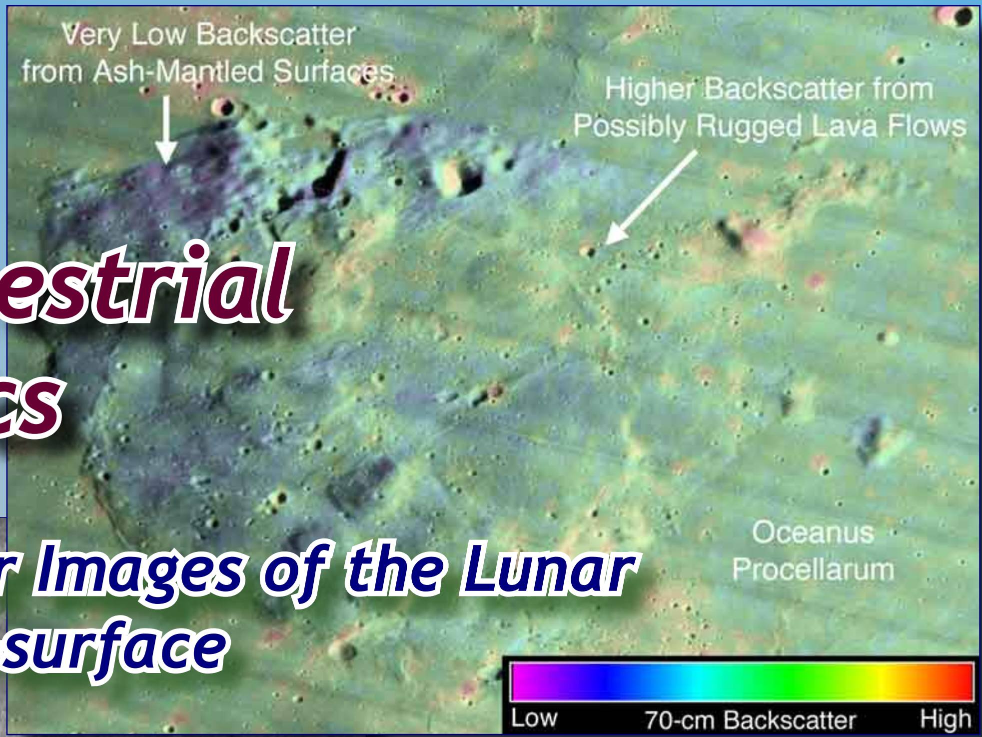
December 2008
Volume 13, Number 4
www.eegs.org

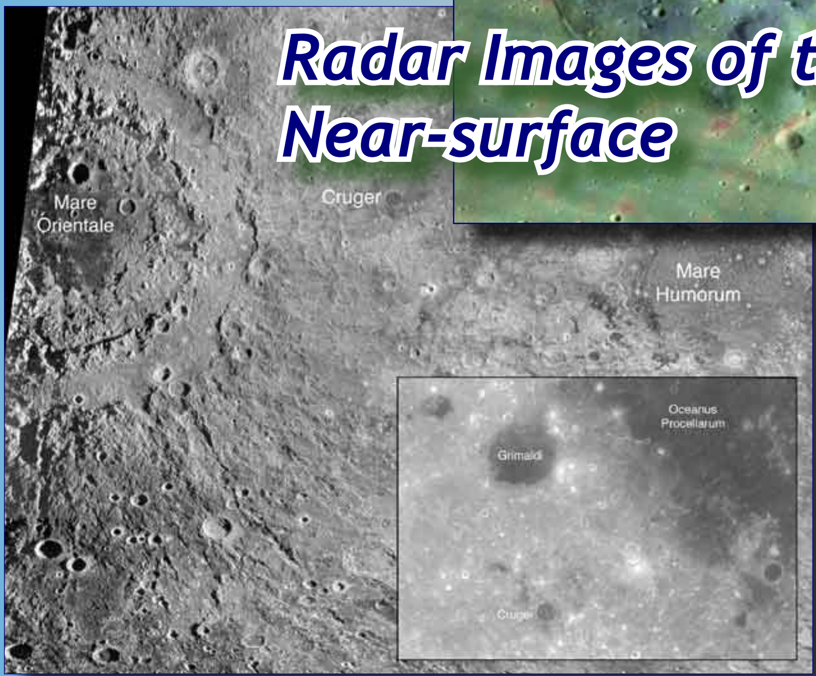
FastTIMES

Magazine for the Near-Surface Geophysical Sciences *Published by the Environmental & Engineering Geophysical Society*

Extraterrestrial Geophysics

Radar Images of the Lunar Near-surface





Also in this issue . . .

- *Locating Cave Habitat with Resistivity*
- *GPR and Resistivity in Egypt*
- *Invitation to SAGEEP 2009, Ft. Worth*
- *NS 2008 Highlights in Krakow*
- *SEG's Geoscientists Without Borders*
- *10 Years of FastTIMES!*

Humanitarian Geophysics in Uganda

On the Cover

Radar images of the Moon provide views beneath the lunar surface. Bruce Campbell explains how radar is being used to better understand lunar landscape history in his article that begins on p. 26. The **upper left** image is an Earth-based, 70-cm radar map of the southwestern nearside of the Moon. The **upper right** image shows color-coded 70-cm radar returns on a Lunar Orbiter photo of Mons Rümker. **Lower right**: Ugandans from St. Denis School help acquire resistivity data in the search for groundwater in an article on humanitarian geophysics projects by John Jackson and Catherine Skokan that begins on p. 52.

What We Want From You

The ***FastTIMES*** editors appreciate most any geophysical contribution. Suggestions for the March 2009 issue include the role of geophysics in geotechnical investigations. We also welcome photographs and brief noncommercial 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 ***FastTIMES*** editorial team by February 21, 2009 to ensure inclusion in the next issue.

Advertisers

Click on the entries to see the ad

Contents

Click on the entries to go directly to the articles


EEGS ANNUAL MEETING
FORT WORTH TEXAS
FORT WORTH STOCK YARDS
2009
22nd SAGEEP
SYMPOSIUM ON THE APPLICATION OF GEOPHYSICS
TO ENGINEERING AND ENVIRONMENTAL PROBLEMS
Expanding Horizons for Near-Surface Geophysics
MARCH 29 - APRIL 2, 2009
Environmental
and Engineering
Geophysical Society
www.eegs.org
SAVE THE DATE!

FastTIMES

FastTIMES (ISSN 1943-6505) is published by the Environmental and Engineering Geophysical Society (EEGS). It is available electronically (as a pdf document) from the EEGS website (*www.eegs.org*).

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 currently $90 for an individual membership, $50 for a student membership with a ***JEEG*** subscription ($20 without ***JEEG)***, and $650 to $3750 for various levels of corporate membership. The membership application is available at the back of this issue, from the EEGS office at the address given below, or online at *www.eegs.org*. See the back for an explanation of membership categories.

Board of Directors

Business Office

1720 South Bellaire, Suite 110, Denver, Colorado 80222-4303; (303) 531-7517; 820-3844 fax; *staff@eegs.org*

Executive Director
Kathie A. Barstnar
staff@eegs.org

Assistant Executive Director
Jackie Jacoby
staff@eegs.org

EEGS Contributors

International Board Liaison
Micki Allen, Markham, ON
mickiallen@marac.com

General Chair, SAGEEP 2009
Douglas E. Laymon, Austin, TX
doug.laymon@tetratech.com

Technical Chair, SAGEEP 2009
Dwain K. Butler, Vicksburg, MS
dwain.k.butler@erdc.usace.army.mil

Editor, JEEG
Janet Simms, Vicksburg, MS
janet.e.simms@erdc.usace.army.mil

FastTIMES Submissions

To submit information for inclusion in ***FastTIMES***, contact a member of the editorial team:

Editor in Chief
Jeffrey G. Paine
jeff.paine@beg.utexas.edu
(512) 471-1260

Associate Editor
Roger A. Young
ryoung@ou.edu
(405) 325-5753

Associate Editor
Moe Momayez
moe.momayez@arizona.edu
(520) 626-5977

Associate Editor
Brad Isbell
bisbell@hgiworld.com
(406) 541-3240

To advertise in ***FastTIMES***, contact:

Jackie Jacoby
staff@eegs.org
(303) 531-7517

The next ***FastTIMES*** will be published in March 2009. Please send articles to a member of the editorial team by February 21. Advertisements are due to Jackie Jacoby by February 21.


pulseEKKO® PRO surveying for bathymetry and sediment stratigraphy - Methuen Lake, Canada.
For the GPR Professional
Address any application with a keen eye
CMP
WARR
Transillumination
Multi-Channel
The pulseEKKO PRO addresses any GPR application from mineral exploration and glaciology to geotechnical investigations and the examination of concrete structures.
■ Unparalleled performance
■ Unmatched versatility for near surface mapping
■ Broad frequency range from 12.5 to 1000 MHz
■ Fully Bistatic
■ Compact and rugged
■ Multiple deployment configurations
Sensors & Software
pulseEKKO® PRO
by Sensors & Software Inc.
subsurface imaging solutions
www.sensoft.ca, sales@sensoft.ca, Tel: (905) 624-8909, North America: 1-800-267-6013

Calendar

*Please send additions, errors, and omissions to a member of the **FastTIMES** editorial team.*

2008

December 15–19	AGU Fall Meeting, San Francisco, California

2009

February 22–25	ASEG 09: 20th Conference and Exhibition, Australian Society of Exploration Geophysicists, Adelaide, South Australia
March 15–19	International Foundation Congress and Equipment Exhibition, Lake Buena Vista, Florida
March 29–April 2	22nd SAGEEP, Fort Worth, Texas
April 19–23	NGWA 2009 Ground Water Summit, Tucson, Arizona
May 24–27	2009 Joint Assembly, Toronto, Ontario, Canada
August 16–19	AAPG/SEG/SPE Hedberg Research Conference, Geological Carbon Sequestration: Prediction and Verification, Vancouver, British Columbia
September 7–9	Near Surface 2009: 15th European Meeting of Environmental and Engineering Geophysics, Dublin, Ireland
October 18–21	Geological Society of America Annual Meeting, Portland, Oregon
October 25–30	SEG International Exposition and 79th Annual Meeting, Houston, Texas
October	9th Symposium, Society of Exploration Geophysicists of Japan

2010

September 5–10	IAEG 2010: 11th Congress of the International Association for Engineering Geology and the Environment, Auckland, New Zealand

President's Message: EEGS Publications

Jonathan Nyquist, President (nyq@temple.edu)

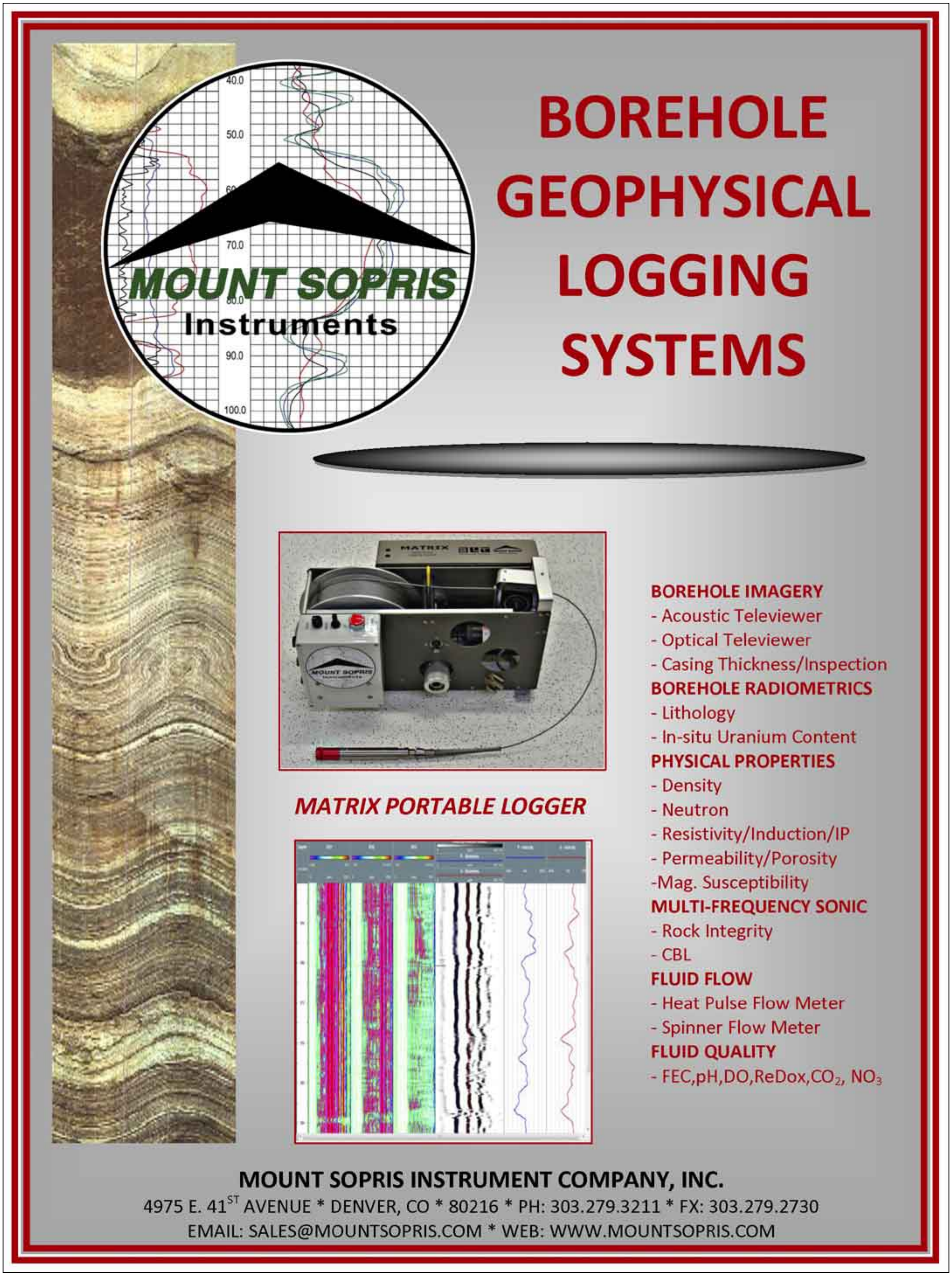
I recall the SAGEEP meeting where we debated forming a new organization to be called the Environmental and Engineering Geophysics Society. Jeff Daniels of Ohio State was adamant that for credibility the new society needed to establish its own journal, and thus the ***Journal of Environmental and Engineering Geophysics*** (***JEEG***) was born. Over a decade later, ***JEEG*** is still growing. Have you had a chance to read the fantastic September issue of ***JEEG*** devoted to geophysics and unexploded ordnance (UXO)? Kudos to guest editor José L. Llopis, and Editor-In-Chief Janet Simms. I know from experience how much work is involved in pulling together a Special Issue, especially one that is more than twice the length of a regular issue of ***JEEG***! Also thanks to Jeff Marqusee and SERDP/ESTCP Program office for helping to sponsor the issue.

JEEG is not the only EEGS publication jewel. I would like to call your attention to what a gem ***FastTIMES*** has become under the stewardship of Editor Jeff Paine. As evidence of its growing popularity, consider that there are just shy of 700 EEGS members, yet between 9/30 and 10/31 the September issue of ***FastTIMES*** was downloaded 8504 times! Clearly, ***FastTIMES*** has graduated beyond a simple society newsletter and drawn the attention of the broader geophysical and engineering community.

The transition of ***FastTIMES*** into a free, downloadable electronic publication has helped boost its popularity as the Internet continues to grow in importance. But I'm sorry to say that EEGS has neglected the hottest publication on the Web. Have you ever typed "EEGS" into the Wikipedia search engine? Created in 2001, this free on-line encylopedia has grown to encompass over 2.6 billion articles, but until recently there was no information on EEGS. Board member Charlie Stoyer, working with Jackie Jacoby of the EEGS Business Office, has remedied this deficiency. By the time you read this, EEGS will be live on Wikipedia. Wikipedia is the "Encyclopedia that anyone can edit," so members can further improve the EEGS entry.

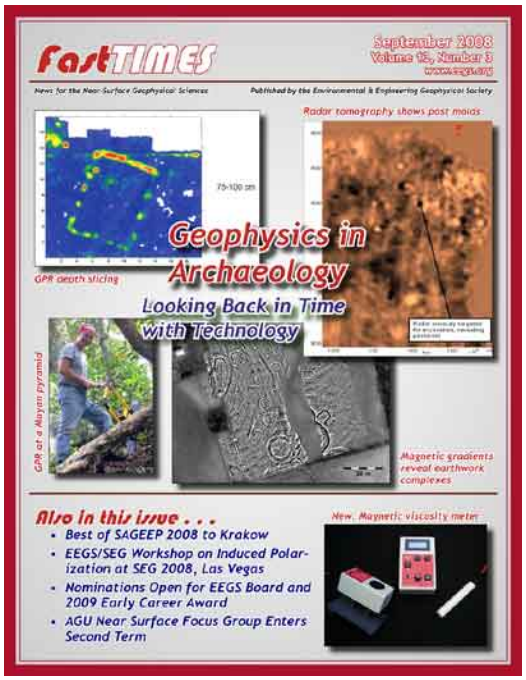
I would like to close by talking about the meeting and the publication that started it all – SAGEEP. Over the years I have read the SAGEEP proceedings as a way to catch the talks I missed during the meeting, and time and again I have mined the proceedings for case histories to use in my teaching. Right now SAGEEP 2009 Technical Chair Dwain Butler, Proceedings Editor Jeff Gamey, and the session chairs are busy assembling the papers for the SAGEEP 2009 volume. A wonderful tradition continues!

So take a few moments to reflect on the benefits of the suite of EEGS publications. Make it your New Year's Resolution to send a copy of this issue of ***FastTIMES*** to a client, a colleague, or a student. And do not forget to leave room in your calendar to attend SAGEEP 2009 in Fort Worth. Registration will be starting soon!


MOUNT SOPRIS
Instruments
BOREHOLE
GEOPHYSICAL
LOGGING
SYSTEMS
MATRIX PORTABLE LOGGER
BOREHOLE IMAGERY
- Acoustic Televiewer
- Optical Televiewer
- Casing Thickness/Inspection
BOREHOLE RADIOMETRICS
- Lithology
- In-situ Uranium Content
PHYSICAL PROPERTIES
- Density
- Neutron
- Resistivity/Induction/IP
- Permeability/Porosity
-Mag. Susceptibility
MULTI-FREQUENCY SONIC
- Rock Integrity
- CBL
FLUID FLOW
- Heat Pulse Flow Meter
- Spinner Flow Meter
FLUID QUALITY
- FEC,pH,DO,ReDox,CO_2, NO_3
MOUNT SOPRIS INSTRUMENT COMPANY, INC.
4975 E. 41ST AVENUE * DENVER, CO * 80216 * PH: 303.279.3211 * FX: 303.279.2730
EMAIL: SALES@MOUNTSOPRIS.COM * WEB: WWW.MOUNTSOPRIS.COM

From the FastTIMES Editorial Team

FastTIMES is distributed as an electronic document (pdf) to all EEGS members, is sent by web link to several related professional societies, and is available to all for download from the EEGS web site at *www.eegs.org/fasttimes/latest.html*. The most recent issue (September 2008, cover image below) was downloaded more than 9000 times through November, and past issues of ***FastTIMES*** 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 ***FastTIMES*** 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. Contact a member of the editorial team to discuss your ideas!

The ***FastTIMES*** presence on the EEGS web site has been redesigned. At *www.eegs.org/fasttimes/*, you'll now find calls for articles, author guidelines, download links for all issues, a history of ***FastTIMES***, and advertising information. Please drop by for a visit!

The editors of ***FastTIMES*** welcome Moe Momayez (right), Associate Professor in the Department of Mining and Geological Engineering at the University of Arizona, who joined the Editorial Team in November. Moe specializes in the development and application of near-surface sensing technologies to characterize geomaterials in soil and rock mechanics, structural stability, site characterization, and mine planning investigations.

The *FastTIMES* Editorial Team

Jeffrey G. Paine, Editor-in-Chief *(jeff.paine@beg.utexas.edu)*

Roger Young, Associate Editor *(ryoung@ou.edu)*

Moe Momayez, Associate Editor (*moe.momayez@arizona.edu*)

Brad Isbell, Associate Editor *(bisbell@hgiworld.com)*

---

10 Years of FastTIMES: A Brief History

by Jeffrey G. Paine

FastTIMES, a magazine for the near-surface geophysical sciences, grew out of a quarterly printed newsletter published by the newly formed Environmental and Engineering Geophysical Society (EEGS). The first issue of "***The EEGS Newsletter***," co-edited by Philip Carpenter and Thom Fisher, was published in December 1992 (Figure 1). The newsletter superseded the previous Society of Engineering and Mineral Exploration Geophysicists newsletter with the formation of EEGS. ***The EEGS Newsletter*** was published from December 1992 through May 1998. Following Phil Carpenter as editor were Steve Daut and Michael Powers (Table 1).

Figure 1. The cover of the first issue of ***The EEGS Newsletter***, published in December 1992.

1998: The Birth of FastTIMES

In August 1998, under editor Michael Powers, ***The EEGS Newsletter*** became "***FastTIMES: The EEGS Newsletter***." According to Mike, the change was "a response to changes within our organization and within our world." The August issue was also the first issue "printed entirely from digital sources" and is the first issue that is available online. The cover and appearance contained upgraded graphics and the new title (Figure 2).

Figure 2. The first ***Fast TIMES: The EEGS Newsletter***, published in August 1998.

Subsequent editors (Table 2) included Ron Kaufmann (1999-2001) and Rick Taylor (2001-2002). With the November 2000 issue, the President's Message moved from the front cover and was replaced with compelling graphics: a sinkhole swallowing a home (Figure 3). Figuratively speaking, it might have represented the fate of the President's Message, sucked off the front cover and moved inside the newsletter.

Going Upscale

Norm Carlson, who published his first issue as ***FastTIMES*** editor in August 2002, was also the first to assign volume and issue numbers to the cover. For reasons lost to the ravages of time, he christened the November 2002 issue as volume 7, number 4 (Figure 4). Count-

Table 1. Editors of ***The EEGS Newsletter***, predecessor of ***FastTIMES***, published from 1992 to 1998.

Editor	Associate Editors	Term	First Issue	Last Issue
Philip Carpenter	Thom Fisher	1992–1993	Dec 1992	Aug 1993
Steve Daut	David Bufo	1993–1997	Nov 1993	—
Michael Powers	—	1997–1998	Aug 1997	May 1998

Table 2. Editors of ***FastTIMES***, which began publication with the August 1998 issue.

Editor	Associate Editors	Term	First Issue (v:n)	Last issue (v:n)
Michael H. Powers	—	1998–1998	3:1	3:2
Ronald D. Kaufmann	—	1999–2001	4:1	6:1
Rick Taylor	—	2001–2002	6:2	7:2
Norman Carlson	—	2002–2003	7:3	8:3
Ronald S. Bell	John Nicholl, Cindy Burton, and Ron Kaufmann	2004–2005	9:1	10:1
Brad Isbell	John Nicholl, Cindy Burton, and Ron Kaufmann	2005–2006	10:2	10:3
Jeffrey G. Paine	Brad Isbell and Roger Young	2006–present	11:1	—

Figure 3. The President's Message sinks off the front cover in November 2000, replaced by geophysical themes.

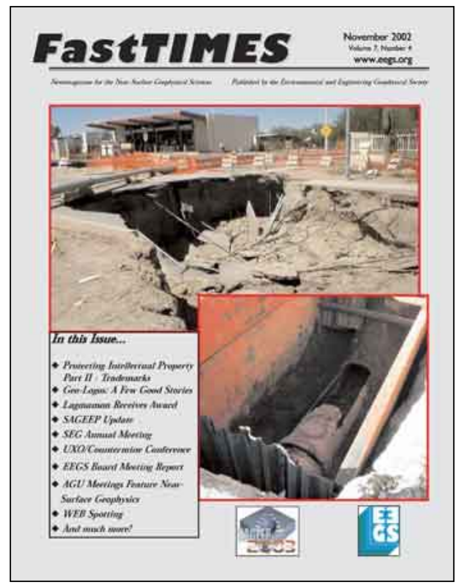


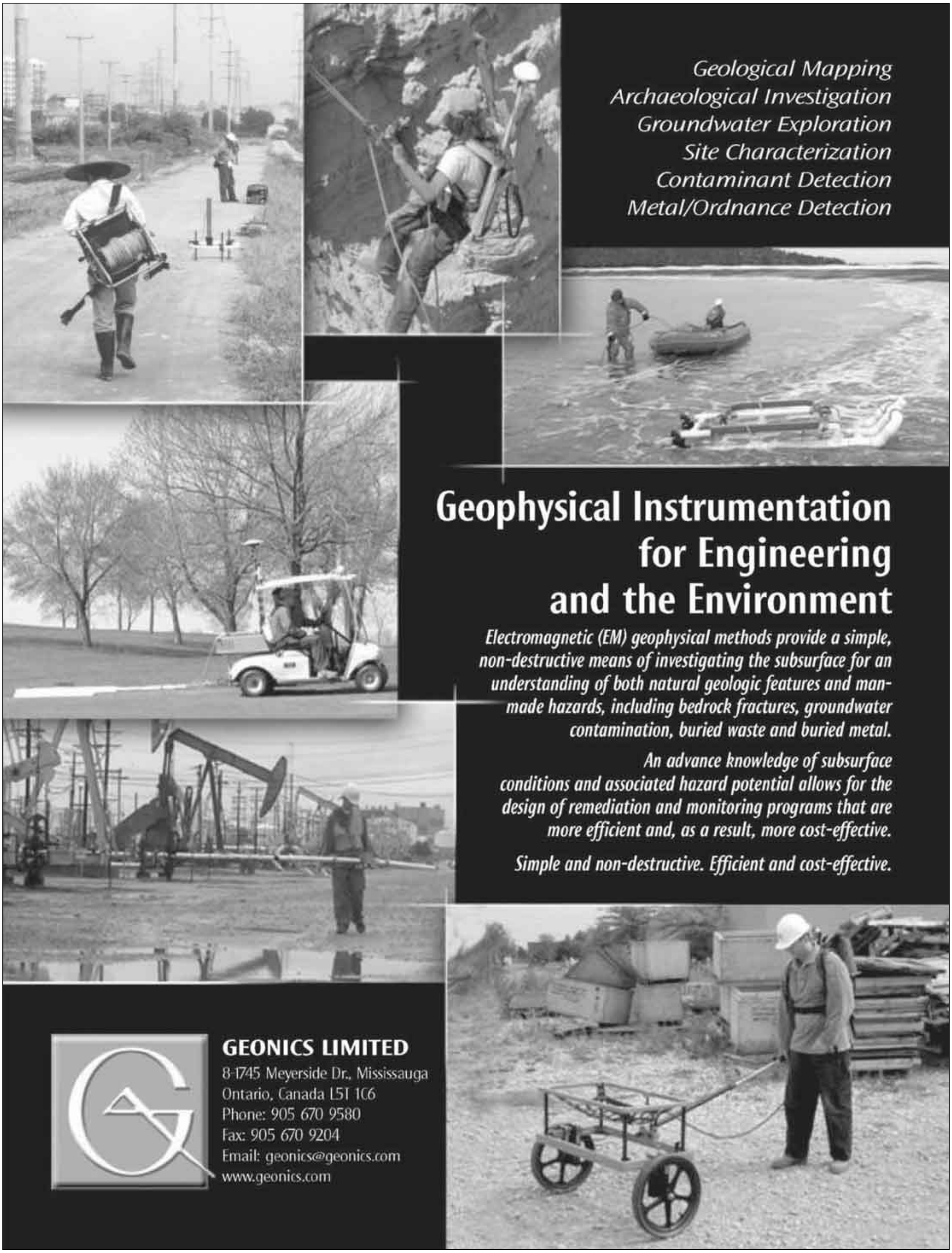
Figure 4. The epochal Volume 7, Number 4, published in November 2002. This is the first numbered issue, and also the first to be called a "newsmagazine" rather than a newsletter.

ing backward, we would then calculate that the first issue of ***FastTIMES*** would have been volume 3, issue 1. Norm is trying to recall how that happened. With this issue, for which Ron Bell served as Special Associate Editor, ***FastTIMES*** evolved from "The EEGS Newsletter" to a "Newsmagazine for the Near Surface Geophysical Sciences."

Ronald Bell served as editor for four issues published in 2004 and 2005. He took ***FastTIMES*** farther upscale, producing content-rich issues highlighting unexploded ordnance (UXO) detection, SAGEEP, environmental and engineering geophysics worldwide (Figure 5), and university research and education. Electronic editions of the printed magazine were posted to the web for download. Ron passed the editor's baton to Brad Isbell, who published the last two printed issues of ***FastTIMES*** in 2005. These issues highlighted UXO and SAGEEP 2005.

All Things Near-Surface: Expansion Beyond EEGS

Following the final issue for 2005, the EEGS Board of Directors took ***FastTIMES*** in a new direction. Beginning with the December 2006 issue, the editorial team of Jeffrey Paine, Roger Young, and Brad Isbell began publishing ***FastTIMES*** in an electronic-only format that is distributed to EEGS members, offered to other geophysical and earth-science societies for voluntary redistribution, and currently is



Geological Mapping
Archaeological Investigation
Groundwater Exploration
Site Characterization
Contaminant Detection
Metal/Ordnance Detection
Geophysical Instrumentation for Engineering and the Environment
Electromagnetic (EM) geophysical methods provide a simple, non-destructive means of investigating the subsurface for an understanding of both natural geologic features and man-made hazards, including bedrock fractures, groundwater contamination, buried waste and buried metal.
An advance knowledge of subsurface conditions and associated hazard potential allows for the design of remediation and monitoring programs that are more efficient and, as a result, more cost-effective.
Simple and non-destructive. Efficient and cost-effective.
GEONICS LIMITED
8-1745 Meyerside Dr., Mississauga
Ontario, Canada L5T 1C6
Phone: 905 670 9580
Fax: 905 670 9204
Email: geonics@geonics.com
www.geonics.com

Figure 5. The “World of Environmental and Engineering Geophysics” issue, November 2004.

freely available for download from the EEGS web site. Content has broadened to include topics such as cold-weather geophysics, shallow-water geophysics, and geophysics in agriculture and archaeology (Figure 6). The editors strive to ensure ***FastTIMES*** remains an interesting and accessible magazine for all things near-surface.

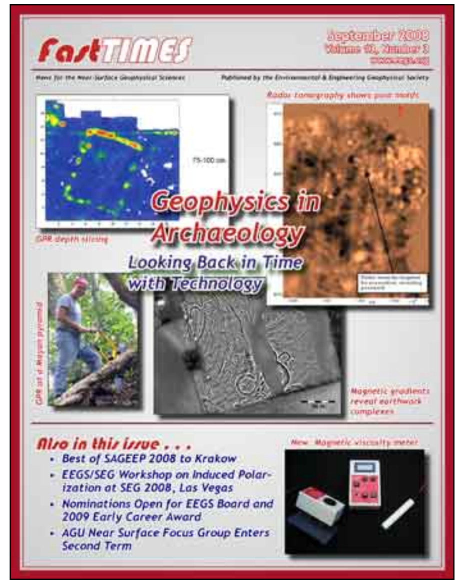


Figure 6. “Geophysics in Archaeology:” an example of the electronic-only editions, September 2008.

Renew your EEGS Membership for 2009 (You Can Do It Online)!

Be sure to renew your EEGS membership for 2009! In addition to the more tangible member benefits (including a print subscription to ***JEEG***, ***FastTIMES*** 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. New this year is an opportunity to donate to the EEGS Foundation during the renewal process. Please watch for the renewal notices arriving by mail and email and renew promptly! As always, members can renew by mail or fax. In addition, EEGS has implemented an online renewal system. Visit *www.eegs.org* to take advantage of this capability.

Sponsorship Opportunities

There are always sponsorship opportunities available for government agencies, corporations, and individuals who wish to help support EEGS's activities. Two specific opportunities are listed below.

Online Delivery of SAGEEP Papers

EEGS already has one founding sponsor (Exploration Instruments) supporting development of an online delivery system to enable SAGEEP papers to be served from the EEGS web site. We are seeking additional sponsors to support maintenance and annual updates. Contact Jeffrey G. Paine (*jeff.paine@beg.utexas.edu*) if you are interested.

SAGEEP 2009 Sponsorship

SAGEEP is heading to Fort Worth,Texas for 2009. SAGEEP would not be possible without the generous support of government and industry sponsors. Sponsorship opportunities for 2009 are available at all levels, including general conference, individual session, icebreaker, conference bag, speaker and session chair gifts, and the Environmental & Engineering Geophysical University sessions. Contact Micki Allen (*mickiallen@marac.com*; 905-474-9118) for more information.

EEGS Publications Join SEG Digital Library on Scitation

The complete journal and proceedings archives of the Environmental and Engineering Geophysical Society (EEGS) have been added to the Society of Exploration Geophysicists' (SEG) Digital Library on the Scitation platform operated by the American Institute of Physics (AIP).

All 13 volumes of the ***Journal of Environmental and Engineering Geophysics*** (***JEEG***) and all 21 annual proceedings of the Symposium on the Application of Geophysics to Environmental and Engineering Problems (SAGEEP) are available within the EEGS Research Collection (*www.segdl.org/eegsrc*).

"Near-surface geophysics is a field of increasing importance, with a growing range of engineering, environmental, and resource applications," said Jonathan E. Nyquist, newly selected EEGS president. "By putting ***JEEG*** and the SAGEEP Proceedings online within the SEG Digital Library, EEGS is giving the work of its member scientists exposure in the broader community of applied geophysicists and with researchers and practitioners in many other disciplines."

The complete ***JEEG*** and SAGEEP Proceedings archives are online thanks to a partnership between EEGS and SEG. In the SEG Digital Library, the EEGS Research Collection will share an interface and search engines with the SEG Research Collection (*www.segdl.org/segrc*), which includes ***Geophysics***, ***The Leading Edge***, the SEG Technical Program Expanded Abstracts, and the online version of the Encyclopedic Dictionary of Applied Geophysics. The EEGS publications have been added to the Digital Cumulative Index, a bibliographic database of applied geophysics literature published by five geoscience societies.

"With EEGS publications, the SEG Digital Library has improved its coverage of geophysical applications in such areas as water resources, fault mapping, groundwater cleanup, and unexploded ordnance," said Fred Aminzadeh, SEG president. "Our alliance with EEGS will facilitate more technical innovation across geophysical disciplines."

EEGS members are gaining access to full-text articles in the EEGS Research Collection plus the SEG Technical Program Expanded Abstracts. SEG members are gaining access to the EEGS Research Collection in addition to the SEG Research Collection access they already enjoy.

Institutions subscribing to ***JEEG*** in print will gain access to the online EEGS Research Collection for the duration of 2008 and will have the opportunity of adding continuing access for 2009. Institutions subscribing to SEG publications will obtain access to the EEGS Research Collection for the remainder of 2008 and can maintain that level of access with an upgraded subscription for 2009.

"We are pleased to add EEGS publications to the Scitation platform, where they will have a natural online home with a wide range of other physical science content," said Douglas LaFrenier, AIP publication sales and market development director.

Subscriptions to EEGS and SEG publications are available through AIP's Circulation and Fulfillment Service at +1-800-334-6908, +1-516-576-2270, or *subs@aip.org*. Rates are available at *http://seg.org/publications/subscriptions*.

EEGS is an applied science organization founded in 1992 with headquarters in Denver, Colorado. EEGS promotes the application of geophysics to environmental and engineering problems primarily

through its publications and its annual meeting, SAGEEP. SEG, founded in 1930 with headquarters in Tulsa, Oklahoma, is the world's largest professional applied geophysics society, with more than 30,000 members in 130 countries. SEG promotes the science of geophysics and the education of a wide range of geoscientists. The society fosters the expert and ethical practice of geophysics in the exploration and development of natural resources, in characterizing the near surface, and in mitigating earth hazards. The society fulfills its mission through its publications, conferences, forums, Web sites, and educational programs.

AIP, founded in 1931, is a not-for-profit membership corporation created for the purpose of promoting the advancement and diffusion of the knowledge of physics and its application to human welfare. It is the mission of the Institute to serve the sciences of physics and astronomy by serving its ten member societies, by serving individual scientists, and by serving students and the general public. AIP provides a spectrum of services and programs devoted to advancing the science and profession of physics. A pioneer in digital publishing, AIP is also one of the world's largest publishers of physics journals and produces the publications of more than 25 scientific and engineering societies.

The JEEG Pages

*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.*

Contents of the December 2008 Issue

Editor's Scratch

Dr. Janet E. Simms, ***JEEG*** Editor-in-Chief
US Army Engineer R&D Ctr.
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
(601) 634-3493; 634-3453 fax
janet.e.simms@erdc.usace.army.mil

The ***JEEG*** editorial board continues to encourage submission of quality articles on the application of geophysics to near-surface problems of all types. As you finalize your manuscripts for SAGEEP 2009 in Fort Worth, please consider going the extra mile to prepare and submit it for publication in an upcoming issue of ***JEEG***!

PEG-40
Portable Energy Source
Propelled Energy Generator
5,000+ Ft. Pounds
3 Sec. Cycle Rate
12 Volt Operation
Manual & Continues
www.rtclark.com tele: 405-751-9696
e-mail: rtclark@rtclark.com

Seismic Accessories
Land Streamers–for efficient seismic surveys
Wall-Lock Borehole Geophones
Rollalong Switches 24, 48 & 96 channel
Geostuff
http://www.geostuff.com
Tel 530-274-4445, fax 530-274-4446

EAGE's Near Surface Geophysics Journal, December 2008

*As a courtesy to the European Association of Geoscientists and Engineers (EAGE) and the readers of **FastTIMES**, we reproduce the table of contents from the December issue of EAGE's **Near Surface Geophysics** journal. The journal is the continuation of the **European Journal of Environmental and Engineering Geophysics** published by the former Environmental and Engineering Geophysical Society — European Section.*

ALSO INTERESTING

Near Surface Geophysics

Volume 6 · Number 6 · December 2008

Content

EAGE
EUROPEAN ASSOCIATION OF GEOSCIENTISTS & ENGINEERS

FastTIMES welcomes short articles on applications of geophysics to the near surface in many disciplines, including engineering and environmental problems, geology, soil science, hydrology, archaeology, and astronomy. In the articles that follow, we glimpse how noninvasive geophysical methods have been applied to extraterrestrial problems, cavity detection, tomographic image processing, and humanitarian endeavors.

Using Earth-Based Imaging Radar to Look Below the Moon's Surface

by Bruce A. Campbell, Center for Earth and Planetary Studies, Smithsonian Institution, MRC 315, P.O. Box 37012, Washington, DC 20013-7012; Phone: (202) 633-2472; Fax: (202) 786-2566; campbellb@si.edu

Introduction

The Moon has been visited by numerous landers and rovers, and by six human missions that spent up to three days on the surface. Even with this wealth of knowledge there is much still to be learned about lunar geologic history, particularly in places distant from the landing sites. In almost all regions, the bedrock of the Moon is covered by a mixed dust and rock layer called the regolith, built up over billions of years by impacts that form craters from microscopic-scale pits to vast multi-ring basins. Atop the basalt flows that fill ancient basin floors, the regolith is 3 to 8 m thick. In older highlands terrain, the regolith is 10 m or more in thickness, with significant layering that reflects overlapping ejecta deposits from the major basins and nearby large craters. Characterizing the differences in regolith composition, thickness, and rock abundance is a vital part of understanding the events and processes that shaped the Moon's surface, and of efforts to locate landing sites that provide access to resources for future explorers.

Remote sensing observations by orbital and Earth-based instruments are the primary source of synoptic information on lunar geomorphology, geochemistry, and regolith physical properties. Data in ultraviolet to thermal infrared wavelengths characterize the upper few microns to centimeters of the regolith. Gamma ray and neutron measurements extend the depth of probing to about a meter with coarse spatial resolution. Only the drill cores and shallow seismic and electrical surveys made by the Apollo astronauts, however, address the vertical and horizontal variations in the regolith, and for just a few sites on the Moon. Ground-based imaging radar can probe to depths of meters to a few tens of meters, with spatial resolution comparable to that of many orbital techniques, to reveal near-surface regolith properties across the Earth-facing hemisphere. This article discusses the basic approach to focused Earth-based radar mapping of the Moon, and offers some highlights of recent geologic discoveries.

Mapping the Moon with Radar

Earth-based radar maps have been produced for over 40 years by transmitting short pulses (which may be achieved through the compression of a much longer, phase-encoded signal) of energy toward the Moon and receiving the reflected signals over some integration period. The echoes are then discriminated by time delay and Doppler shift, which are in turn related to the different distances and velocities, relative to the radar's location, of each point on the lunar surface (for example, Pettengill and Thompson, 1968). Contours of equal delay correspond to small circles about the point on the Moon closest to Earth during the observation, and lines of equal Doppler shift are parallel to the apparent spin axis. A detailed mathematical model for the motion of the Moon relative to the observer is used to link the reflected signals with spatially resolved locations on the lunar surface to form a map of backscattered power.

In our recent observations, we transmit a radar signal at either 12.6-cm or 70-cm wavelength from the 300-m Arecibo Observatory in Puerto Rico, and receive the reflected echoes at the 100-m Green Bank Telescope (GBT) in West Virginia. The transmitted signal is adjusted to hold a single target at fixed time delay and frequency throughout a 16- to 50-minute observing period, and both telescopes point at this location. Other sites on the Moon drift in delay and frequency shift during this time, which leads to smearing in a raw image product. We use a focusing technique to compensate for these drifts and assemble a high-resolution map covering the entire region illuminated by the antenna beam (Figure 1) (Campbell and others, 2007).

Arecibo transmits a circularly polarized radar signal, and we use the GBT to receive both reflected senses of circular polarization. These two channels are important because they contain information on both mirror-like echoes from locally flat parts of the Moon and diffuse echoes associated with rocks, 2 cm and larger for the 12.6-cm echoes and 10 cm or larger for the 70-cm echoes, on and within the regolith. We measure the transmitted power and the strength of the GBT thermal noise to allow calibration of the echoes to backscatter cross section. A calibrated dataset allows comparison between radar returns from lunar geologic features and terrestrial terrain observed by systems like the NASA/JPL AIRSAR.

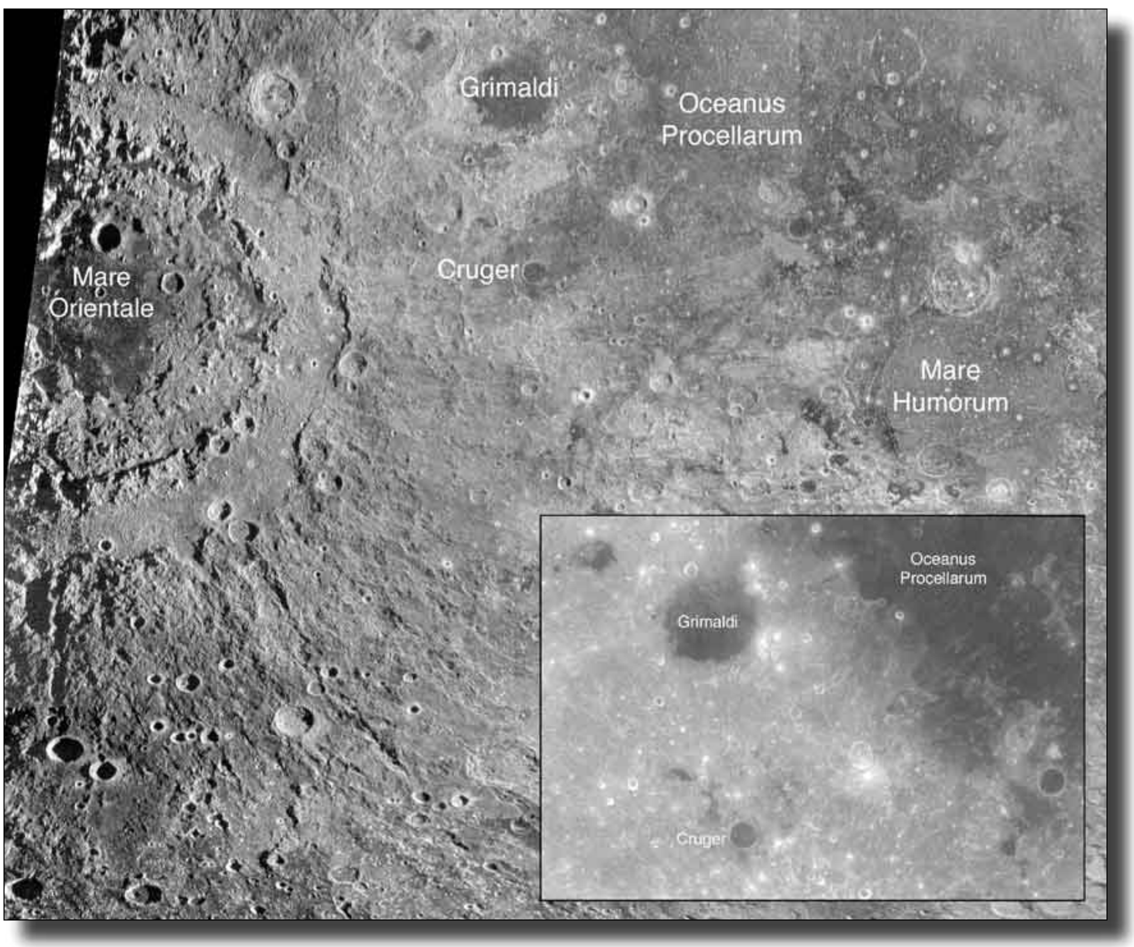


Figure 1. 70-cm radar map of the Moon's southwestern nearside. Mare Orientale fills the 320-km diameter inner ring of the Orientale Basin at upper left. The area of low radar return surrounding Cruger crater and extending northeast toward Oceanus Procellarum is a deposit of ancient basalt buried by Orientale-derived, light-toned highland debris. The inset figure shows a Clementine 750-nm image of the cryptomare region, illustrating the dominant effect of the highlands material on the surface albedo.

Early Lunar Volcanism: Cryptomaria

Basaltic volcanism began on the Moon soon after the formation of the feldspar-rich highlands crust from a global magma ocean. Much of this basalt forms the optically dark maria, but some early deposits have been buried by lighter-colored highlands debris excavated by crater- or basin-forming impacts. Such hidden basalt flow complexes are called cryptomaria. Detection of these deposits is possible through multi-spectral methods that identify mafic material brought to the surface by small craters that penetrate the overlying deposits. Radar mapping at 70-cm wavelength can probe to considerable depth to reveal cryptomare materials over large areas where they are mixed with the mantling highland debris.

On Earth, radar penetration is limited to very dry locations, because even small amounts of water mixed with natural salts lead to high attenuation of the signal. Lunar rocks, formed without water, can have much lower losses and hence allow greater radar penetration. In the feldspar-rich highlands, microwave losses are very low and the 70-cm radar signal can probe to depths up to 50 m. In the basaltic mare regolith the penetration depth is just a few meters and largely controlled by the abundance of ilmenite ($FeTiO_3$) (Carrier and others, 1991). This great difference in absorption properties makes the 70-cm radar echoes very sensitive to mixing of basalt with highlands material in the upper few tens of meters of the regolith.

One of the largest cryptomare deposits occurs east of Orientale, the last giant basin to form. These basalt flows appear to have flooded low-lying areas west of the vast Oceanus Procellarum mare complex, but were buried by highlands material when Orientale formed about 3.9 billion years ago. At optical wavelengths the area west of Oceanus Procellarum is generally light-toned, with a few outcrops of post-Orientale basalt in crater floors (Figure 1 inset). The 70-cm image, however, shows an extensive region of lower radar return extending west from the visible mare toward the crater Cruger (Figure 1). Comparison of the radar data with multispectral information suggests that this and other areas of low return represent an increasing amount of basalt mixed with the low-loss highland material within about 40 m of the surface (Campbell and Hawke, 2005). The cryptomaria mapped to date east of Orientale cover an area equivalent to that of Nebraska, with additional deposits north of the basin and perhaps even more basalt flows beneath ejecta too thick to be probed with radar.

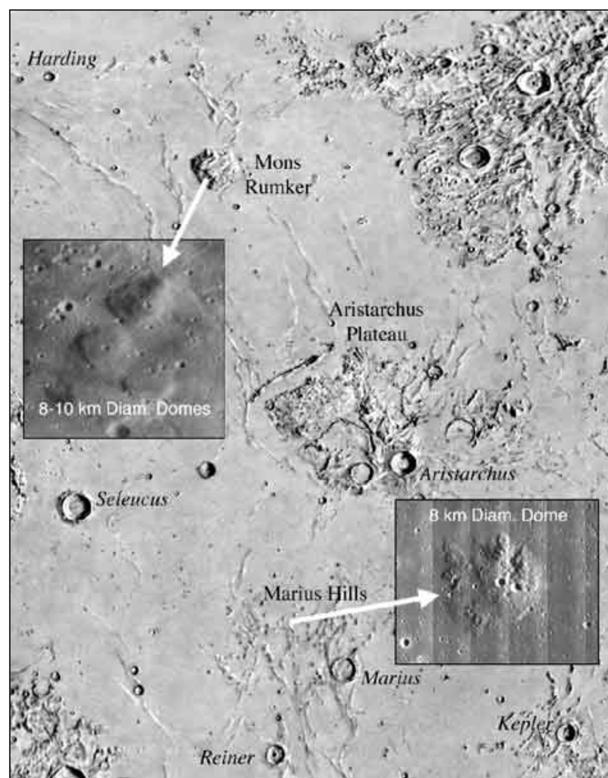


Figure 2. Portion of a USGS shaded-relief view of the northwestern lunar nearside with three major volcanic dome and plateau features noted. Insets are Lunar Orbiter images of 8- to 10-km diameter domes in the Marius Hills and Mons Rümker regions.

Pyroclastic Deposits and Rugged Lava Flows

The northwestern lunar nearside is dominated by the plains, formed by low-viscosity magmas at high eruption rates, of Mare Imbrium and Oceanus Procellarum. Within these smooth plains are three major volcanic complexes (the Marius Hills, Aristarchus Plateau, and Mons Rümker) that preserve a record of much more rare viscous or explosive eruptions (Figure 2). New high-resolution radar data are revealing details on the thickness and physical properties of these enigmatic deposits.

On the Aristarchus Plateau, rapid release of volatiles early in the mare-forming eruptions created fire fountains that distributed up to a 30-m thickness of glass beads almost 200 km from the vent. These mantling materials have few included rocks, so they appear very dark in radar images (Figure 3). Concurrent effusive basalt eruptions and later crater-forming events affect the final thickness and rock abundance of these mantling layers, which are of great interest as potential resources for volatiles and condensed metallic species. The 70-cm radar data reveal a bimodal distribution of pyroclastic thickness on the Aristarchus Plateau, with areas south and east of the large sinuous rille Vallis Schröteri only perhaps 5- to 10-m deep above a base of lava flows erupted concurrent with the fire-fountaining. These results are confirmed by the 12.6-cm data, which show high-backscatter patches where small craters have excavated the flows and contaminated the pyroclastic deposit with 2-cm and larger rocks (Campbell and others, 2008a).

The Marius Hills and Mons Rümker complexes have dome-like features with steep margins that are very different from typical smooth, mare-forming plains (Figure 2 insets). It has long been suggested

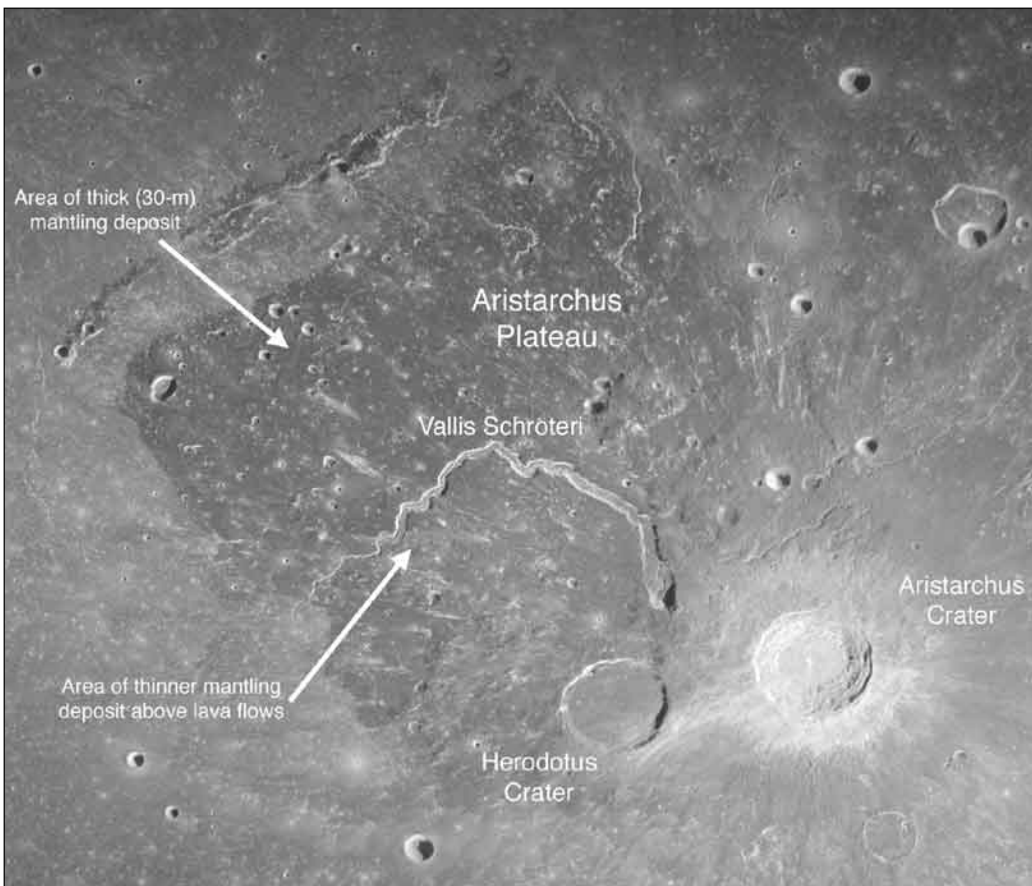


Figure 3. 12.6-cm radar map of the Aristarchus Plateau, a 170 x 200 km crustal block about 2 km in elevation above the surrounding maria. Aristarchus crater is 40 km diameter. Pyroclastic deposits across the plateau are radar-dark due to a combination of fine-grained material and possible higher electrical losses. Brighter streaks and patches are due to increased rock abundance from either Aristarchus ejecta or excavation of competent lava flows beneath the ash.

that these features represent eruptions of more viscous material, but the radar data show previously unknown aspects of both regions. In the Marius Hills, the steep-sided domes have polarization properties similar to those of rugged, near-rim ejecta from young impact craters. This suggests a blocky surface texture, like that of SP Flow in Arizona, which must arise due to relatively uncommon lunar magma properties and/or eruption rates. Mons Rümker appears to be a hybrid of features and deposits observed in the Aristarchus Plateau and Marius Hills regions, with potentially very rugged lava flows beneath a 3 to 6 m mantling layer of pyroclastic material formed late in the history of the dome complex (Figure 4) (Campbell and others, 2008b). Radar studies of these uncommon landforms raise interesting questions about the role of volatiles, magma cooling, and eruption dynamics in forming the spectrum of lunar volcanic features.

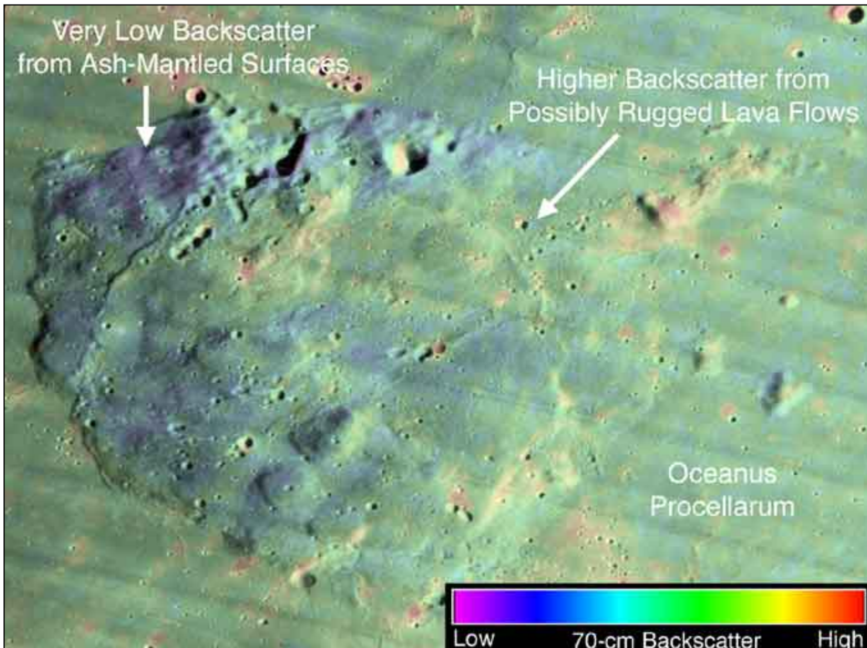


Figure 4. Color-coded 70-cm radar returns on Lunar Orbiter photo of Mons Rümker (80-km diameter). The central and northeast portions of the dome complex have elevated backscatter that may indicate rugged lava flows, while the majority of the region has very low echoes suggesting a rock-poor, pyroclastic mantling deposit.

Ongoing Work

The 70-cm lunar maps are available through the NASA Planetary Data System (*http://pds-geosciences.wustl.edu/missions/lunar_radar/index.htm*). We are currently mapping the entire near side of the Moon at 12.6-cm wavelength with 80-m resolution (four looks per pixel), and these images will also be archived with the PDS.

References

Campbell, B. A., Carter, L. M., Hawke, B. R., Campbell, D. B., and Ghent, R. R., 2008a, Volcanic and impact deposits of the Moon's Aristarchus Plateau: A new view from Earth-based radar images: Geology, v. 36, p. 135–138, doi:10.1130/G24310A.1.

Campbell, B. A., Hawke, B. R., and Campbell, D. B., 2008b, Surface morphology of domes in the Marius Hills and Mons Rümker regions of the Moon from Earth-based radar data: Journal of Geophysical Research, in press.

Campbell, B. A., Campbell, D. B., Margot, J. L., Ghent, R. R., Nolan, M., Chandler, J., Carter, L. M., and Stacy, N. J. S., 2007, Focused 70-cm radar mapping of the Moon: IEEE Trans. on Geoscience and Remote Sensing, v. 45, no. 12, p. 4032–4042, doi:10.1109/TGRS.2007.906582.

Campbell, B. A., and Hawke, B. R., 2005, Radar mapping of lunar cryptomaria east of Orientale basin: Journal of Geophysical Research, doi:10.1029/2005JE002425.

Carrier, W. D., Olhoeft, G. R., and Mendell, W., 1991, Physical properties of the lunar surface: In: *Lunar Sourcebook*: Cambridge University Press, New York.

Pettengill, G. H., and Thompson, T. W., 1968, A radar study of the lunar crater Tycho at 3.8-cm and 70-cm wavelength: Icarus, v. 8, p. 457–471.

Electrical Resistivity Imaging as a Tool for Assessing Endangered Karst Invertebrate Habitat

by Blake Weissling and Kemble White, Cave and Endangered Invertebrate/Environmental Geophysics Research Laboratories, SWCA Environmental Consultants, San Antonio, Texas (bweissling@swca.com)

Introduction

The problem of identifying and delineating potential subterranean habitat for endangered species in both karst and pseudokarst environments is a challenging task, compounded by the endemicity of the species and by the frequent obstacles to human access for habitat assessment. More often than not, the endangered species (troglobites) in question are invertebrates and/or amphibians that have adapted to the subterranean world and have followed an evolutionary path distinguishing them genetically from their surface relatives. Deciphering the genetic path of these subterranean species not only has implications for evolutionary biology (Culver, 1982; Krajick, 2001) but for the geologic evolution of karstic terrains (White and others, 2008). These karst or pseudokarst (for example, volcanic lava tube systems) habitats may be generally grouped into either classical cave environments or mesocavernous environments described by Howarth (1983) as small voids, cracks, and passages inaccessible to humans, but accessible, or perhaps even preferred, by troglobites. Because these subsurface features are often undetectable as well as inaccessible, quantifying them or even verifying their presence can be highly uncertain, yet they may actually be the primary habitat of species of interest.

The detection and delineation of a potential subterranean habitat has been addressed through application of electrical resistivity imaging (ERI) techniques. A survey was conducted in an extrusive volcanic (pseudokarst) terrain on the south shore of Kaua'i, Hawai'i, a site known for lava tube formation, and habitat for the endangered eyeless Kaua'i Cave Wolf Spider (*Adelocosa anops*) and the Kaua'i Cave Amphipod (*Spelaeorchestia koloana*) (USFWS, 2006). Both galvanic DC resistivity, using an Advanced Geosciences Inc. (AGI) Supersting R8 DC resistivity system, and charged capacitance coupling resistivity, using a Geometrics Inc. OhmMapper TR-2 system, were employed. The latter system was particularly useful at the Kauai site to facilitate data collection over exposed basaltic bedrock, an environment not conducive to the insertion and use of metal electrodes. Supersting lines were acquired with a mixed array combining the horizontal resolution sensitivity of the dipole-dipole array with the vertical resolution sensitivity of the inverse Schlumberger array (Weissling 2008; Zhou and others, 2002). At both sites, surveys were conducted over known and mapped cave passages for validation of the techniques. Forward simulation modeling was conducted to verify resistivity anomaly signatures of known void spaces. Results were highly encouraging and serve to reinforce the void-imaging capabilities of both electrical resistivity techniques.

Study Site and Methods

The study site is a 100-hectare (250-acre) property of rural, agricultural, and developed land situated near the village of Koloa on the south shore of the island of Kaua'i. The area is characterized geologically as 150,000 to 300,000 year old rejuvenation-phase pahoehoe lava flows and lava tube systems that trend approximately northeast to southwest, at a gentle 2 percent seaward gradient. At least two open tube systems are known at the site with surface entrances, both of which have been identified as habitat for the two endangered karst invertebrates described above. Due to the age of the basalt flows in the region, surface weathering and soil development were conducive in most places to the use of

→

the Supersting system. Contact resistance values ranged from 3000 to 10,000 ohms in dry conditions and 1000 to 3000 ohms in wet conditions, owing to the resistive vesicular basalt bedrock and limited soil. Application of a dilute saline solution to the insertion area of the electrodes significantly improved contact resistance. The capacitance-coupled OhmMapper system was particularly useful in areas of exposed bedrock and for several long reconnaissance lines where galvanic (electrode) techniques were not deemed cost or time effective.

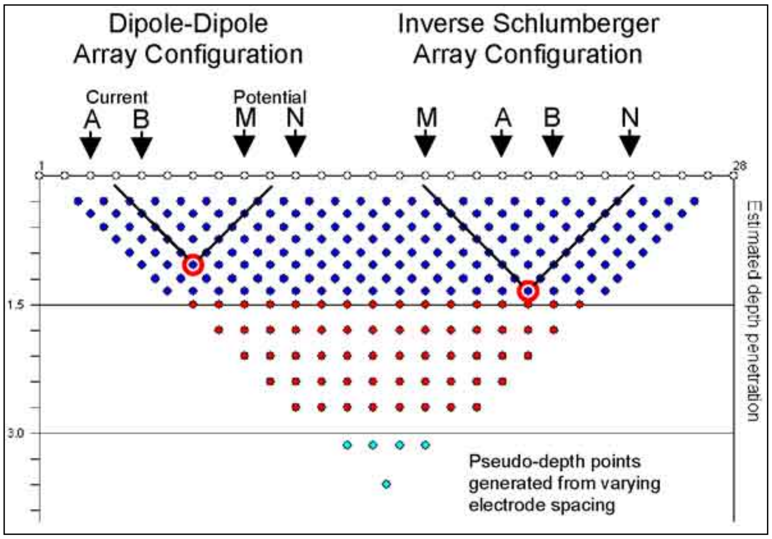


Figure 1. Example pseudodepth section and electrode configuration of a mixed ERI array.

Twenty Supersting R8 profiles were collected over a six-day period, comprising about 2150 m of resistivity data. The majority of these profiles were collected with a 56 electrode mixed (dipole-dipole and inverse Schlumberger) array at a 2-m electrode spacing. Extensive testing of this array configuration in a variety of karst environments has clearly demonstrated its utility and validity. Figure 1 depicts the specific electrode configurations for each array type and the resulting pseudodepth points generated.

Seven OhmMapper TR-2 profiles were collected over a three-day period, comprising about 1500 m of resistivity data. The OhmMapper TR-2 system (Figure 2) operates only in a dipole-dipole configuration and the dipole configuration (spacing) is fixed. To obtain data at deeper levels, the separation between the receiving and transmitting dipoles must be manually changed in the cables. This is accomplished by adding a longer separation cable between dipole segments. With a longer separation set, the entire array is towed again along the same

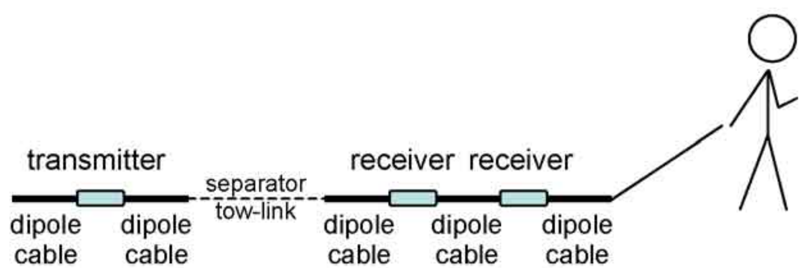


Figure 2. OhmMapper TR-2 (left) being towed by author. Cartoon (right) depicts dipole setup of the TR-2 system.

path for collecting data for a deeper level. OhmMapper datasets were collected using a dipole length of 2.5 m, and with dipole separation cables of 2.5, 5, 10, 15, and 20 m, giving a maximum of five depth levels. Each measurement, collected once per second (1 Hz), is transmitted to a console worn by the operator. All data sets for each successive pass along the survey line are uploaded from the console to special software for merging to a single data file. This file is then uploaded to the inversion software for processing.

All apparent resistivity data pseudosections for the Supersting and OhmMapper surveys were edited for noisy data and electrodes and were inverted with AGI's EarthImager 2D software using smooth-model inversion. Targeted RMS error for convergence was less than 5 percent.

Figure 3. Supersting line setup across surface footprint of a lava tube on a golf course adjacent to the study site.

Results

Validation of the ERI technique over a known void feature is crucial to a successful and defensible result. A known lava tube on a golf course adjacent to the project site (Figure 3) was used for validation of the Supersting technique. The width of the lava tube at the survey location was about 5 m, with a ceiling thickness of 3 to 4 m.

The ERI Supersting profile acquired over the golf course feature is shown in Figure 4, along with the measured and calculated apparent resistivity pseudosections. The inverted section converged in eight iterations with an RMS error of less than 3 percent. The known lava tube feature (A) was successfully delineated in location, approximate depth, and dimension. New, previously unknown features (B) likely represent open or partly collapsed lava tube systems.

The use of forward simulation or synthetic modeling is also a valuable and useful tool for assessing the validity of ERI anomalies. The survey planner modeling tools in the EarthImager software package (www.agiusa.com) were used to simulate the apparent resistivity

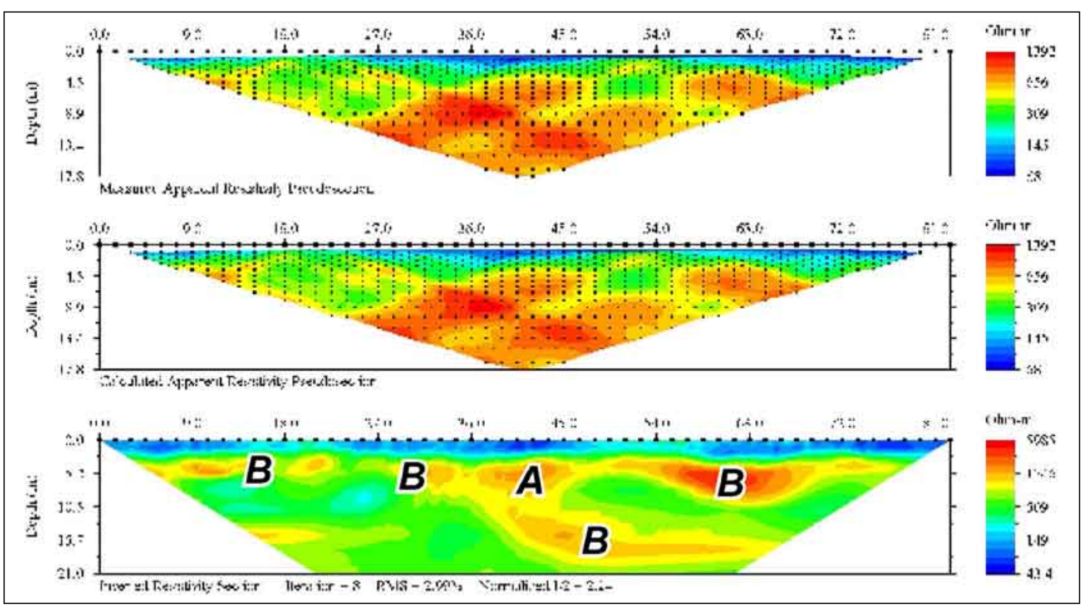


Figure 4. Measured (top) and apparent (middle) resistivity pseudosections and inverted section (bottom) of the golf course Supersting validation line.

→

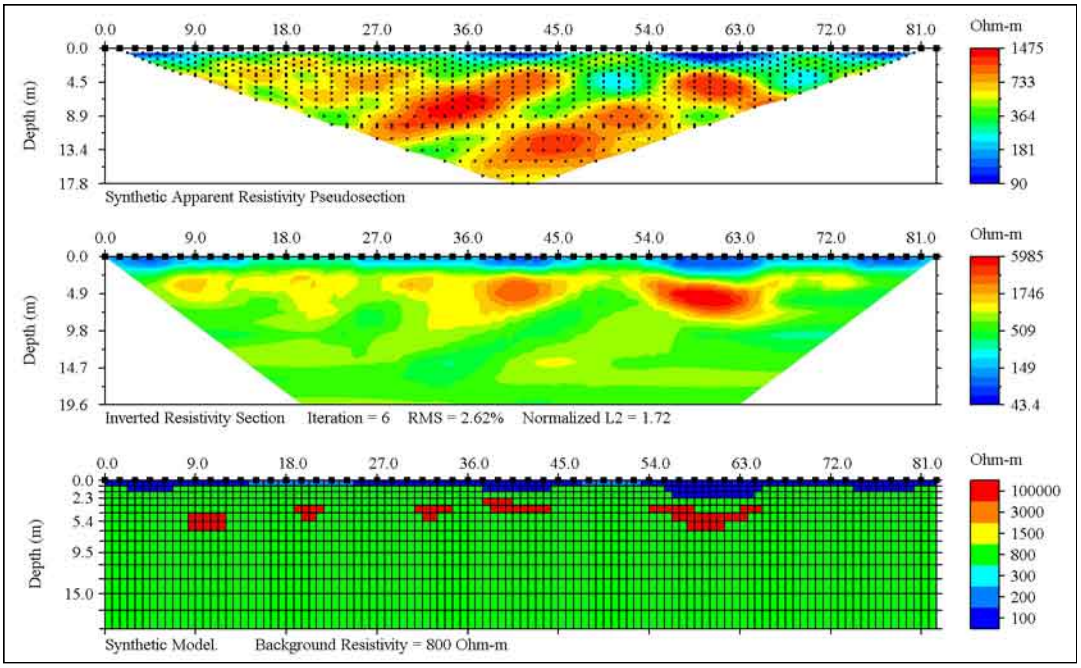


Figure 5. Forward simulation (top) of apparent resistivity pseudosection, inverted result (middle), and synthetic model (bottom) of the known and conjectured golf course lava tube features

pseudosection and inverted section of the golf course lava-tube anomalies (Figure 5). A resistivity of 800 ohm-m was assigned to the model background (basalt bedrock) while void space features (lava tubes) were assigned a resistivity of 100,000 ohm-m. The relatively moist and conductive golf course turf was modeled with a resistivity of 100 ohm-m. As can be seen in a comparison of the actual and synthetic inversion of the apparent resistivity sections, there is an overall excellent match of the lava tube anomalies, in terms of both morphology and resistivity value. Note that the same resistivity scale (log scale) was used for both inversion sections.

The results from the modeling provided the justification to interpret similar high resistivity anomalies seen on other ERI lines in the adjacent project area as evidence for lava tube void space.

This project also provided the opportunity to directly compare co-located resistivity profiles from the Geometrics OhmMapper TR-2 system and the AGI Supersting R-8 system (Figure 6). There are few examples of such comparisons in the literature. The opportunity to compare system approaches in such a geophysically challenging and interesting environment was a bonus.

A 300+ meter OhmMapper line was shot along a north-south road in the project area. This road would have intersected potential lava tubes at oblique angles, thus affording an excellent opportunity to image these features. Evidence for near-surface tubes was strong due to occurrence of collapsed tube features adjacent to the road. The middle section of the OhmMapper line was re-shot with a 112 meter Supersting line. As can be seen with the inverted profiles spatially registered (Figure 6), there is an excellent match of anomaly shape and dimension and overall resistivity structure in the top 7 to 8 m of both profiles.

Conclusion

Multiple high resistivity anomalies, apparent on numerous ERI lines, were interpreted as open or partially open lava tube systems, an interpretation supported by validation with known features as well as by synthetic modeling. These features were subsequently delineated and mapped. The resulting

→

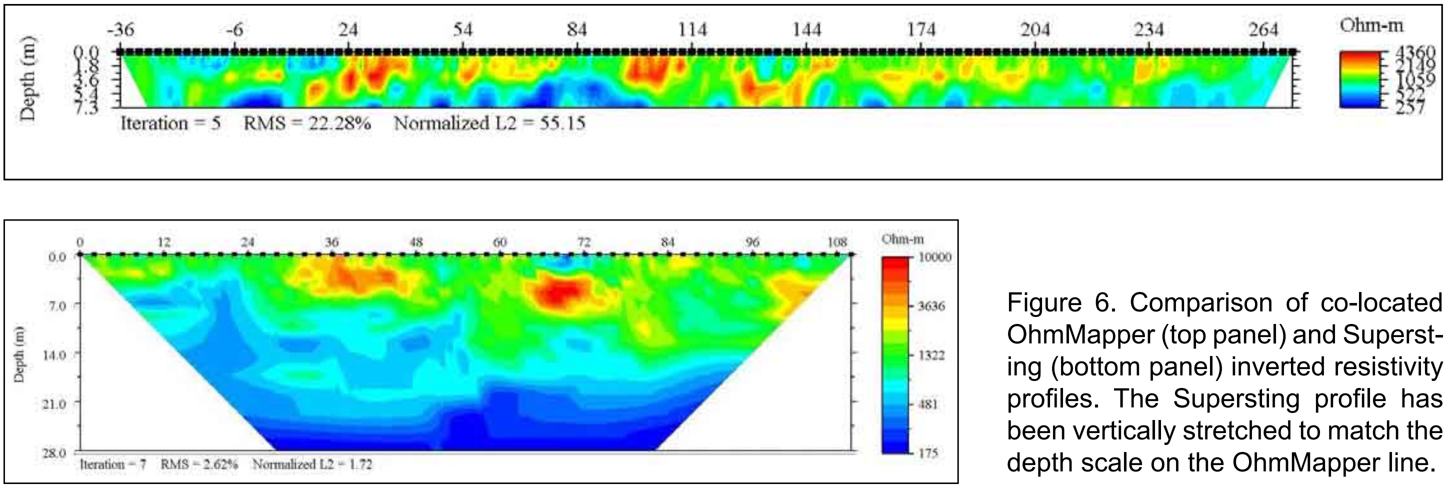


Figure 6. Comparison of co-located OhmMapper (top panel) and Superst-ing (bottom panel) inverted resistivity profiles. The Supersting profile has been vertically stretched to match the depth scale on the OhmMapper line.

map-view morphology of the geophysically detected features was entirely consistent with surface observations of the lava tube systems. A previously unexplored section of a known lava tube at the study site, detected with ERI, was subsequently explored and confirmed as habitat for the Kauai Cave amphipod.

References

Culver, D. C., 1982, *Cave Life: Evolution and Ecology*: Harvard University Press, Cambridge, Massachusetts, 189 p.

Howarth, F. G., 1983, Ecology of cave arthropods: Annual Review of Entomology, v. 28, p. 365–389.

Krajick, K., 2001, Cave biologists unearth buried treasure: Science, v. 293 (5539), p. 2378–2381.

U. S. Fish and Wildlife Service, 2006, Recovery Plan for the Kauai Cave Arthropods: the Kauai Cave Wolf Spider (*Adelocosa anops*) and the Kauai Cave Amphipod (*Spelaeorchestia koloana*): U. S. Fish and Wildlife Service, Portland, Oregon, 64 p.

Weissling, B. P., 2008, Advances in electrical resistivity imaging of karst voids: Geological Society of America, Abstracts with Programs, v. 40, no. 3, p. 30.

White, K., Davidson, G. R., and Paquin, P., in press, Hydrologic evolution of the Edwards (Balcones Fault Zone) Aquifer recharge zone as recorded in the DNA of Eyeless Cicurina Cave Spiders, Southcentral Texas: Geology.

Zhou, W., Beck, B. F., and Adams, A. L., 2002, Effective electrode array in mapping karst hazards in electrical resistivity tomography: Environmental Geology, v. 42, p. 922–928.

Locating Buried Cavities Using Resistivity and GPR Surveys at Luxor, Egypt

by Mehrez Elwaseif [1,3], Mohamed Abdalla[1], and Mahdy Abdel-Rahman[2]
[1] National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Cairo, Egypt
[2] Department of Geophysics, Ain-Shams University, Abbassia, Cairo, Egypt
[3] Graduate School, Dept. of Earth and Environmental Sciences, Rutgers University, Newark, NJ, USA
(Mehrez@andromeda.rutgers.edu

Abstract

Resistivity imaging and ground-penetrating radar (GPR) methods have provided rapid and effective prospecting for many archaeological sites around the world. However, these methods cannot provide accurate quantitative information about the dimensions of the buried features, especially if existing in a complicated geological medium such as clayey soil moistened with saline water. The resolution of the GPR method is low in such conditions, and the resistivity inversion generally produces images with a smooth distribution of resistivity so it is difficult to specify the edges of anomalies within those images. In this study, we suggest an image processing technique that can be applied to resistivity images to locate the edges of anomalies accurately. The method was applied to synthetic resistivity data representing a model of a buried cavity and determined its depth and dimensions accurately. We conducted 2D resistivity and GPR surveys to locate any buried archaeological relics at a site in the western bank of Luxor, Egypt. The resistivity data included eight parallel lines, while the GPR data included forty parallel radar profiles. Both methods were able to detect some interesting anomalies that are probably related to hidden archaeological features. Finally, we applied the edge detection method on a real resistivity image to locate the edges of a likely buried-cavity anomaly and compared the detected boundaries with a GPR profile. Results from both approaches were comparable.

Introduction

2D resistivity and GPR methods have been applied widely to map hidden archaeological structures at sites all over the world (Fiore and Chianese, 2008; Quarto and others, 2007; Berard and Maillol, 2007). Detection of buried features is based upon the difference in the physical properties (such as electrical resistivity and radar wave velocity) between the features and the host medium. The high level of saline groundwater in some archaeological sites or the complexity of feature shapes, sizes, or positions can mask them and make determining their depth and geometries difficult. The ability of the resistivity method to locate isolated archaeological features is largely dependent on the array configuration, unit electrode spacing, and the success of the inversion process. The dipole-dipole array is more appropriate in mapping archaeological features due to its relatively high sensitivity to horizontal changes in resistivity (Dahlin and Zhou, 2004). The unit electrode spacing controlled the depth of investigation and the resolution of the method in locating closely spaced features. The cell size of the mesh used by the inversion program is normally equal to the unit electrode spacing. If the spacing between buried features is less than the unit electrode spacing, they will not be modeled accurately (Loke, 2002). The smoothness constrained regularization is used widely in inverting resistivity data, since the method does not require including a starting subsurface model in the inversion process (Loke and Lane, 2002; Olayinka and Yaramanci, 2000). This regularization attempts to minimize the squares of the differences between the measured and modeled apparent resistivity. The inversion process produces smooth minimum structure models (Loke and Barker, 1996b). The GPR technique is powerful in locating buried archaeological relics (Telford and others, 1990; Parasnis, 1986; Reynolds, 1997). Dielectric constant is a critical parameter for GPR surveys because it controls propagation velocity of electromagnetic waves through materials, and reflection coefficients across interfaces of different materials. Dielectric constant is primarily a function of mineralogy, porosity, pore fluid, frequency, geometry, and electrochemical interaction (Daniels, 1996).

The joint application of resistivity and GPR methods in archaeological sites can provide valuable information on the subsurface distributions of archaeological features such as walls, statues, and tombs. However, the geometries of these features cannot be estimated directly by using the commercially available processing programs. The GPR results can show the depth of burial accurately, but they provide a rough estimate of the horizontal extension of features by observing the width of the hyperbolic shape. The anomalies in the inverted resistivity images have a gradational boundary, so that the depth of burial and geometries cannot be resolved directly. Further post-processing steps could be applied on these images to locate the exact edges of these anomalies. Image processing techniques, such as edge detector methods, can be applied on resistivity images to locate feature edges accurately. Nguyen and others (2005) applied the image gradient method on synthetic resistivity images to detect faults. Their approach worked well in the case of thin top layer and in the presence of high resistivity contrast, whereas it gave ambiguous results in the case of a thick, resistive top layer and low resistivity contrasts. The results of the image gradient method can be improved when applied on a region of interest (ROI) within the image so that other regions will not be affected. In this paper, we (1) applied an edge detection method (Roberts' cross-gradient operator) on a synthetic resistivity model representing a buried cavity to determine its burial depth and dimensions, (2) conducted 2D resistivity and GPR surveys at Qurnet Murai, located about 30m to the west of Merenptah temple in the western bank of Luxor to map the yet undiscovered archaeological features, and (3) applied the edge detector method on a real resistivity image and compared the detected edges with the GPR results.

Roberts' Cross-gradient Operator

Edge detection methods can be applied on resistivity images to locate the edges of different anomalies by calculating the image gradient. Computation of the gradient involves obtaining the partial derivatives at every pixel location within an image (Gonzalez and Woods, 1992). Roberts' cross-gradient operator was applied to locate the actual edges of anomalies within resistivity images. The masks of this operator and the way of identifying the edges on a sample image are shown in Figure 1. Let a 3 x 3 resistivity image having gray values intensity of 'Z's'. The first-order partial derivative at Z5 in the x and y directions can be estimated using the operator masks (equations 1 and 2). The magnitude of

$$G_x = (z_9 - z_5)\text{K} \quad (1)$$

$$G_y = (z_8 - z_6)\text{K} \quad (2)$$

$$\nabla f = mag(\nabla F) = \left[G_x^2 + G_y^2\right]^{1/2} \text{K} \quad (3)$$

$$\alpha(x, y) = \tan^{-1}\left(\frac{G_y}{G_x}\right)\text{K} \quad (4)$$

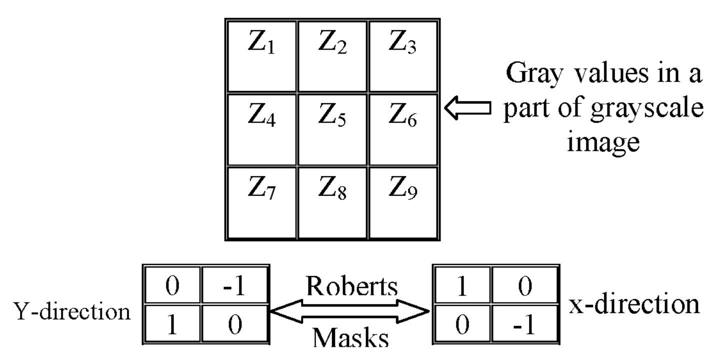


Figure 1. Masks and equations used to compute the gradient using Roberts' operator (after Gonzalez and Woods, 1992).

the gradient vector ($mag\nabla f$) defined by equation 3 is used to indicate the presence of an edge at a point within the image. The direction angle of the gradient vector ($\alpha(x,y)$) is given by equation 4. The direction of an edge is perpendicular to the direction of the gradient vector (Gonzalez and Woods, 1992).

Three image pre-processing steps should be applied to resistivity images before applying the Roberts' operator to enhance the contrast between different pixels and reduce noise. The first step converts the input resistivity image to 32-bit grayscale image so that it is ready for the following image processing steps. The anomaly region within the image is then selected so that other regions will not have any impact on the results. Finally, the Gaussian blur filter is performed to preserve the edges of the anomaly and reduce extreme values (noise) by replacing each pixel with its neighborhood mean (Nixon and Aguado, 2002). Two post-processing steps are applied after the Roberts' operator to locate the sharpest boundaries of the anomaly ("true boundaries") by thresholding the image with the maximum gray value intensity and finally to plot the anomaly in 3D (Figure 2). The Java-based image processing program, Image J, developed at the National Institutes of Health was used for all processing steps (Barthel, 2006).

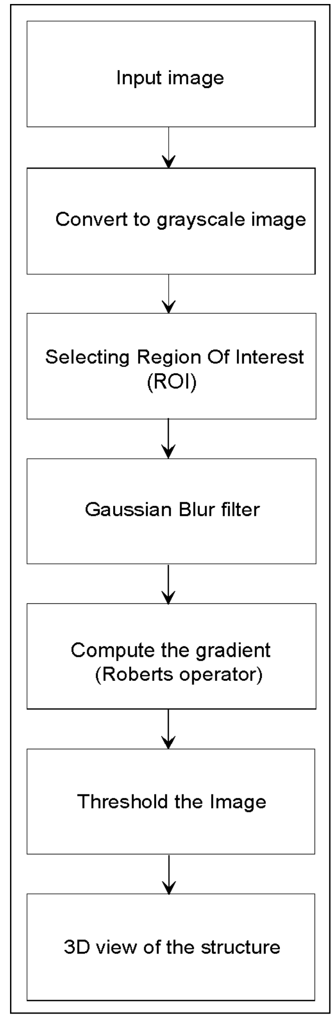


Figure 2. Processing flow chart of the edge detection method.

Application to Synthetic Data

The Roberts' cross-gradient operator could be applied on the output image from any code that employs the smoothness constraint in the regularization. We chose the RES2DMOD program (Loke and Barker, 1996) due to its popularity and commercial availability. The program was utilized to calculate the synthetic apparent resistivity pseudosections for a single cavity buried in a homogeneous medium with resistivity 1 ohm-m (Figure 3a). The cavity was buried at 1.4 m depth, having a width of 5.3 m, length of 2.2 m, and a resistivity of 100 ohm-m. Thirty-two electrodes were used to create the synthetic data using dipole-dipole array configuration. The unit electrode spacing was 1 m and six depth levels were used, providing 390 measurements and an investigation depth around 4.5 m. The synthetic data were contaminated with 2% Gaussian noise to simulate the data measured in the field. After that, the data were inverted using the smoothness constraint method (Loke and Barker, 1996). Figure 3b shows the resultant image after the inversion process. The cavity anomaly has width of 4.6 m, length of 2.4 m, and depth of 1.3 m depth (based on the brown contour). The detected boundary, after applying the previously mentioned image processing steps, is shown in Figure 3c. The edges of the anomaly are at the same depth (1.4 m) as the original model, having a width of 5.2 m and length of 2.4 m. The average accuracy of the method in locating the true depth and geometries of the cavity is about 95 percent. A 3D view of the cavity is shown in Figure 3d.

Field Data Acquisition and Processing

The resistivity and GPR surveys were conducted at a site known as Qurnet Murai in the west bank of Luxor, Egypt (Figure 4). The western bank of Luxor contains more than thirty known temples such as Habu and Hatshepsut. The resistivity and GPR surveys were acquired in an attempt to map any

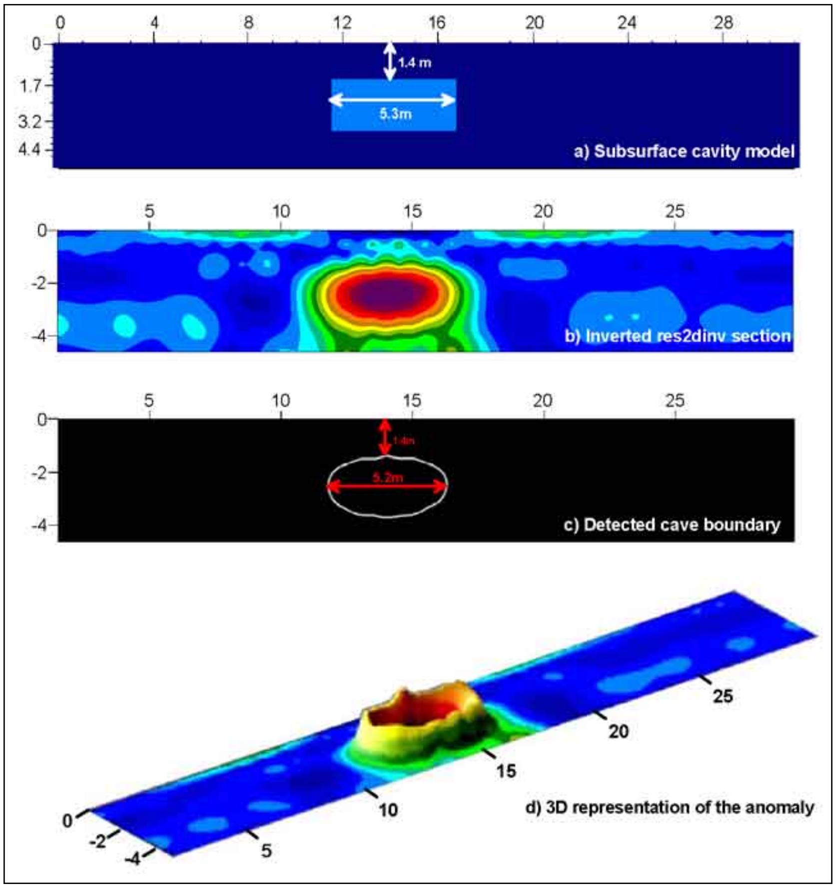


Figure 3. Results of applying the Roberts' cross-gradient operator on the synthetic cavity model.

hidden archaeological relics (such as walls, tombs, and statues) underneath this site.

2D Resistivity Lines

Eight parallel 2D resistivity profiles were acquired using dipole-dipole array configuration. Thirty two electrodes were employed with 1 m unit electrode spacing. Each profile was 32-m long and 5-m apart from each other. The data were inverted using the smoothness-constrained approach (Gunther, 2004). The same image processing sequence described in Figure 2 was applied to the inverted resistivity images to locate the boundaries of the detected anomalies. Finally, the anomalies were displayed in 3D.

GPR profiles

Forty parallel radar profiles were acquired, each of which is 45-m long and 1-m apart from the other. The number of traces, number of samples, trace incre-

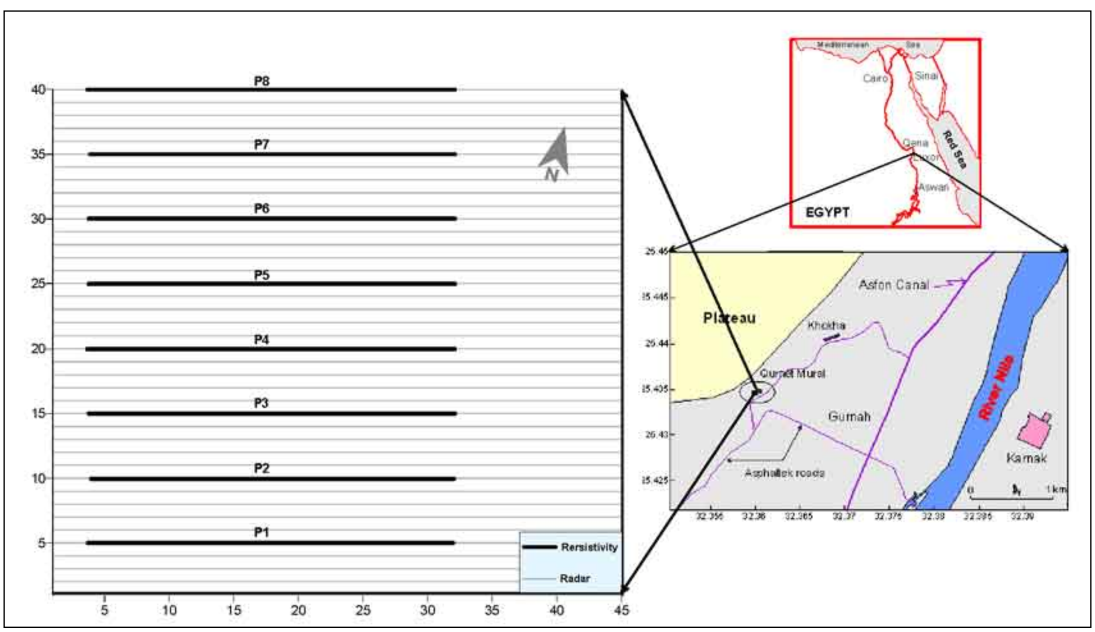


Figure 4. Map of the resistivity and radar profiles.

ment, and time increment were 899, 512, 0.05, 0.195 ns, respectively.

The GPR data were subjected to several processing steps: (1) performing quality control (QC) for the whole dataset to cancel or to repeat the distorted data due to high noise, (2) stacking traces to enhance the resolution of GPR profiles (Chen and Huang, 1998), (3) applying the static correction to shift the traces to ground level, and (4) applying average and band pass filters to remove the low frequency bias from the traces. The processing increased the interpretability of the GPR profiles by removing unwanted random noise and enhancing events of interest.

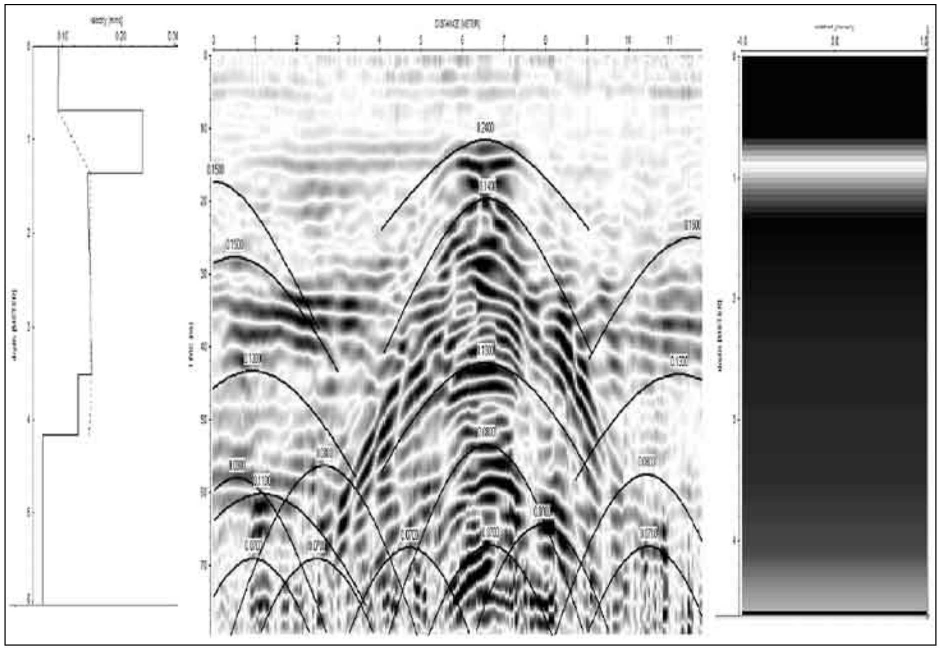


Figure 5. 1D/2D velocity models based upon a radar profile acquired over a known cavity at the site.

Velocity analysis of the radar waves was undertaken to convert the radar time sections to depth sections. Figure 5 shows the 1D/2D velocity models estimated from a radar profile acquired over a known cavity near the study area. The average wave velocity estimated from the hyperbolas in the radargrams is 0.136 m/ns. The depth of targets within the radar sections are calculated using the velocity of radar waves, which is inversely proportional to the dielectric permittivity of the medium.

Application to Field Data

The Roberts' cross-gradient method successfully located the true depth and dimensions of a synthetic cavity model with an accuracy of about 95 percent. The method was applied to the inverted resistivity image of Qurnet Murai survey site. The resultant edges were compared with the results of a GPR profile acquired in the same location as the resistivity profile.

Figure 6a shows the inversion results from the second resistivity profile (P2). The resistivity values vary widely within the section. The surface layer, representing dry silty clayey soil, has a relatively high resistivity value of about 1500 ohm-m. The resistivity decreases with depth, reaching about 10 ohm-m in some regions due to higher moisture or salt content within the silty clayey soil. A relatively high resistive anomaly, having resistivity around 3000 ohm-m, is evident at a depth 1.52 m and offsets of 15 to about 20 m. The anomaly is probably caused by a buried cavity partially filled with silty clayey soil.

The Roberts' cross-gradient method was applied to the inverted resistivity image to locate the edges of the anomaly. After applying the Roberts' operator, the located edges indicate that the anomaly extends downward to the end of the section and has irregular shape. The anomaly vertex is located at depth

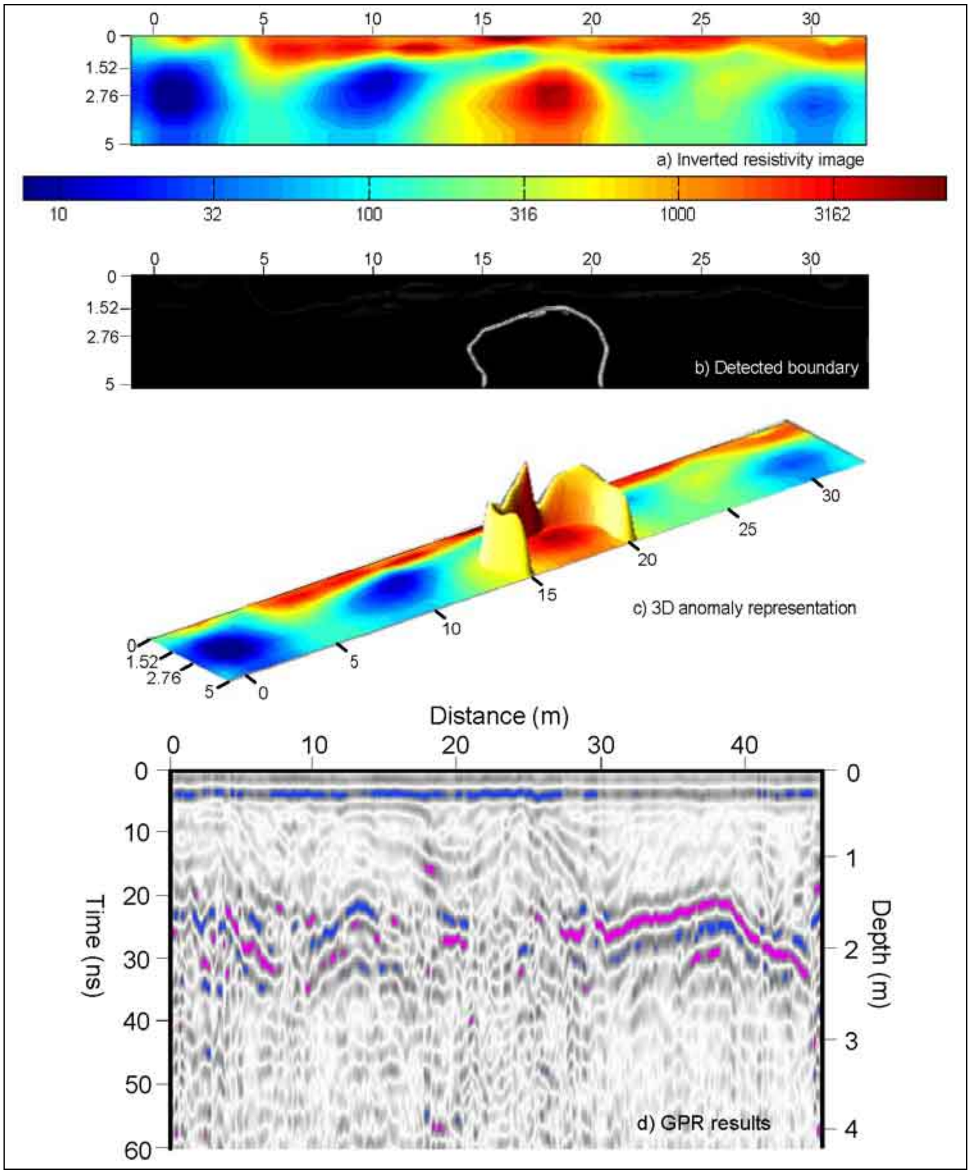


Figure 6. Comparison between the results of resistivity (a through c) and radar (d) profiles taken in the same location.

1.5 m and has a maximum width of 7 m (Figure 6b). A 3D view of the anomaly is also shown (Figure 6c).

Figure 6d shows the radar section acquired in the same location as the resistivity profile. The radar signals are highly attenuated in the top and bottom portions of the section (from 0 to about 20 ns, and from about 32 to 60 ns, respectively). High attenuation is observed in the low-resistivity clayey soils because the electromagnetic radar waves convert to electric current (Daniel, 1993). A relatively strong radar return appears in the zone between about 20 and 32 ns. Two hyperbolic anomalies are clearly shown in the radar section at a depth 1.5 m and at surface distances of 13.5 m and 38 m. The first hyperbolic anomaly appears at the same depth as the one detected from resistivity profile. However, the peak of the hyperbolic shape occurs at a surface location that differs from the located resistivity boundaries. This is because the starting point of measurements of both methods was different due to the irregularity of the ground surface (Figure 4). The second hyperbolic anomaly is not shown in the resistivity profile because the maximum length of the resistivity profile is 32 m, whereas this anomaly appears at a surface offset of 38 m. These radar anomalies are probably caused by hidden cavities.

Discussion and Conclusion

The results of the radar and resistivity surveys could be integrated to provide a detailed description of the shallow subsurface at archaeological sites and to image buried archaeological structures. However, these methods cannot provide accurate quantitative information about the buried features such as burial depth and dimensions. The penetration depth of the GPR method is limited in the presence of clayey soil and high salt content. The maximum depth achieved by this method at the survey site was about 2 m, so no buried features could be seen at greater depths. The method can provide accurate depth estimates of buried objects (by applying accurate wave propagation velocities), while it may just give a rough estimate of the lateral extent of objects (depending on the frequency, acquisition parameters, and subsurface geologic conditions). Inversion of the resistivity data using the smoothness-constrained approach produces models with smooth resistivity distribution. The resistivity anomalies are characterized by gradational boundaries that preclude determining the exact boundary location.

We suggest an image-processing approach that can be applied to resistivity images to extract extra information not available from the inversion process, such as burial depth and feature geometry. The Roberts' edge detector operator was applied to locate the edges of a synthetic model representing a single buried cavity. The detected edges were consistent with the true edges of the cavity model. Further, the method was applied to a real resistivity image acquired from Qurnet Murai survey site. The located edges were comparable with a radar profile acquired in the same location. The anomaly edges revealed in the resistivity data were clearly visible in the radar section at the same depth.

References

Barthel, K., 2006, 3D-Data Representation with ImageJ: Proceedings of the First ImageJ User and Developer Conference, p. 4.

Berard, B., and Maillol, J., 2007, Multi-offset ground penetrating radar data for improved imaging in areas of lateral complexity — Application at a Native American site: Journal of Applied Geophysics, v. 62, p. 167–177.

Chen H., and Huang T., 1998, Finite-difference time-domain simulation of GPR data: Journal of Applied Geophysics, v. 40, no. 1-3, p.139-163.

Dahlin, T., and Zhou, B., 2004, A numerical comparison of 2D resistivity imaging with 10 electrode arrays: Geophysical Prospecting, v. 52, p. 379–398.

Daniels, D., 1996, *Subsurface-Penetrating Radar*: London, The Institute of Electrical Engineers.

Di Fiore, B., and Chianese, D., 2008, Electric and magnetic tomographic approach for the geophysical investigation of an unexplored area in the archaeological site of Pompeii (Southern Italy): Journal of Archaeological Science, v. 35, p. 14–25.

Gonzalez, R., and Woods, R., 1992, *Digital Imaging Processing*: New Jersey, Prentice Hall.

Gunther, T., 2004, Inversion methods and resolution analysis for the 2D/3D reconstruction of resistivity structures from DC measurements: Ph.D. thesis, Freiberg University of Mining and Technology.

Loke, M., and Barker, R.,1996, Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method: Geophysical Prospecting, v. 44, p. 131–152.

Loke, M., and Lane, G., 2002, The use of constraints in 2D and 3D resistivity modeling: 8th EEGS-ES Meeting, Portugal.

Loke, M., Acworth, I., and Dahlin, T., 2003, A comparison of smooth and blocky inversion methods in 2-D electrical imaging surveys: Exploration Geophysics, v. 34, p. 182–187.

Nguyen, F., Garambois, S., Jongmans, D., Pirard, E., and Loke, M., 2005, Image processing of 2D resistivity data for imaging faults: Journal of Applied Geophysics, v. 75, p. 260–277.

Nixon, M., and Aguado, A., 2002, *Feature Extraction and Image Processing*: Newnes, Linacre House, Jordan Hill, Oxford OX2 8DP.

Olayinka, A., and Yaramanci, U., 2000, Use of block inversion in the 2-D interpretation of apparent resistivity data and its comparison with smooth inversion: Journal of Applied Geophysics, v. 45, pp. 63–82.

Parasnis, D., 1986, *Principles of Applied Geophysics*: New York, Methuen and Co., Ltd.

Quatro, R., Schiavone, D., and Diaferia, I., 2007, Ground penetrating radar survey of a prehistoric site in southern Italy: Journal of Archaeological Science, v. 34, p. 2071–2080.

Reynolds, J., 1997, *An Introduction to Applied and Environmental Geophysics*: John Wiley & Sons, Inc.

Telford, W., Geldart, L., and Sheriff, R., 1990, *Applied Geophysics*: New York, Cambridge University Press.

Mean Traveltime Curves: A Simple Tool for Traveltime Analysis, Velocity Tuning, and Anomaly Detection in 2D Transmission Tomographic Surveys

by J. L. Fernández-Martínez[*,1], L. M. Pedruelo-González[1], and J. W. Rector[2]
[1] Mathematics Dpt. Oviedo University, Spain
[2] Department of Civil and Environmental Engineering, University of California Berkeley
[*] Visiting Professor at the University of California Berkeley

Summary

Tomography methods belong to the class of non-destructive inspection techniques and are widely used in engineering applications. One of the main disadvantages of these methods is their data dependence, since data errors are often present in transmission tomography experiments. We present the mean traveltime curves (robust and non-robust descriptors) as a simple method to analyze and to interpret traveltime in 2D transmission tomography experiments. These curves also allow the inference of velocity models which can be taken into account in the resolution of the tomographic inverse problem. These curves admit an analytical expression for layered isotropic and elliptically anisotropic media explored using any kind of acquisition geometry. This method has been published recently in the programs MTCLAB and AMTCLAB, and can be easily implemented in a spreadsheet for use in field studies. We show the application of this method to real and synthetic data sets to illustrate the effect of geological heterogeneities, faults, intrusions, and cavities.

Introduction

Tomographic methods have been widely used in mining exploration (for example, Dyer and Fawcett, 1994), geotechnical studies and civil engineering (for example, Smith and Dyer, 1990), and hydrogeology (for example, Hyndman and Harris, 1996). These methods are aimed at inferring the velocity distribution of a real geological medium by means of the inversion of the measured traveltime data acquired from their boundaries. The numerical resolution of this inverse problem is iterative because the traveltime paths are unknown and depend on the velocity distribution of the geological medium. Thus, specific programs are needed for solving the traveltime inverse problem.

The mean traveltime curves (robust and non-robust descriptors) are conceptually much simpler, since they describe the variation of the main statistical parameters of the traveltime distribution for different source and receiver gathering subsets as a function of a gather index. The theoretical mean traveltime curves (Fernández-Martínez and others, 2006, 2008) assume that the geological medium can be divided in homogeneous layers, either isotropic or elliptically anisotropic, and constitute a simple method to accomplish a guided structured analysis of the data variability before inversion and to analyze traveltime quality in 2D acoustic transmission tomography experiments. Comparison of the theoretical mean traveltime curves to the empirical counterparts allow the inference of background velocity models that are valid at experiment scale and that can be taken into account in the resolution of the inverse problem as a regularization term. The robust mean traveltime curves (MTC) are more resistant to the presence of outliers, and thus they are preferred to infer the velocity model. These curves admit analytical expression for zonally isotropic and elliptically anisotropic media explored using any kind of acquisition geometry. We show the application of this method to a granitic medium (Febex Project, Nagra, Switzerland), to a sedimentary sequence showing how to detect a layer transition, and finally we perform synthetic modelling to show the effect on these curves on faults, dikes, and cavities.

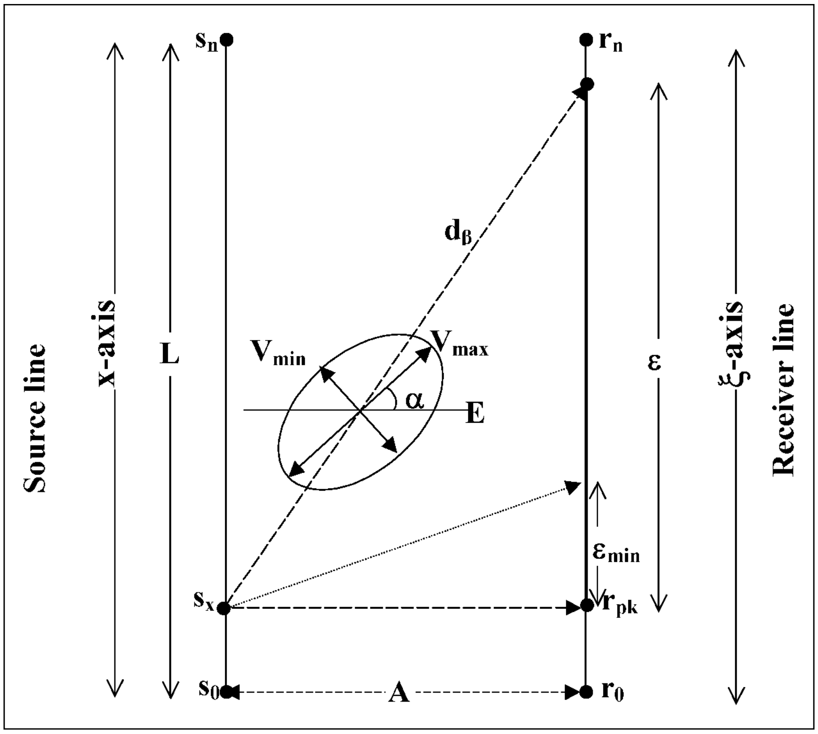


Figure 1. Rectangular recording geometry case. Variables involved in the zone analysis. Isotropy corresponds to the case $V_{min} = V_{max}$.

The Mean Traveltime Curves

Mean and Standard Deviation Curves

We illustrate the method for the simplest case, a geological domain, Ω (homogeneous and isotropic), explored using a rectangular recording geometry (sources and receivers along two parallel boreholes, Figure 1). Due to isotropy and homogeneity, traveltime variations in each source gather follow the hyperbolic law:

$$t(\xi; x_s) = \sqrt{t_0^2 + \frac{(\xi - x_s)^2}{V^2}}$$

where ξ describes the receiver position (with respect to the gather origin), V is the constant velocity of the medium, and t_0 is the minimum traveltime in each gather.

Fernández Martínez and others (2006) found the theoretical models for the mean time and the standard deviation of the traveltime distribution for different source and receiver gathering subsets. For rectangular acquisition geometry, these curves are symmetric with respect to the middle point of the gather line ($x_S = L / 2$). These curves have also been generalized for the case of an irregular acquisition geometry (Fernández-Martínez and others, 2006), which provoke them to lose their symmetry (Figure 2).

MTC analysis can be considered as a linear tomography method, since it uses straight approximation of seismic ray-paths (Berryman, 1994).

The Robust Mean Traveltime Curves

Also, using the same hypothesis (homogeneous and isotropic medium) it is possible to determine the p-percentiles of the traveltime distribution:

$$P\left(t(\xi; x_s) < m_p\right) = p \in (0,1)$$

Three cases arise:

$$0 < x_s < \frac{pL}{2} \Rightarrow m_p(x_s) = \sqrt{t_0^2 + \frac{(pL - x_s)^2}{V^2}}$$

$$\frac{pL}{2} < x_s < L - \frac{pL}{2} \Rightarrow m_p(x_s) = \sqrt{t_0^2 + \frac{(pL)^2}{4V^2}}$$

$$\frac{pL}{2} < x_s < L - \frac{pL}{2} \Rightarrow m_p(x_s) = \sqrt{t_0^2 + \frac{((p-1)L + x_s)^2}{V^2}}$$

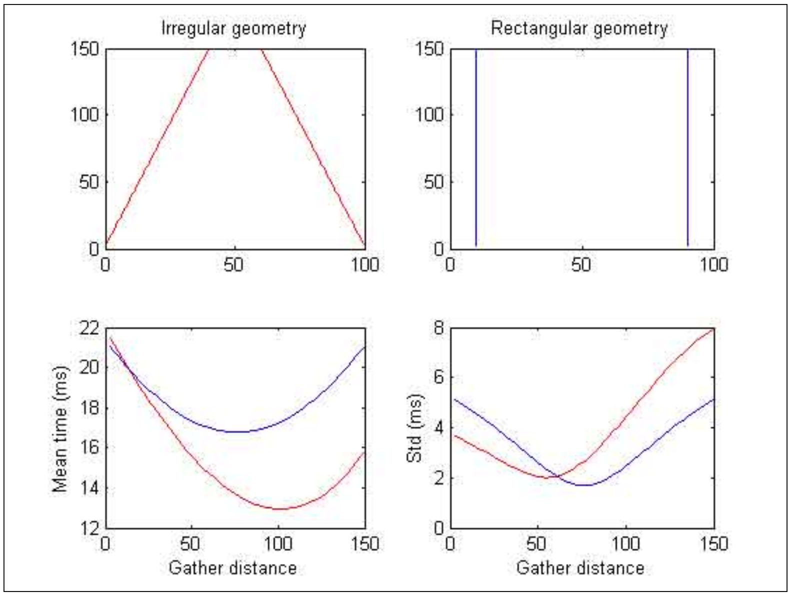


Figure 2. Comparison of mean traveltime curves for rectangular and irregular acquisition geometries.

The p-percentile curves are symmetric with respect to the middle of the gather line, and have a sill interval whose length is a constant value that is related to the isotropic velocity:

$$V = \frac{\sqrt{A^2 + \left(\frac{pL}{2}\right)^2}}{m_{pc}}$$

It is possible to determine the median, low, and upper quartile curves, and other curves related to the dispersion of the traveltime distribution, such as the inter-quartile range curve:

$$iqr(x_s) = m_{3/4}(x_s) - m_{1/4}(x_s)$$

and the minimum absolute deviation:

$$mad(x_s) = \frac{1}{L}\int_0^L \left| t(\xi; x_s) - m_{1/2}(x_s) \right| d\xi$$

Also, as is true for the mean and standard deviation curves, the so-called robust descriptors can be generalized to any kind of recording geometry (Figure 3a, b). The irregular configuration provokes asymmetry of these curves and the sill becomes a dipping straight line (Fernández-Martínez and others, 2008d).

Detecting Anisotropies: A Simple Geometrical Approach

The MTC method has been generalized recently to geological media showing an angular dependency of the velocity (Fernández-Martínez and Pedruelo-González, 2008b, c). Let us suppose that the recording geometry is rectangular, and assume that the velocity model describing the inspected geological medium has elliptical form given by the following parameters: the maximum velocity (V_{max}), the anisotropy direction (α), and the ratio of anisotropy ($\lambda = V_{min} / V_{max}$). In this case, the traveltime corresponding to a seismic ray with a direction angle β, measured counter-clockwise with respect to the V_{max} direction (Figure 1), satisfies the relation:

$$t_\beta(\varepsilon) = \frac{d_\beta}{v_\beta} = \frac{\sqrt{A^2 + \varepsilon^2}}{v_\beta}$$

where d_β is the distance between the source and the receiver (defining this direction), A is the minimum distance between the source and the line of receivers, ε is the distance between the hypothetical receiver located at the perpendicular line to the considered source and the receiver where the seismic ray arrives, and v_β is the velocity in the β direction. Furthermore, v_β can be written in terms of the anisotropic parameters as follows:

$$v_\beta = \sqrt{\frac{\lambda^2 \left(A^2 + \varepsilon^2\right)\left(1 + \tan^2 \alpha\right)}{2\varepsilon A \tan\alpha\left(\lambda^2 - 1\right) + \left(\lambda^2 \varepsilon^2 + A^2\right)\tan^2 \alpha + \left(\lambda^2 A^2 + \varepsilon^2\right)}}\, V_{max}$$

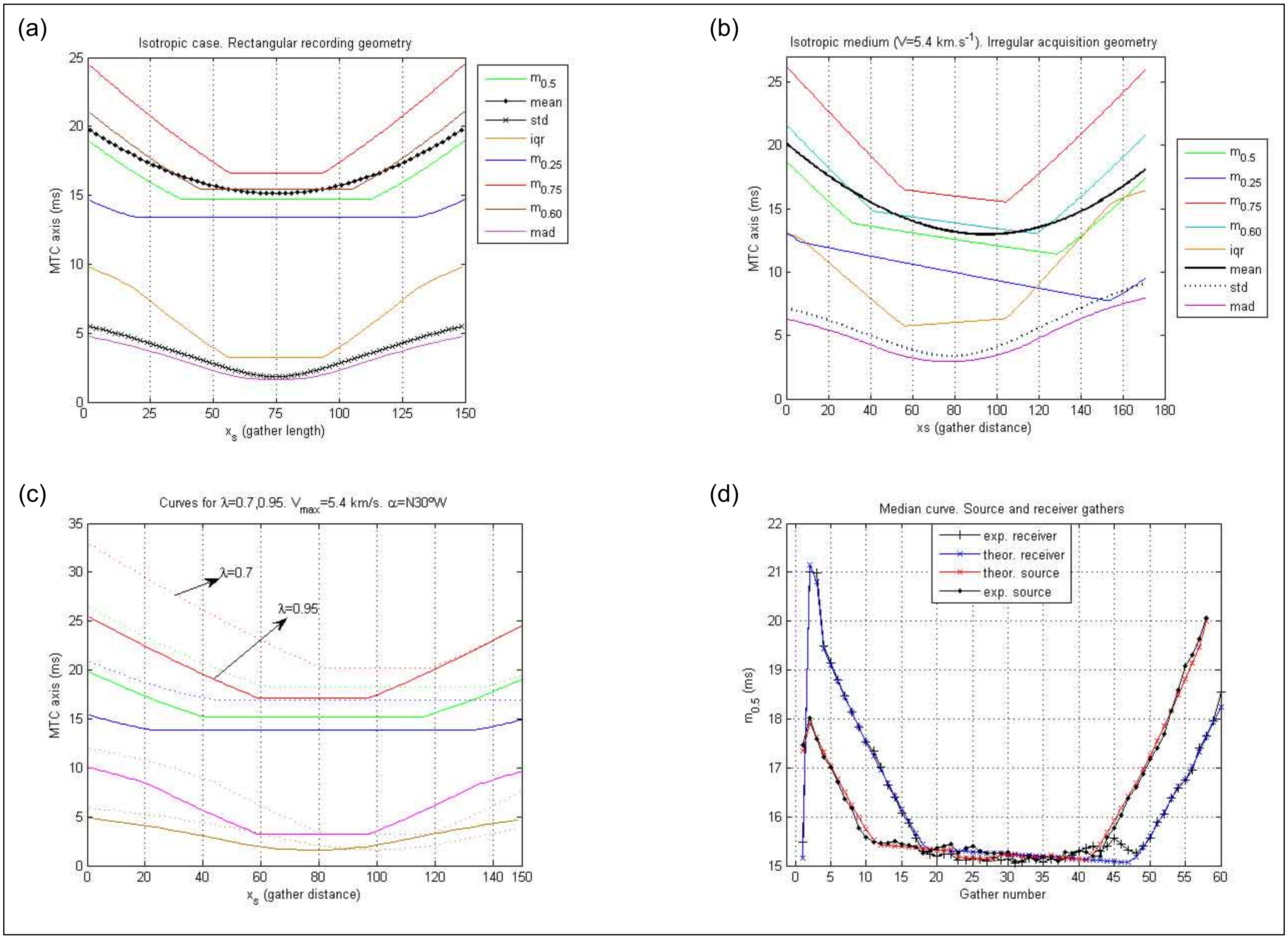


Figure 3. Robust mean traveltime curves: (a) isotropic case; (b) effect of the irregular recording geometry; (c) effect of the anisotropy parameters; (d) median curve for a granitic medium (Grimsel site) (Fernández-Martínez and others, 2008).

and thus,

$$t_\beta(\varepsilon) = \sqrt{\frac{\left(1+\lambda^2 \tan^2\alpha\right)\varepsilon^2 + 2A\tan\alpha\left(\lambda^2-1\right)\varepsilon + A^2\left(\lambda^2+\tan^2\alpha\right)}{\lambda^2\left(1+\tan^2\alpha\right)V_{\max}^2}} \qquad (1)$$

Mean traveltime curves are obtained by inserting the former expression (1) in the mean and standard deviation definitions. Robust mean traveltime curves can be deduced in the same way we have shown for the homogeneous isotropic media.

Anisotropic mean traveltime curves have several interesting properties. In particular, the degree of asymmetry of the anisotropic mean traveltime curves (displacement of the mean time and standard deviation minima from the middle of the gathering line) is related to the ratio and direction of anisotropy as follows:

$$\varepsilon_{\min} = \frac{A\left(1-\lambda^2\right)\tan\alpha}{\left(\lambda\tan\alpha\right)^2+1}$$

The approximate direction of anisotropy (α) can be visually estimated (northeast or northwest) by the displacement of the minimum of these curves with respect to the middle point of the gather line ε_{min}. Also, the least-squares fit of the empirical mean traveltime curves provides a simple method to estimate (at the pre-inversion step) a macroscopic elliptical anisotropic model that matches the empirical traveltime distribution.

Figure 3c shows how the robust MTC curves depend on the anisotropic parameters: anisotropy induces a vertical shift of the percentile curves towards higher values as the anisotropic ratio, $\lambda = V_{min} / V_{max}$, decreases (the medium becomes more anisotropic). The effect of the anisotropic direction is a lateral shift of the mean traveltime curves. For instance, for a source-left recording configuration, the shift is toward the right of the middle point of the line source if the anisotropy direction is northwest, and toward the left if the anisotropy direction is northeast. Finally, increasing the maximum velocity lowers the percentile values of the traveltime distribution.

The anisotropic parameters (λ, α, V_{max}) can be inferred from the experimental traveltime counterparts (Fernández-Martínez and Pedruelo-González, 2008). The method consist of dividing the domain into fairly homogeneous zones (isotropic or anisotropic), reducing the misfit between the experimental traveltime curves and the theoretical predictions in each gather, and solving the following optimization problems (one for each robust mean time curve in the source and receiver gathers):

$$\left(V_{\max}, \alpha, \lambda\right)^* = \min_{\left(V_{\max}, \alpha, \lambda\right) \in M} \left\| MTC - MTC^*_{\left(V_{\max}, \alpha, \lambda\right)} \right\|_2^2$$

M is the search space:

$$\begin{aligned} 0.8 &\le \lambda \le 1 \\ -90 &\le \alpha \le 90 \\ V_l &\le V_{\max} \le V_u \end{aligned}$$

Lower and upper bounds for the zones of analysis can be deduced from prior information or from the analysis of the isotropic mean traveltime curves themselves, as we have shown for the zonal isotropic case (Fernández Martínez and others, 2006). Due to the low number of parameters (3) and the presence of equivalent models and local minima, optimization is done in the real study case by means of a global algorithm. Figure 3d shows the fit of the experimental median curve in the source and receiver domains for a granitic medium (Grimsel site, NAGRA, the Swiss National Cooperative for the disposal of Radioactive Waste). As can be observed, the theoretical curves account for the variabilities observed in the experimental using a weak anisotropic velocity model. A more detailed description of this data set can be seen in Fernández-Martínez and Pedruelo-González (2008b).

Numerical models have also shown us that the upper quartile curve is the most sensitive to anisotropy. The other curves are not very different for parameters in the range of weak anisotropy. For instance, anisotropy only provokes a lateral shift in the inter-quartile range curve; the sill value is constant for any anisotropy ratio.

The method has given rise to open-source programs MTCLAB and AMTCLAB (Fernández-Martínez and others, 2006; Fernández-Martínez and Pedruelo-González, 2008b) developed at the Department of Mathematics of Oviedo University (Spain). This method can be implemented easily in a spreadsheet for field studies.

The Effect of Geological Heterogeneities

The Effect of a Layer Transition

In this section we show how to detect the foundation in a geotechnical study in the United Kingdom, done in collaboration with Zetica International Geoservices. The geological domain consisted of a horizontally stratified detritic sequence composed of 33 m of sand and lime having a very competent limestone at its base that produces a large acoustic impedance contrast. The recording configuration was rectangular: two parallel boreholes at a distance of 15.2 m with 55 sources and receivers at a spacing of 1 m. Figure 4 shows the empirical and fitted mean traveltime curves. A discontinuity can be observed at 35 m marking the transition to limestone.

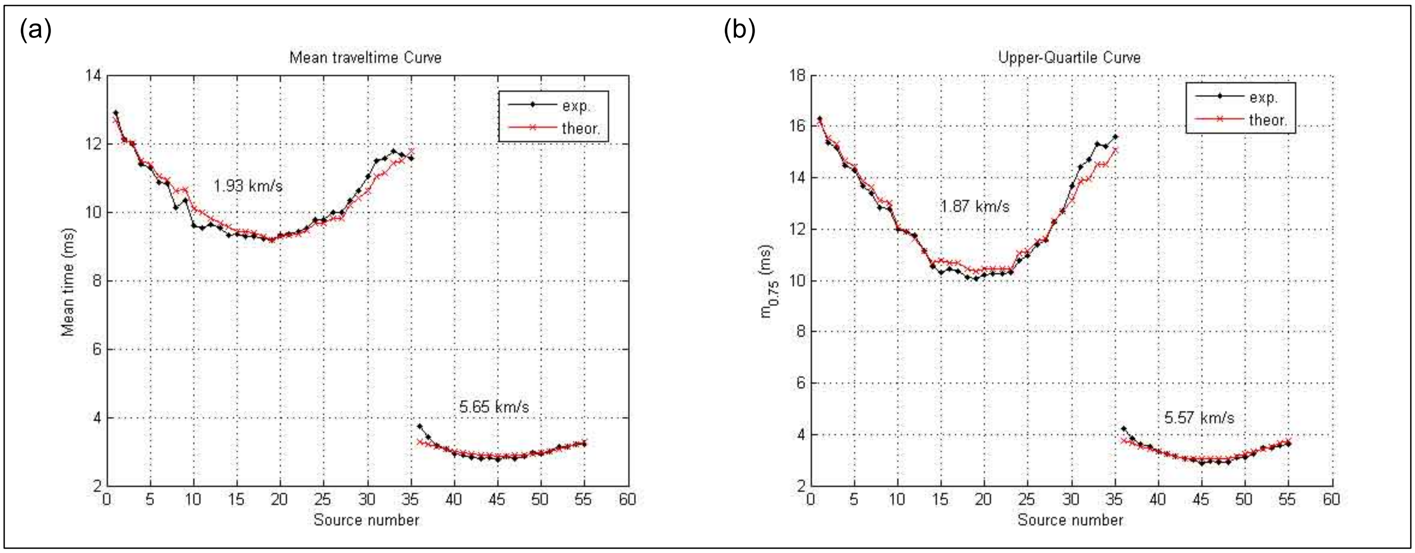


Figure 4. Experimental and theoretical mean traveltime curves. MTC provides a very coherent velocity model: 1.87 to 1.93 km/s for the detrital sequence and 5.57 to 5.65 km/s for the underlying limestone. The transition is well represented by a discontinuity on the mean and upper-quartile curves.

The Effect of Faults and Intrusions

Figure 5 shows the effects of a fault (low velocity anomaly) and one intrusion (high velocity anomaly) on several mean traveltime curves: mean, median, and inter-quartile range. It can be observed that robust descriptors localize very well the position of these geological features. The effect on the mean traveltime curves depends on the position and extent of these geological heterogeneities and on the background velocity difference.

The Effect of Voids and Cavities

Voids and cavities might be detected depending on their size and position in the geological domain. Basically they produce the same kind of effects shown for the faults, but in some situations their effect cannot be clearly differentiated on the mean traveltime curves. If the cavity is close to the line of sources or receivers, it can be easily identified through the standard deviation curve, which is affected along the gathers by the cavity. To perform these synthetic simulations, we have supposed that the geological medium has a background velocity of 4 km/s and the velocity in the cavity is 0.4 km/s.

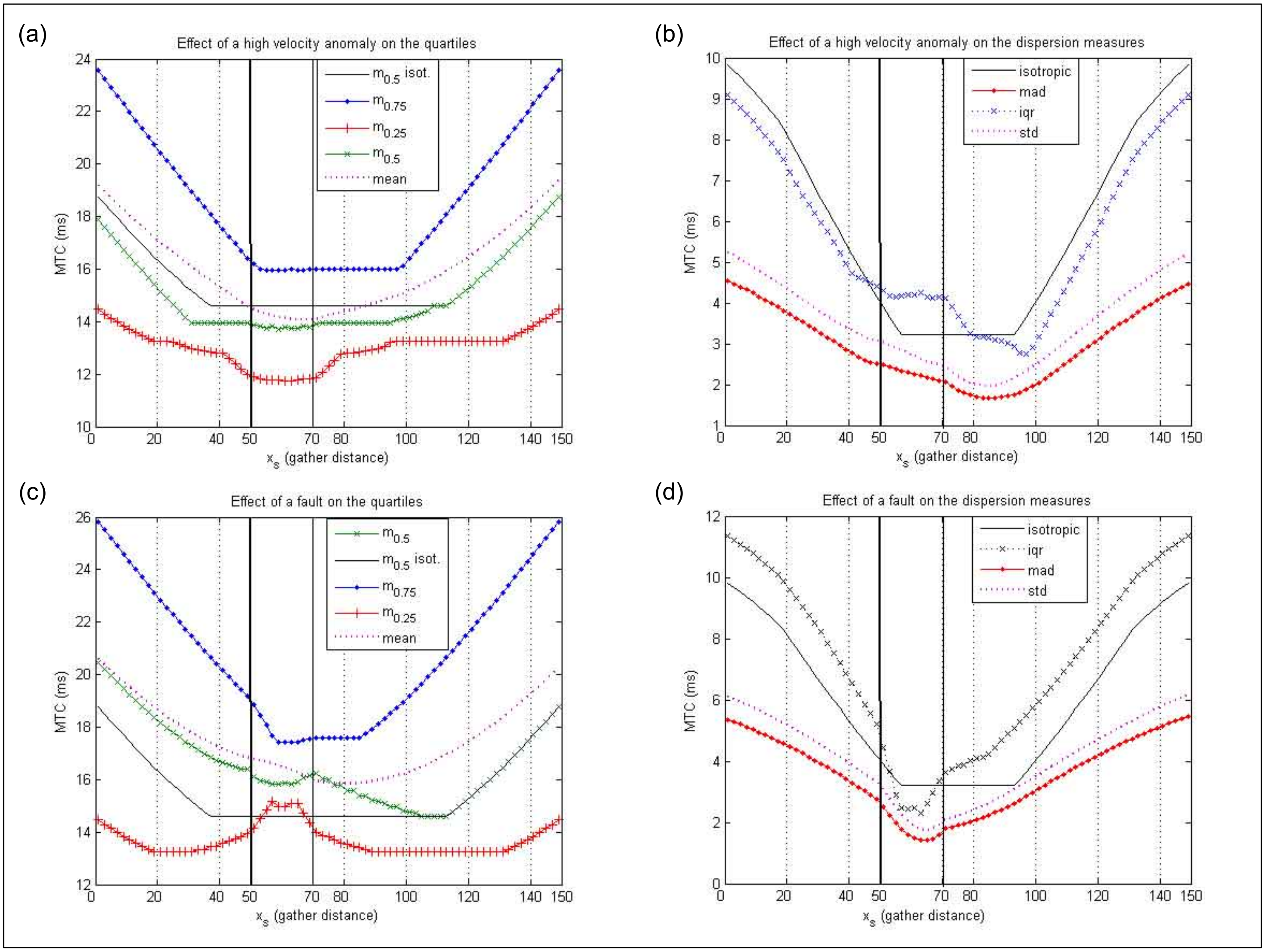


Figure 5. Effect of a fault and an intrusion on different mean traveltime curves.

Figures 6a and b show the results for a cavity 10-m high and 5-m wide, located close to the source gathers 27 to 33. The cavity affects all the mean traveltime curves, but its effect is better detected on the lower- and upper-quartile curves (Figure 6a). The effect of this cavity on the dispersion curves is better seen on the inter-quartile range.

Figures 6c and d show the effect of a cavity of 20-m high and 3-m wide, placed at the center of a geological domain (source and receiver gathers 32 to 43). The conclusions are similar to the case shown in Figures 6a and b. The effects on the mean curve (which is shifted toward highest mean traveltime values) and the standard deviation curve (which is laterally compressed) are not easy to interpret, but the robust curves are easier to interpret.

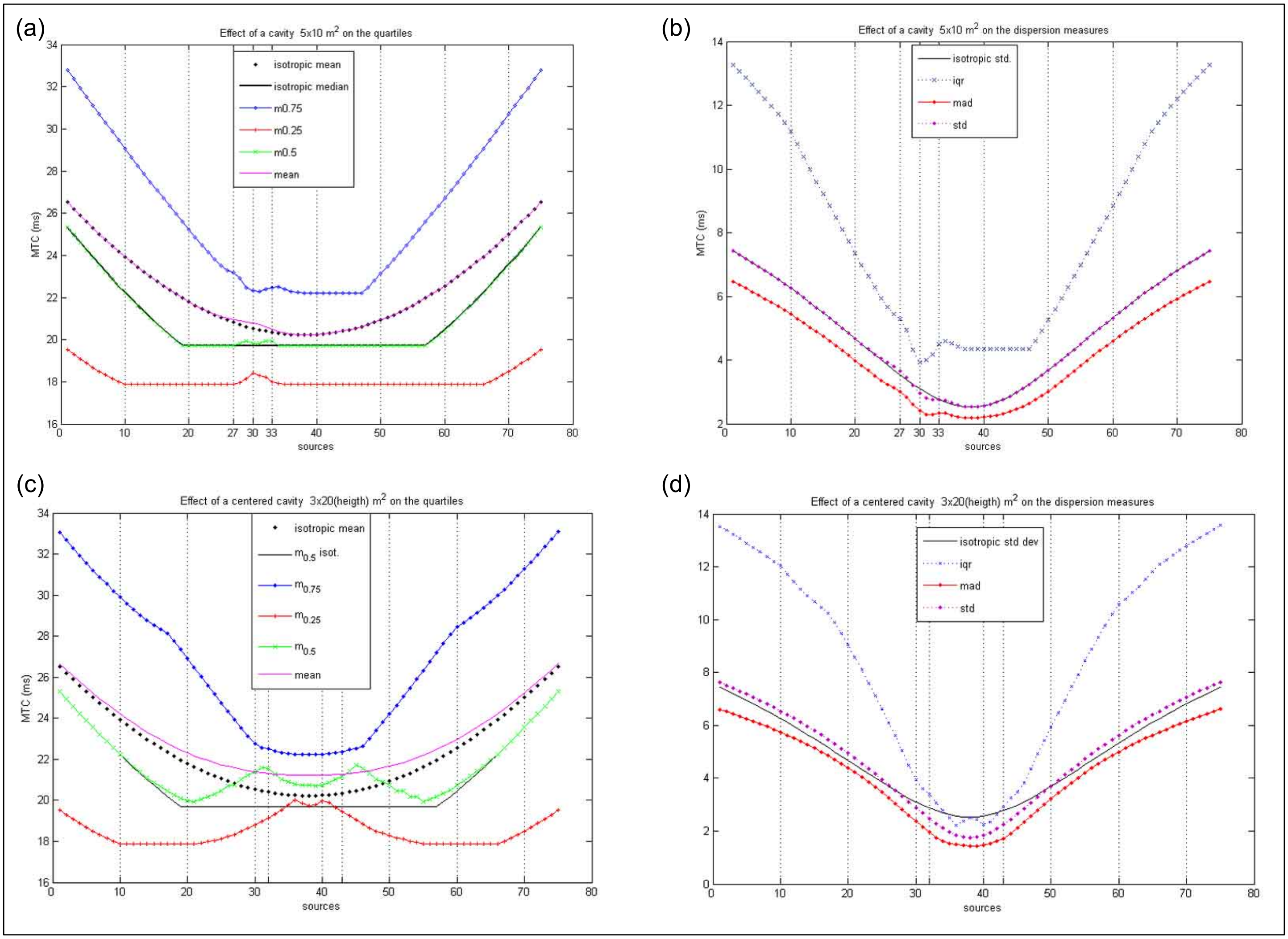


Figure 6. (a, b) Effect of a 5 m x 10 m cavity on the quartiles and on the dispersion curves. (c, d) Effect of a 3 m x 20 m cavity on the quartiles and on the dispersion curves.

Numerical simulations have also demonstrated the following attributes:

1. Narrow vertical cavities (with the larger dimension parallel to the line of sources or receivers) are well detected by the lower-quartile and inter-quartile range curves. These cavities are better detected if they are close to the gathering line (positions A or B) than if they are located on the center of the domain (positions C and D), as shown in Figure 7.
2. Narrow horizontal cavities (with the larger dimension perpendicular to the line of sources or receivers) are much more difficult to detect, but the observations in point 1 remain valid.
3. Cavities in positions C and D are harder to detect. Narrow horizontal cavities in position D are not detected. This result basically means that cavity detection depends on the number of rays passing through the cavity.

Finally, real experiments are affected by measurement noise, and the void detection becomes harder. Nevertheless, mean traveltime curves is an easy methodology to implement and can always be performed to complement other types of geophysical investigations.

Conclusions

We have presented mean traveltime curves as a simple method to perform traveltime analysis in tomographic experiments. This approach promotes a better understanding of the data variability before inversion and provides the geophysicist an approximate zonal isotropic or anisotropic model that can be used in the inverse problem as a reference model on the regularization term. Finally, interpretation of these curves may help detect geological heterogeneities, including layer transitions, faults, dikes, cavities, and angular anisotropy.

Acknowledgments

We would like to thank NAGRA and Zetica International Geoservices for the permission to use data sets to illustrate this method. This work benefitted from a sabbatical grant at University of California at Berkeley (Department of Civil and Environmental Engineering) given by the Secretaría de Estado de Universidades y de Investigación of the Spanish Ministry of Science and Innovation.

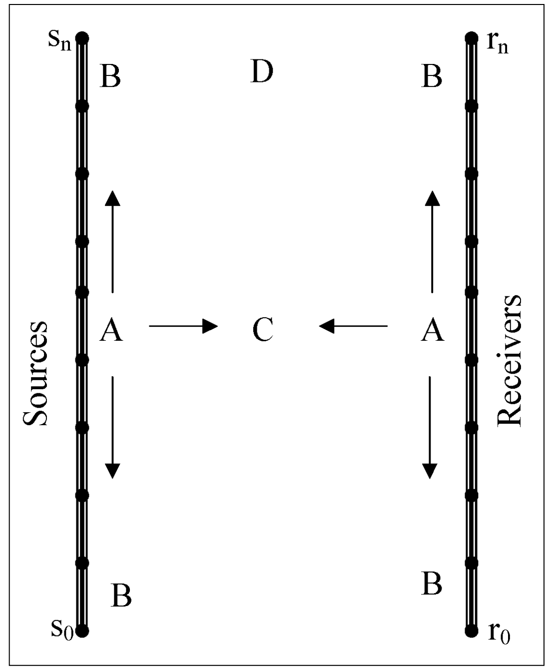


Figure 7: Positions of the cavities with respect to the lines of sources and receivers depending on the degree of difficulty to be detected (ranging from A to D).

References

Berryman, J. G., 1994, Constraints on minimum velocity variance for seismic traveltime tomography: Geophysical Journal International, v. 119, p. 689–692.

Dyer, B. C., and Fawcett, A., 1994, The use of tomographic imaging in mineral exploration: Exploration and Mining Geology, v. 3, no. 4, p. 383–387.

Fernández-Martínez, J. L., Fernández-Alvarez, J. P., and Pedruelo-González, L. M., 2006, Mean traveltime curves analysis: a method to improve understanding of data behaviour in 2-D transmission tomography at the pre-inversion stage: Mathematical Geology, v. 38-3, p. 343–374.

Fernández-Martínez, J. L., Fernández-Alvarez, J. P., and Pedruelo-González, L. M., 2008a, MTCLAB: a MATLAB®-based program for traveltime quality analysis and preinversion velocity tuning in 2-D transmission tomography: Computers & Geosciences, v. 34, no. 3, p. 213–225.

Fernández-Martínez, J. L., and Pedruelo-González, L. M., 2008b, Anisotropic mean traveltime curves: a method to estimate anisotropic parameters from 2D transmission tomographic data: Mathematical Geosciences, manuscript accepted for publication.

Fernández-Martínez, J. L., Pedruelo-González, L. M., and García-Gonzalo, E., 2008c. AMTCLAB: a MATLAB®-based program for traveltime analysis and velocity tuning in 2D elliptical anisotropic media: Computers & Geosciences, manuscript accepted for publication.

Fernández-Martínez, J. L., Pedruelo-González, L. M., and Rector, J. W., 2008d, Robust mean traveltime curves in 2D transmission tomographic surveys: Journal of Applied Geophysics, manuscript submitted for publication.

Hyndman, D. W., and Harris, J. M., 1996, Traveltime inversion for the geometry of aquifer lithologies: Geophysics, v. 61, no. 6, p. 1728–1737.

Smith, J., and Dyer, B. C., 1990, Seismic tomography as a tool for monitoring condition of a concrete dam: in Expanded Abstracts, Ground Engineering Group, Technical note 526, v. 89, p. 289–293.

Humanitarian Geophysics

by John M. Jackson and Catherine Skokan, Colorado School of Mines, Golden, Colorado 80401; jmjackso@mines.edu; cskokan@mines.edu

Introduction

In recent years, there has been a growing interest in humanitarian engineering. The names vary: service learning, community service, and charitable work, for example. Since 2003, with a grant from the Hewlett Foundation, Colorado School of Mines (CSM) has offered a minor in Humanitarian Engineering with an emphasis in groundwater, renewable energy, and sustainability. The goal of the program is to create a socially aware engineer that is knowledgeable of multiple technologies and their abilities to service people in need. At that point, the question of "how" arises: how is it best "to serve" or "to provide aid" to a group in need?

Many areas around the world are now in need of the world's most precious commodity: fresh water. With a widening gap between the world's rich and poor, it is the responsibility of the "haves" to use their technological knowledge to help the "have nots." The World Bank (2007) supports the idea that groundwater plays an important role in poverty reduction. Likewise, locating groundwater sources is thought to be one of the most important roles of the geophysicist in humanitarian projects (van Dongen and Woodhouse, 1994).

As the program grows and more experience is gained in service projects, education plays an even more important role. Education is not limited to the developed educating the undeveloped, but even more so, the undeveloped teach the developed countless concepts in sustainability in relation to technology and economics. Many case studies have shown that undeveloped groups have the social networks and co-operative strategies that can effectively diffuse technologies to the sustainable level (Ramaswami and others, 2007). The goals of the humanitarian engineer are threefold; one, use advanced technology to help and support the groundwater effort throughout the world; two, implement it in a sustainable manner (Mulder, 2006); and three, implement and open communication that will aid in a two-way educational effort. This paper demonstrates the progress of Humanitarian Engineering at Colorado School of Mines through three case studies and will also comment on future projects.

Figure 1. OhmMapper survey in Senegal.

Senegal

The population of 1200 in the rural community of Rao, about 19 km south of St. Louis in northern Senegal, is sustained by agricultural activities mostly in growing purple onions. In Rao, over-pumping of wells led to water-table drawdown. Because the village and their wells are so close to the ocean, some wells have experienced salt-water intrusion and contamination. Salt-water intrusion is becoming a critical problem in coastal areas worldwide. It was originally planned to use DC resistivity to map the depth to water table and to the saltwater lens in the onion fields of the village of Rao. However, due to the dry surface sand, there was a high contact resistance with the electrodes. Although methods are available to lower this contact resistance, an alternative method was used which involved capacitive coupling instead. The Geometrics OhmMapper system measures the electrical properties of rock and soil without cumbersome galvanic electrodes used in traditional resistivity surveys. The data collected are similar to dipole-dipole resistivity data. To map the water table with a minimum depth of 8 m, a dipole spacing of 10 m with an "n" of 4 was used (Figure 1). An inversion program, RES2DINV, was used to interpret the data. The data (Figure 2) show the low resistivity of the salt water lens as shallow as 10 m (Skokan, 2005).

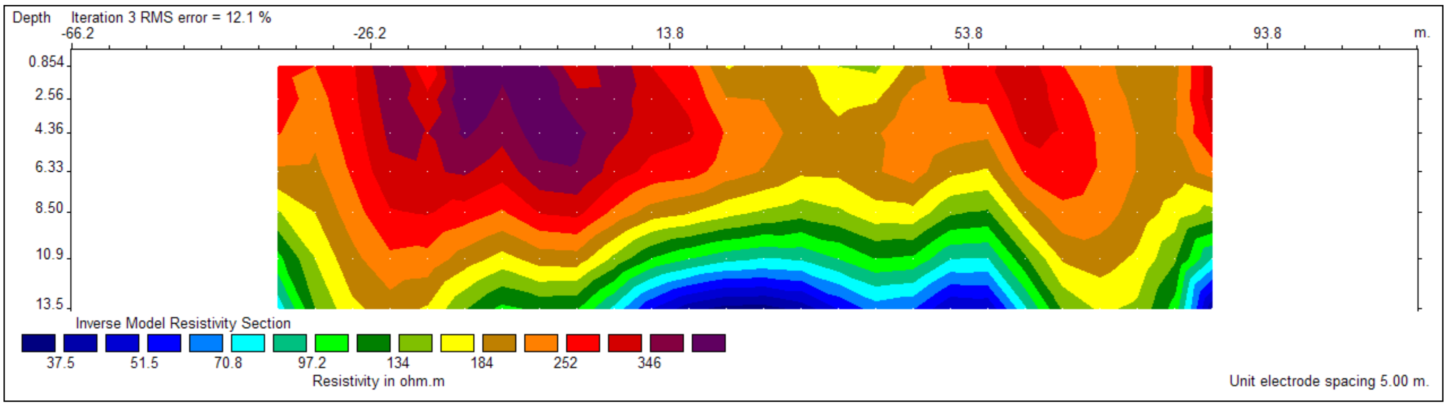


Figure 2. Sample inverted resistivity profile from Rao, Senegal showing the low-resistivity zone caused by salt water (Skokan, 2005).

The village dug a well to a depth of 8 m based upon the data. Along with the geophysical survey, the civil and mechanical engineering students designed a drip irrigation system from the well. Because of the availability of fresh water and the drip irrigation system, the village farmers were able to expand their crops to include cabbage and tomatoes. This variety of crops allowed more income to the village.

Honduras

Colinas de Suiza is located within the municipality of Villanueva in the State of Cortez at the southern portion of the Sula Valley in north-central Honduras. In October 1998, Hurricane Mitch hit Honduras and dropped more than a half a meter of water in 36 hours. This had devastating flooding effects on the rivers and low-lying areas. More than 3000 people died and nearly 9000 people were missing from Honduras alone. As a result of this disaster, many of the survivors who lived in the low-lying areas sought higher ground to live. Colinas de Suiza is a village of 10,000 people arranged on a hillside overlooking the Sula Valley. The people are poor, with average incomes of $6 US per day. Currently, they pay just over $1 for a 55-gallon drum of water delivered by truck (Figure 3). An average family will use three 55-gallon drums of water per day. The people are paying one half of one person's income for water.

Due to these increasing water needs, the village wished to drill a well near another village's pre-existing well. The issue to be solved through groundwater mapping was how deep can the second well be drilled. The near-surface water is contaminated by improper disposal of sewage. Deeper wells often have a greater chance of providing a clean water supply. A dipole-dipole, direct-current resistivity survey was undertaken to help define the depth and extent of the water table. Knowing that the present well is drawing water from an 80-m depth, it was desirable to make measurements to a depth of at least 100 m. A Syscal Pro multichannel resistivity system was chosen for the task because of its ease of operation and depth capabilities. For the Honduras survey, the maximum 96 electrodes were placed at 5-m spacings. A dipole-dipole, roll-along configuration with a maximum n of 7 was programmed for spacings of 5, 25, and 50 m. Figure 4 shows the electrode array and depth of investigation for the 0.5-km line. Results indicate an overall low resistivity due to high clay content and a saturation of water from near the surface to the depth of investigation. This has allowed the placement of a deeper well than the 80-m present one (Skokan and Munoz, 2006). A piping system is being completed to supply water for the village from the well.

Figure 3. A water delivery truck, Colinas de Suiza, Honduras.

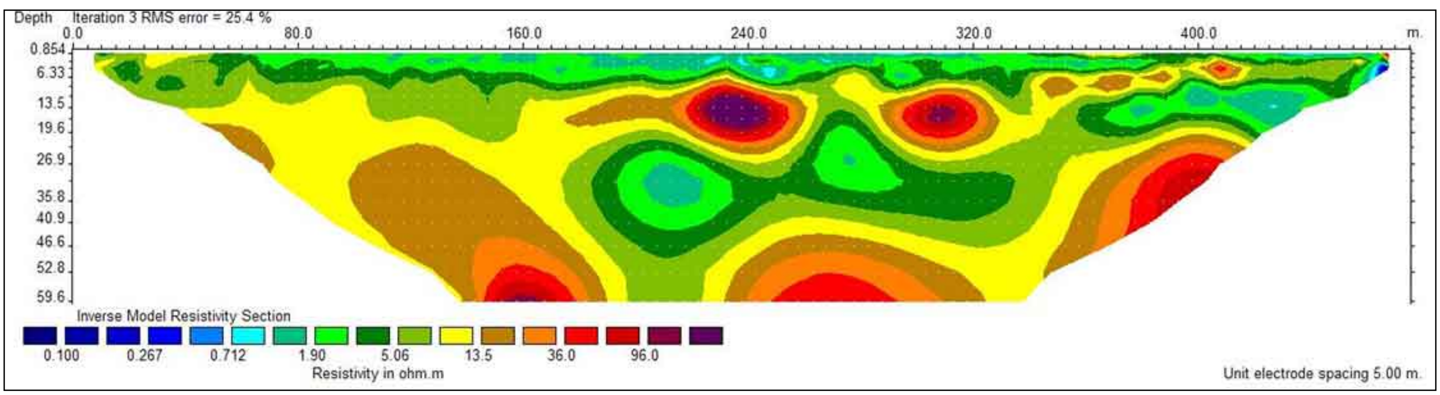


Figure 4. Resistivity data from Colinas de Suiza well site (Skokan and Munoz, 2006).

Uganda

Through the Humanitarian Engineering program at the Colorado School of Mines, a working relationship was formed with St. Denis, a secondary school in Makondo, Uganda. St. Denis is located approximately 400 km southwest of Kampala, Uganda. Because the number of students is growing, water demands have outgrown the supply. Currently, the water supply at St. Denis must accommodate 220 students, 16 teachers, and 10 workers. This leads to a consumption of 270,000 liters/term with 3 terms/year. These numbers are expected to at least double in the next two years as the school's population grows (Lutaaya, 2007). In this region, there are two wet seasons and two dry seasons. During the rainy seasons, the school can collect enough water to supply the students. However, during the dry seasons, the school struggles to meet the water demand. During these times, students must walk 2 km round-

Figure 5. Children collecting water from a community well near the St. Denis school in Makondo, Uganda.

trip to collect water from a community well (Figure 5) that frequently has long lines for its use (Jackson, 2008). Additionally, at least one well was cited as having contamination.

Based on this preliminary information, a DC resistivity survey was chosen as the most efficient method for collecting data. The goals of the survey were to (1) locate the water table and (2) determine if the groundwater is contaminated. Dipole-dipole and Schlumberger sounding arrays were placed in three areas using the Advanced Geosciences, Inc. (AGI) Supersting Earth Resistivity and IP Meter. The data were analyzed using 1-D and 2-D inversions. The resulting inversions located the water table at all three locations and suggested a layer of contaminated water in a perched aquifer in one area (Figure 6).

During the field investigation, the process of education and sustainability began. The engineers shared the theory and practicality of their technology while the Ugandans shared their concepts and goals of sustainability (Figure 7). Rather than just a service project, an attempt was made for the Ugandans to

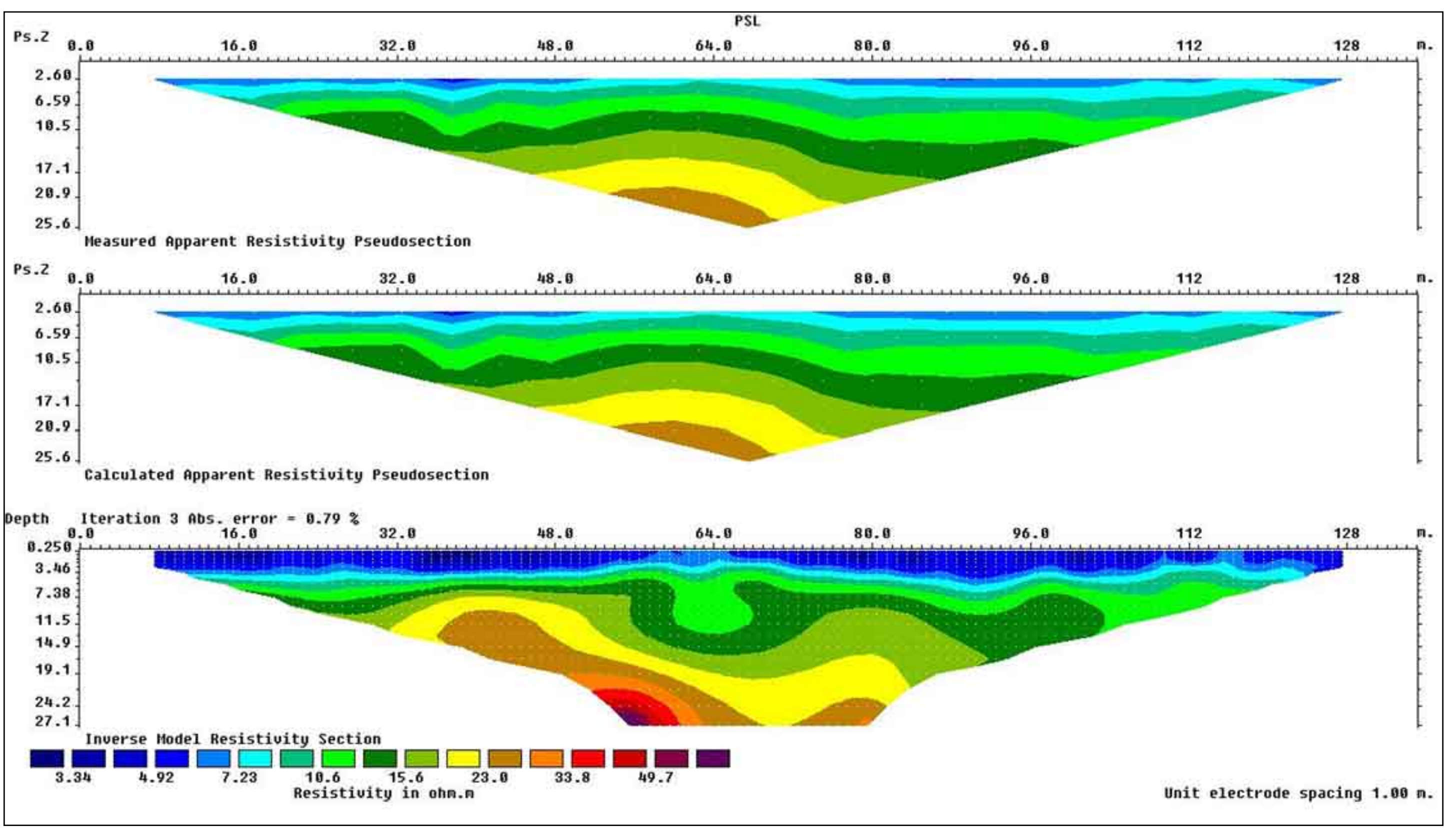


Figure 6. 2-D inversion of Schlumberger sounding data (Jackson, 2008).

Figure 7. (above) Discussing the theory of ground water mapping. (right) St. Denis School representative helping with the geophysical survey.

take ownership. By educating them on the theory, they understood what the goals were. By allowing and encouraging the community to help with the data collection, residents were able to take ownership and feel proud.

Future Work

The Humanitarian Engineering program is starting two new projects. The first is an add-on to the ongoing project in Honduras. There are ever-increasing water needs in the area and future wells are planned. Because of the threat of salt-water intrusion, geophysics must be used in every area planned for a future well. Also, there are plans for CSM students to develop technology that the non-geophysicist can use and understand. The purpose of such technology would be for the locals to have real-time knowledge if they are over-pumping and salt-water contamination is threatening their wells. Other mountain villages of Honduras have need for water as well. Often, the village is located in a volcanic region where the water supply may be fault- or structure-controlled, making the location of wells even more difficult. We hope that geophysics will help choose better locations for new water wells.

The second project is in Gulkana, Alaska and is proof that humanitarian needs are not limited to developing countries. In Gulkana, twenty seniors have worked on the design of a recreational vehicle (RV) park for an Athabascan tribal community. The community has an 80 percent unemployment rate and needs a source of income. Development of tribal lands into an RV park would provide jobs for the community and offer a central location for social and governmental gatherings. For the RV Park to succeed, a water distribution system is needed. However, when wells were drilled, one well was flowing at a substantial rate while the other was dry. Due to complicated local geology, high clay content, and volcanics, a complex geophysical survey and assessment must be made to understand the underground water system. To ensure success, a joint effort between engineers, geophysicists, and the Athabascan tribe must be made.

Conclusion

Through the Senegal, Honduras, and Uganda case studies, it is clear that the Humanitarian Engineering program at Colorado School of Mines is succeeding in helping in the worldwide groundwater effort. Efforts at using advanced technology, educating students, educating the developing world, and promoting sustainable development are all being met. The Humanitarian Engineering program would like to encourage you to consider what you can do to achieve the same goals and even further the progress being made. Humanitarian projects can be easy, successful, economical, and rewarding.

Acknowledgments

We would like to acknowledge David Munoz, director of the Humanitarian Engineering program at the Colorado School of Mines for the support through the Hewlett Foundation for these projects. Thanks also to Geometrics for their loan of the OhmMapper equipment. Additional thanks to Heritage Geophysics for the Syscal Pro Resistivity system.

References

Jackson, John, 2008, Geophysical report: groundwater investigation for St. Denis Secondary School, Makondo, Uganda: submitted for publication.

Lutaaya, Charles, Headmaster at St. Denis, Email Communication, May 11, 2007.

Mulder, Karen, editor, 2006, *Sustainable Development for Engineers*: Greenleaf Publishing.

Ramaswami, A., Zimmerman, J. B., and Mihelcic, J.R., 2007, Integrating developed and developing world knowledge into global discussions and strategies for sustainability: 2: Economics and governance: Environmental Science & Technology, v. 10.

Skokan, C., 2005, Geophysics and its application to humanitarian engineering – a groundwater example in Rao, Senegal: SAGEEP, Atlanta, Georgia.

Skokan, C., and Munoz, D., 2006, A groundwater study in Colinas de Suiza, Villanueva, Honduras: SAGEEP, Seattle, Washington.

van Dongen, Pieter, and Woodhouse, Melvin, 1994, Finding groundwater: a project.

Manager's guide to techniques and how to use them, World Bank Water and Sanitation Program.

World Bank, 2007, *Groundwater Resource Development in Minor Aquifers*: World Bank Briefing Note Series No. 13.

FastTIMES publishes contributions from societies and individuals with an interest in near-surface geophysics. Representatives of the Society of Exploration Geophysicists Geoscientists Without Borders program and Boise State University contributed the items below. Contributions from others are always welcome.

Geoscientists Without Borders Announces the First Projects Selected Under the Society of Exploration Geophysicists' New Program

India and Thailand will be the sites for the first two projects sponsored by the new Geoscientists Without Borders program. This exciting program, launched in early 2008, applies geophysical technology to the needs of people from all areas of the globe through projects designed to tangibly impact the community around them. Much work has gone into launching the program and the SEG Foundation is pleased to announce the first projects selected for award under the Geoscientists Without Borders program.

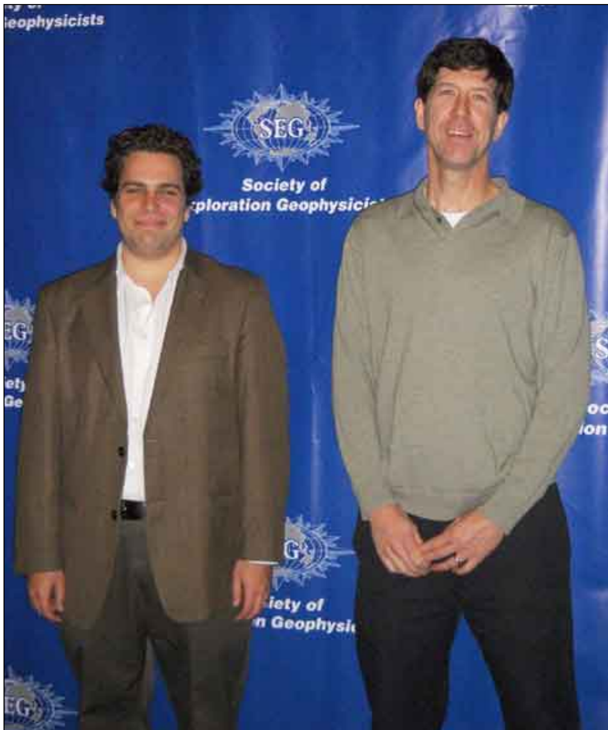
Chairman of the SEG Foundation Board of Directors, Gary Servos, described both the effort and the excitement of the announcement.

> *"Geoscientists Without Borders was the dream of passionate committed individuals in SEG, brought into reality with the key founding investment by Schlumberger. Keep your eye on this program because this is just the beginning and I am proud to be a part of it."*

As Servos stated, one of the early investments in the SEG Foundation's Advancing Geophysics Today – Inspiring Geoscientists for Tomorrow campaign was made by Schlumberger to establish the program in late 2007. Both projects selected will carry the mission of this new program forward into action in 2009. Joining universities and their students with communities in two foreign countries, the projects demonstrate the useful and often critical use of geophysics to assist communities with significant needs for such basic resources as fresh water.

Conducting a resistivity survey in India.

One of the initial projects will address the severe water crisis in rural India. Clemson University and the Foundation for Ecological Security (an India non-profit organization) will use electromagnetic induction to map soil moisture and shallow aquifers in the Salri watershed in the State of Madhya Pradesh, India. The scarcity of fresh water is a longstanding problem in central India that impacts the health, productivity, and quality of life for millions of people. Although the annual rainfall for the area is between 45 and 60 inches per year, most of it falls in only three months. The goal of this project is to increase the water supply through water capture, storage, and usage management. Geoscientists



Grant recipients (left) Dr. Stephen Moysey of Clemson University and (right) Dr. Lee Liberty of Boise State University.

Without Borders will provide tools and knowledge that will assist villagers in making water management decisions that will favorably impact water supply throughout the year. Dr. Stephen Moysey of Clemson University and Dr. Rangoori Ravindranath of the Foundation for Ecological Security will lead the efforts.

Under the second project, three distinct humanitarian efforts will take place in northern Thailand encompassing efforts to (1) mitigate earthquake hazards, (2) address water quality issues, and (3) preserve cultural heritage through archaeological mapping. Seismic, ground penetrating radar, electrical, gravity, and magnetic methods are to be used to address geotechnical problems in Chiang Mai, Thailand. Boise State University, in partnership with Chiang Mai University in Thailand, will advance humanitarian geophysics in Southeast Asia through a student-based approach, by teaching students geophysical skills that can be used in their home regions.

Undergraduate and graduate students, as well as professionals and teachers, will gain hands-on experience with geophysical data acquisition, processing, and interpretation, creating reports that address local environmental and engineering problems. Leading the effort are Research Scientist Lee Liberty, Dr. Kaspar Van Wijk, and Dr. Spencer Wood of Chiang Mai University (retired from Boise State University), and Dr. Fongsaward Singharajwarapan and Dr. Siriporn Chaisri, of Chiang Mai University, Thailand.

About the SEG Foundation

The SEG Foundation is a 501(c)(3) charitable not-for-profit organization that supports the educational mission of SEG. With a mission to advance geophysics today and inspire the geoscientists of tomorrow, the SEG Foundation supports many grant programs: scholarships, travel grants, field camp support, and projects of special merit. The Geoscientists Without Borders Committee expects to award projects twice each year. Go to the SEG website at *www.seg.org* to look at all the opportunities to participate in SEG member programs and SEG Foundation grant programs.

Water well within ruins, Thailand.

About SEG

The Society of Exploration Geophysicists, the international society of applied geophysics, is a not-for-profit organization that promotes the science of geophysics and the education of applied geophysicists. SEG fosters the expert and ethical practice of geophysics in the exploration and development of natural resources, in characterizing the near surface, and in mitigating Earth hazards. The Society, which has 30,000 members in 130 countries, fulfills its mission through its publications, conferences, forums, web sites, and educational opportunities.

For more information, contact Rhonda Jacobs, SEG Grant Programs Manager, at +1 918 497 5598 or by email at rjacobs@seg.org.

Boise State University is First-round Recipient of SEG Foundation Geoscientists Without Borders Program

by Lee M. Liberty, Kasper van Wijk, Spencer Wood, Emily Hinz, and Dylan Mikesell, Department of Geosciences, Boise State University, Boise, Idaho 83725-1536

Boise State University (BSU) was selected as a first-round recipient of the SEG Foundation Geoscientists Without Borders program with a project titled "The advancement of humanitarian geophysics in Southeast Asia: a student-based approach." This new program applies geophysics to humanitarian and environmental projects around the globe. The BSU award will establish a field camp with Chiang Mai University (CMU) in northern Thailand for participants throughout Southeast Asia.

Based on the BSU/Colorado School of Mines geophysics field camp model, faculty and graduate students from the Center for Geophysical Investigation of the Shallow Subsurface (CGISS) at BSU will direct concurrent investigations at three field sites. Field-based data collection will include seismic, ground-penetrating radar, electrical, gravity, and magnetic methods. A one-week data analysis component will follow the one-week field phase, with a student-authored technical report summarizing the field methods, processing steps, and findings at each site.

Earthquake hazards field studies will examine the history and character of the active Mae Tha fault and potential for ground shaking within the adjacent Chiang Mai Basin. Hydrogeophysics field studies will include aquifer characterization to help track groundwater contaminants within the Chiang Mai Basin and archaeological field studies will map the extent and geophysical character of underdeveloped sites in northern Thailand. Results from each site will help address humanitarian concerns by working with government and university personnel.

The goal of a sustaining field camp to train the next generation geophysicists throughout Southeast Asia will begin in January 2009 with a visit to each field site for preliminary data collection and planning with CMU faculty. Applications for scholarships for the January 2010 field camp will begin during early 2009. Students proficient in English from qualifying institutions throughout Southeast Asia are eligible to apply. For more information, visit http://cgiss.boisestate.edu/gwb or email gwb@cgiss.boisestate.edu.

Coming Events

FastTIMES highlights upcoming events of interest to the near-surface community. Send your submissions to the editors for possible inclusion in the next issue.

ASEG's 20th International Conference and Exhibition

February 22–25, 2009, Adelaide, Australia

The 20th International Conference and Exhibition takes place in Adelaide, South Australia from February 22–25, 2009. It is being co-hosted by the Australian Society of Exploration Geophysicists (ASEG) and Petroleum Exploration Society of Australia (PESA). The conference theme is "Brighter, Deeper, Greener; Geophysics in a Changing Environment" which reflects not only changes in the natural environment but also the challenges facing the geoscientific community as we strive to operate with ever-changing expectations and targets. Never before has the management of our planet depended so much on what geophysics has to offer.

The number of technical papers received has been overwhelming; with a provisional program requiring five concurrent streams to fit in all the selected Technical papers and Plenary plus Keynote speakers. The technical program is currently over-subscribed with a waiting list still growing. Refer to this link for the latest details and program outline: http://www.sapro.com.au/ASEG/program.htm

Plenary speakers are **Eric Finlayson** and **David Knox**. Eric Finlayson is Head of Exploration for Rio Tinto, based in London. David Knox is Chief Executive Officer and Managing Director of Santos. Keynote speakers are **Craig Beasley**, **John Hughes**, **Peter Malin**, **Lucy MacGregor**, and **Max Meju**. Craig Beasley is Vice-President of WesternGeco. He was President of the SEG during 2004-2005 and is serving as the Chair of the newly formed SEG Committee for "Geoscientists Without Borders." John Hughes is a consultant geophysical operations adviser running his own company, having retired from corporate life in 2007 after 20 years as Santos' Chief Operations Geophysicist. Peter Malin is the Director of the Institute for Earth Science and Engineering, University of Auckland, Auckland, New Zealand. His research interests include borehole seismology for earthquake and geological investigations. Lucy MacGregor leads the R&D group of Offshore Hydrocarbon Mapping (OHM), and has over ten years' experience as a leading researcher in CSEMI and its application to the detection and characterization of fluids in the earth. She was one of the co-founders of OHM in June 2002. Max Meju is an expert in computational and applied electromagnetics. He wrote the book *Geophysical Data Analysis: Understanding Inverse Problem Theory and Practice*. He was awarded William Bullerwell Prize in 1996 and the Gerald W. Hohmann Prize in 2002.

In conjunction with the conference, the SEG will be holding their Distinguished Instructor Short Course (DISC) in Adelaide on Thursday, February 26, immediately following the conference. The 2009 DISC speaker, Patrick Corbett, will be leading the workshop titled "Petroleum Engineering: Integration of Static and Dynamic Models." Patrick was an EAGE Distinguished Lecturer in 1998 and an SPE Distinguished Lecturer in 1998–99. He was awarded the Wegener Medal by the EAGE in 2005 and has co-written two books (*Statistics for Petroleum Engineers* and *Geoscientists and Cores from the Northwest European Hydrocarbon Province*).

Online registration is available via the conference website at http://www.sapro.com.au/ASEG/registration.htm. For further information, please contact Sapro Conference Management (Attn: Rob Bulfield) on +61 8 8352 7099 or by email at aseg2009@sapro.com.au.

22nd Symposium on the Application of Geophysics to Engineering and Environmental Problems

March 29–April 2, 2009, Fort Worth, Texas

The Environmental and Engineering Geophysical Society (EEGS), general chair Doug Laymon, and technical chair Dwain Butler invite you to attend the 22nd Annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP) being held in the Renaissance Worthington Hotel in downtown Fort Worth, Texas. Fort Worth is a city filled with culture and western heritage and is known as the city "Where the West Begins." Fort Worth has much to offer and enjoy including the historical stockyards, great museums, exciting downtown, wonderful restaurants, and fun nightlife in Sundance Square. The SAGEEP 2009 theme is "Expanding Horizons for Near-Surface Geophysics."

We have a great technical program this year with more than 150 presentations and posters covering a wide range of subjects, including recent developments in near-surface methods, innovative uses of geophysics for challenging engineering and environmental problems, and many interesting case histories. We will also have several special sessions on topics such as **cavities and tunnels**, **agricultural geophysics**, **humanitarian water supply**, and a **special session sponsored by the NGWA**. We will also have a **student poster session**. New this year will be keynote sessions speakers. Short courses will expose attendees to state-of-the-practice geophysical techniques and allow for the refreshing of one's skills. Course topics are borehole geophysics, surface waves, GPR, and refraction tomography.

Back by popular demand for its second year are the Environmental & Engineering Geophysics University (EEGU) sessions. EEGU 2009 is a series of classroom-style sessions in which near-surface methods and their applications are presented non-technically for new students of the discipline, teachers, and managers or technical staff who are considering geophysics in an environmental or engineering investigation but wish to know more before proceeding. These sessions will be concurrent with the technical program and will be open to single- or multiple-day registrants.

This year's outdoor demonstration should be a well-attended event that will include demonstrations of state-of-the-art geophysical equipment and techniques at the historical Fort Worth Stockyards. The outdoor demonstrations will also be a combined event for students with a social time at Billy Bob's, (*www.billybobstexas.com*), "The Worlds Largest Honky Tonk."

You will not want to miss the EEGS Conference Evening. It will be held in the historical Ashton Train Depot, instrumental in the growth of Fort Worth. It will be a wonderful night in a great atmosphere with good music, drinks, food, friends, and colleagues (*http://theashtondepot.com*). Be sure to attend! Also reserve yourself a spot for the EEGS Luncheon where we will hear a presentation by this year's Early Career Awardee.

We are offering two field trips. The first, on Sunday, March 29th, will consist of a guided Segway tour of downtown Fort Worth. The second field trip, a walking tour on Wednesday, April 1st over an extended lunch hour, will include a lecture and tour of the Trinity River Project (*http://www.trinityrivervision.org/TRVWEB/Default.aspx*). The master plan for this project addresses such issues as the environment, ecosystems, flood protection, recreational opportunities, access to the waterfront, preserving green space, and urban revitalization based around the river.

An educational technical program, social and networking opportunities, and a chance to experience the city where the west begins are just some of the reasons not to miss SAGEEP 2009! For the latest information, visit the conference web site at www.eegs.org/sageep/index.html or contact SAGEEP 2009 General Chair Doug Laymon by email at doug.laymon@tetratech.com. So mark your calendar for March 29–April 2, 2009, register early, make your travel arrangements, and we will see you in Fort Worth!

Call for Papers, Near Surface 2009

The 15th European Meeting of Environmental and Engineering Geophysics is being organized by the Near Surface Geoscience Division of the EAGE for September 7–9, 2009 in Dublin, Ireland. Program information and proposed topics for which you are invited to contribute abstracts are available on the EAGE website at www.eage.org.

Recent Events

***FastTIMES** presents contributed summaries of recent events to inform readers who were unable to attend. As a service to others, please send the editors summaries of events you attend for possible inclusion in future issues.*

Krakow Near Surface Meeting Highlights Polish Mining Geophysics Expertise

by Henryk Marcak, Zenon Pilecki, and John Arthur

EAGE's Near Surface 2008, the 14th European Meeting of Environmental and Engineering Geophysics, took place in the historic town of Krakow, Poland's academic center. The conference was attended by some 250 participants and exhibitors from 35 countries.

The objective of the Near Surface annual conference is to promote the development and application of near-surface geophysical research in applied geoscience. At the 2008 meeting, as well as the coverage of the regular conference topics on the environment and engineering, some emphasis was put on issues in mining geophysics. This reflected one of the most important interests for geophysical development in Poland.

The Near Surface 2008 conference dinner was held underground in the Wieliczka salt mine within the Krakow Word Heritage area.

Overall, about 130 papers and posters were presented covering geophysical achievements in the field of civil engineering, environmental problems on mining and industrial terrains, archaeological sites, groundwater exploration and protection, detection of pollution and remediation monitoring, detection of sinkholes and cavities, slope stability studies, detection of natural and induced seismicity and, of course, applications in mining technologies. During the breaks in the program, delegates were able to sample the delights of Polish pastries while talking to representatives from the 29 organizations exhibiting their services. Unfortunately, unseasonable rain caused the cancellation of the planned field demonstrations.

There were some notable presentations given by keynote speakers. On the first day, Prof. Stanislaw Lasocki, from AGH University of Science and Technology in Krakow, discussed problems of statistical properties in the mining-related seismic process. Day two was headlined by a presentation on “Seismic methods to detect gas hydrate-bearing sediments” by Prof. José M. Carcione from Instituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) in Trieste. And on the last day, participants were treated to Dr. Jorge Herwanger from WesternGeco discussing rocks under stress and geomechanical monitoring using time-lapse seismic data.

Traditionally, four of the best SAGEEP papers are presented during a special opening session on Monday. Those presenting were Jianghai Xia from Kansas Geological Survey, John Williams from the U. S. Geological Survey, Jenny Upwood from Geomatrix Earth Science in the UK, and Michael W. Asten from Flagstaff GeoConsultants in Australia.

On Thursday, at the end of the conference, a field trip on seismology in coal mines allowed participants to get acquainted with the issue of rock burst threat in coal mines in Poland and the tasks and organization of geophysical mine divisions. There were visits to Ziemowit and Bobrek coal mines and the regional seismological observatory in the Central Mining Institute in Katowice. Lunch was enjoyed at a traditional Polish restaurant.

Field trip to a Polish coal mine.

The event was organized under the auspices of the EAGE Near Surface Geoscience Division in collaboration with the Faculty of Geology, Geophysics, and Environmental Protection at AGH University of Science and Technology. The AGH UST is the most prestigious technical institution of higher education in Poland. It was founded after the First World War. Over 34,000 students have the opportunity to study in 28 faculties with over 160 specializations each year. Thirty to forty geophysicists graduate each year from the Institute of Applied Geophysics. These students find employment, not only in companies collaborating with mining or directly in the mining industry in Poland, but also in geophysical and geological companies in countries all over the world. Some of them are employed by oil and gas enterprises such as Geofizyka Krakow and Geofizyka Torun prospecting in Poland and abroad. Some of them work in enterprises resolving environmental and engineering problems related to landslides, engineering structures foundation, including tunnels and mining excavations, recognition of near surface cavities, and weak zones of geological and anthropological origin or ground contamination.

With the continuing importance of mining in Poland, a very large group of geophysicists work on mining problems, both those occurring on the surface disturbed by mining and also underground dealing with mining processes. In many underground mines, continuous microseismological and seismoacoustic observations are routinely carried out. Results of the measurements are used mainly for rock burst risk assessment and estimation of the effectiveness of using preventative methods. Other geophysical methods such as seismic, geoelectric, GPR, and gravity are also used for this aim and also for recognition of geological features of mined deposits. On mining and post-mining terrains, geophysics is used to help resolve problems emerging from discontinuous deformation, ground vibrations caused by mining shocks, water contamination, and investigation of ground properties.

In addition to AGH University of Science and Technology, scientific research in the area of near-surface geophysical investigation is being developed at the Institutes of Polish Academy of Sciences in Warsaw and Krakow, and in the Central Mining Institute in Katowice and University of Silesia.

As well as its professional value, Krakow is a fascinating place to visit. Krakow is a modern university city full of historical monuments that make for an unforgettable atmosphere. The old town has been developing since 1257 and remains relatively unscathed by time and wars with one of the largest town squares in Europe. In 1978, UNESCO placed the historical architectural section of Krakow on the list of the 12 most precious world monuments. Krakow, the former capital of Poland, has a long history. In Medieval times the Gothic and Renaissance town was built surrounded by defensive walls. Wawel Royal Castle dominated the town and the presence of Polish royalty led to the establishment of Poland's first university, Jagiellonian University. Krakow's long history, layout, and distinguished architecture make a special place for Poles and attract millions of visitors from all over the world each year. The conference dinner was held underground in the Wieliczka salt mine, included within the Krakow World Heritage site. Over 700 years old, it is one of the extraordinary mining enterprises and a major tourist attraction.

The conference dinner was preceded by a guided tour through galleries that are still preserved as originally decorated by the miners. There are 17th and 19th century chapels, the most beautiful of which is St. Kinga's Chapel, carved out of a huge block of salt, and there are also some wonderful salt lakes. During the meal, delegates were enthusiastically entertained by the student AGH Representative Orchestra and the evening was suitably rounded off by much dancing!

The 14th Near Surface meeting was a great opportunity for geoscientists to get information related to geophysical research and development. It was also a good occasion to renew old and make new friendships, continuing the tradition of the community dedicated to dealing with environmental and engineering problems through a better understanding of geoscience.

Fully Funded PhD and MS Opportunities at Michigan State University

The Department of Geological Sciences at MSU invites applicants for competitive PhD and MSc research assistantships in Hydrogeophysics, Environmental Geophysics, and Hydrogeology. Projects include the imaging of root-zone moisture fluxes of biofuel crops, multidisciplinary studies of fluid flow and solute transport in heterogeneous aquifers, studies of density driven flow, and simulating the influence of land use and climate on water and nutrient fluxes.

The application deadline for Fall 2009 admission is January 15, 2008, but early applicants are encouraged for fellowship opportunities.

Visit the department website for program and application details (*http://geology.msu.edu/research.html*). Contact Dr. David Hyndman (*hyndman@msu.edu* — *http://hydrogeology.glg.msu.edu/*) or Dr. Remke Van Dam (*rvd@msu.edu* — *http://www.msu.edu/~rvd/ag/*) for more information.

Multiple Employment Opportunities at the U.S. Army Engineer Research and Development Center

The Geotechnical Engineering and Geosciences Branch (GEGB) of the Geotechnical and Structures Laboratory (GSL) at the U.S. Army Engineer Research and Development Center (ERDC) is announcing the need for additional geophysicists, geologists and geotechnical engineers. The ERDC is a consortium of seven laboratories headquartered in Vicksburg, Mississippi composed of approximately 2500 scientists and engineers. The ERDC is the research arm of the Army Corps of Engineers and performs science and engineering research and development for all of the Department of Defense as well as most other government agencies. We are looking to hire at all levels (BS, MS, PhD). If you are interested in potential employment, please respond with a resume and any questions that you may have. Additional information about the ERDC can be found at *www.erdc.usace.army.mil*.

Hydrogeophysics Special Section in The Leading Edge

by Richard D. Miller, Editorial Board Member, ***The Leading Edge*** (*rmiller@kgs.ku.edu*)

The Society of Exploration Geophysicists' magazine, ***The Leading Edge*** (***TLE***), publishes special sections each month highlighting emerging or active areas of applied geophysics. The near-surface community has an opportunity to enlighten the entire geophysical community on the high quality and innovative nature of their work. A special section on Hydrogeophysics is scheduled for the October 2009 issue of ***TLE***. The deadline for papers to be considered for the Hydrogeophysics special section is June 2009. If you have any comments, questions, or would like to submit a paper, please contact Rick Miller at *rmiller@kgs.ku.edu*.

Post-Doctoral Research Position, Engineering Geophysics Research Unit, UCD School of Architecture, Landscape and Civil Engineering

Applications are invited for a post-doctoral research position in the Engineering Geophysics Research Unit (EGRU) based in the Geotechnical Section of the School of Architecture, Landscape and Civil Engineering at University College Dublin. The position is funded for 30 months under an innovation partnership sponsored by Enterprise Ireland. The partner company is APEX Geoservices Ltd, a specialist engineering geophysics company based in Wexford.

School of Architecture, Landscape and Civil Engineering The School is engaged in research, and teaching on all aspects of buildings and civil engineering systems, see *www.ucd.ie/arcel*

Geotechnical Section The Section consists of two lecturers, eight researchers and one technician. It focuses on a wide range of geotechnical issues including embankment stability, foundation settlement, piled foundations, characterization of soft ground and peats, deep excavations in urban areas, and offshore geotechnics. Collaborative research is carried out with the Norwegian Geotechnical Institute, the Norwegian Public Roads Administration, TU Delft, the BRE, Hokkaido University as well as industry partners.

Engineering Geophysics Research Unit (EGRU) Current projects include the application of surface wave methods for foundation investigation in Irish and UK soils, investigation of railway embankment failures using seismics, resistivity and GPR, mapping of quick clays in Norway, development of techniques for non-invasive mapping of soil physical properties and characterisation of Irish tills using resistivity methods. The unit currently has one full-time post doctoral researcher, one Ph.D. student and three M.Sc. students. Funding is received from the Environmental Protection Agency, National Roads Authority, and Enterprise Ireland.

Job Description

Arising out of the recent approval of a Research Innovation Partnership, there is an opening for a post-doctoral researcher at the EGRU. It is envisaged that opportunities for further research and related funding will be generated during the course of the partnership. This is an ideal opportunity for a person with the vision and drive to participate in the development of a world-class engineering geophysics research unit.

Details of Post

The position will be based in UCD and covers the following topics:

- Use of surface-wave techniques for assessment of road pavements and railway ballast.
- Research into innovative methods of acquisition and processing of 3D geophysical data for application to engineering investigations.
- Development of 3D data inversion techniques and extraction of physical property information.
- Integration of physical property matrices with direct investigation information using GIS for assessment of rock excavatability and karst hazard.

The partnership has access to a full suite of modern geophysical equipment and a large database of related projects, both academic and commercial, as well as the laboratory facilities of the Geotechnical Section. Funding is available for equipment, site work, and attendance at conferences and seminars. Regular publications form part of the deliverables of the project. Salary range is €45,000 – 50,000 (non scale).

Duties and Responsibilities

- Carry out research in accordance with the objectives of the Innovation Partnership.
- Collaborate with other researchers in the School.
- Have regular progress meetings and reviews with the sponsoring company and funding agency.
- Publish research findings.
- Assist in administrative duties related to the project.

Requirements

Candidates should:

- hold a PhD in geophysics, physics, mathematics, computing, civil or geotechnical engineering,
- have a record of publications on relevant engineering geophysics topics,
- have practical experience in the engineering geophysics industry,
- be familiar with current trends and research in engineering geophysics,
- have strong mathematical and computational skills, and
- have good analytical, communications, and presentation skills.

Please send CV to: Mike.Long@ucd.ie by 5 p.m., January 5, 2009.

Join EEGS Now!

Environmental and Engineering Geophysical Society

EEGS
1720 S. Bellaire Street; Ste. 110
Denver, CO 80222-4303
Phone: (303).531-7517 Fax: (303) 820-3844
Email: staff@eegs.org

2009 MEMBERSHIP APPLICATION

Name: Dr./Mrs./Ms./Mr. ______________________________

Company/Organization: ____________________ Office Phone: ____________________

Title: ____________________ Fax: ____________________

Address: ____________________ Home Phone: ____________________

City: ____________ State: ___ Zip: ____ Country: ____________________

Email: ____________________ Website: ____________________

A. Individual Membership Dues Schedule: Select only one Membership Category.

Individual Memberships:

- ☐ $90 Individual Member
- ☐ $50 Student Member with JEEG Subscription (recent graduates may receive this rate for two years after graduation. Submit documentation of graduation date).
- ☐ $20 Student Member without JEEG Subscription (submit copy of current student ID).

A. Membership Dues Investment* ____________

B. Corporate Membership Dues Schedule: Select only one Membership Category.

Corporate Memberships:

- ☐ $ 650 Donor
- ☐ $2,350 Associate
- ☐ $1,800 Partner
- ☐ $3,950 Benefactor

B. Corporate Membership Investment* ____________

C. Mailing Lists:
EEGS occasionally makes the mailing list available to companies and associations in the industry. If you would like your name *withheld* from these mailings, please check this box: ☐

Payment Information:

☐ Check/Money Order ☐ Visa ☐ MasterCard ☐ AMEX ☐ Discover

Card Number: ______________________________ Exp. Date: ____________

Name on Card: ______________________________

Signature: ______________________________

Total Due $________

Make your check or money order (in US Dollars) payable to: EEGS.
Return this form with payment to: EEGS, 1720 S. Bellaire St., Suite 110, Denver, CO 80222, USA
Credit Card Payments can be faxed to EEGS at (303) 820-3844.

Questions? Call (303) 531-7517

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

Membership Information

EEGS welcomes membership applications from individuals (including students) and businesses. The membership application is available from the EEGS office or online at www.eegs.org.

Individual $90

Member receives annual subscriptions to ***JEEG*** and ***FastTIMES*** along with discounts for EEGS publications, SAGEEP registration, and other EEGS functions.

Student $50

Member receives annual subscriptions to ***JEEG*** and ***FastTIMES*** along with discounts for EEGS publications, SAGEEP registration, and other EEGS functions.

Student (without JEEG) $20

Member receives annual subscriptions to ***FastTIMES*** along with discounts for EEGS publications, SAGEEP registration, and other EEGS functions.

Corporate Benefactor $3,750

Member receives 2 individual memberships, 2 exhibit booths at SAGEEP, marketing inserts in SAGEEP delegate packets, a link on the EEGS website, listing in ***FastTIMES***, advertising discounts in ***JEEG***, ***FastTIMES***, and the directory.

Corporate Partner $1,800

Member receives 3 individual memberships, 3 registrations to attend SAGEEP, marketing inserts in SAGEEP delegate packets, a link on the EEGS website, listing in ***FastTIMES***, and advertising discounts in ***JEEG***, ***FastTIMES***, and the directory.

Corporate Associate $2,250

Member receives 2 individual memberships, 1 exhibit booth at SAGEEP, marketing inserts in SAGEEP delegate packets, a link on EEGS website, listing in ***FastTIMES***, and advertising discounts in ***JEEG***, ***FastTIMES***, and the directory.

Corporate Donor $650

Member receives 1 individual membership, 1 registration to attend SAGEEP, a link on EEGS website, and advertising discounts in ***JEEG***, ***FastTIMES***, and the directory.

Corporate Members

Corporate Benefactor

Aeroquest International Ltd.
www.aeroquest.ca

Geometrics, Inc.
www.geometrics.com

Corporate Partner

Your Company Here!

Corporate Associate

ABEM Instrument AB
www.abem.com

Advanced Geosciences, Inc.
www.agiusa.com

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

ALT: Advanced Logic Technology
www.alt.lu

Exploration Instruments LLC
www.expins.com

Foerster Instruments Inc.
www.foerstergroup.com

Fugro Airborne Surveys
www.fugroairborne.com

GEM Advanced Magnetometers
www.gemsys.ca

Geomar Software Inc.
www.geomar.com

Geonics Ltd.
www.geonics.com

Geophex, Ltd.
www.geophex.com

Geophysical Survey Systems, Inc.
www.geophysical.com

Geostuff
www.georadar.com

GISCO
www.giscogeo.com

Heritage Group Inc.
www.heritagegeophysics.com

hydroGEOPHYSICS, Inc.
www.hydrogeophysics.com

Interpex Ltd.
www.interpex.com

MALA GeoScience
www.malags.com

Mount Sopris Instruments
www.mountsopris.com

Petros Eikon Inc.
www.petroseikon.com

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

Scintrex
www.scintrexltd.com

Sensors & Software, Inc.
www.sensoft.ca

Terraplus Inc.
www.terraplus.ca

Zonge Engineering & Research Org., Inc.
www.zonge.com

Corporate Donor

Akron srl
www.akronservizi.it

Geogiga Technology Corp.
www.geogiga.com

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

Intelligent Resources, Inc.
www.rayfract.com

KD Jones Instrument Corp.
www.kdjonesinstruments.com

Northwest Geophysics
www.northwestgeophysics.com

Technos, Inc.
www.technos-inc.com