: ______________________________
Company: ______________________________
Address: ______________________________
City/State/Zip: ______________________________
Country: ______________ Phone: ______________
E-mail: ______________ Fax: ______________

Ship To (If different from "Sold To")**:**

Name: ______________________________
Company: ______________________________
Address: ______________________________
City/State/Zip: ______________________________
Country: ______________ Phone: ______________
E-mail: ______________ Fax: ______________

Instructions: Please complete this order form and fax or mail the form to the EEGS office listed above. Payment must accompany the form or materials will not be shipped. Faxing a copy of a check does not constitute payment and the order will be held until payment is received. Purchase orders will be held until payment is received. If you have questions regarding any of the items, please contact the EEGS Office. Thank you for your order!

Merchandise Order Information:

ITEM DESCRIPTION	QTY	T-SHIRT COLOR WHITE/GRAY	MEMBER RATE	NON-MEMBER RATE	TOTAL
EEGS Mug			$10	$10	Sold Out
T-shirt (Medium)			$10	$10	Sold Out
T-shirt (Large)			$10	$10	Sold Out
T-shirt (X-Large)			$10	$10	
T-shirt (XX-Large)			$10	$10	Sold Out
EEGS Lapel Pin			$3	$3	
SUBTOTAL – MERCHANDISE ORDERED:					

TOTAL ORDER:

SUBTOTAL – Merchandise Ordered:	
STATE SALES TAX: (If order will be delivered in Colorado – add 3.7000%):	
CITY SALES TAX: (If order will be delivered in the City of Denver – add an additional 3.5000%):	
SHIPPING AND HANDLING (US - $7; Canada/Mexico - $15; All other countries - $40):	
GRAND TOTAL:	

Payment Information:

☐ Check #: ______________ (Payable to EEGS)

☐ Purchase Order: ______________
(Shipment will be made upon receipt of payment.)

☐ Visa ☐ MasterCard ☐ AMEX ☐ Discover

Card Number: ______________ Cardholder Name (Print): ______________

Exp. Date: ______________ Signature: ______________

Three easy ways to order:
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Internet: www.eegs.org
Mail to: EEGS
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Denver, CO 80222-4303

THANK YOU FOR YOUR ORDER!

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EEGS/Forms/Merchandise Order Form/2010 Prices and details on this form are as accurate as possible, but are subject to change without notice.