fast | times

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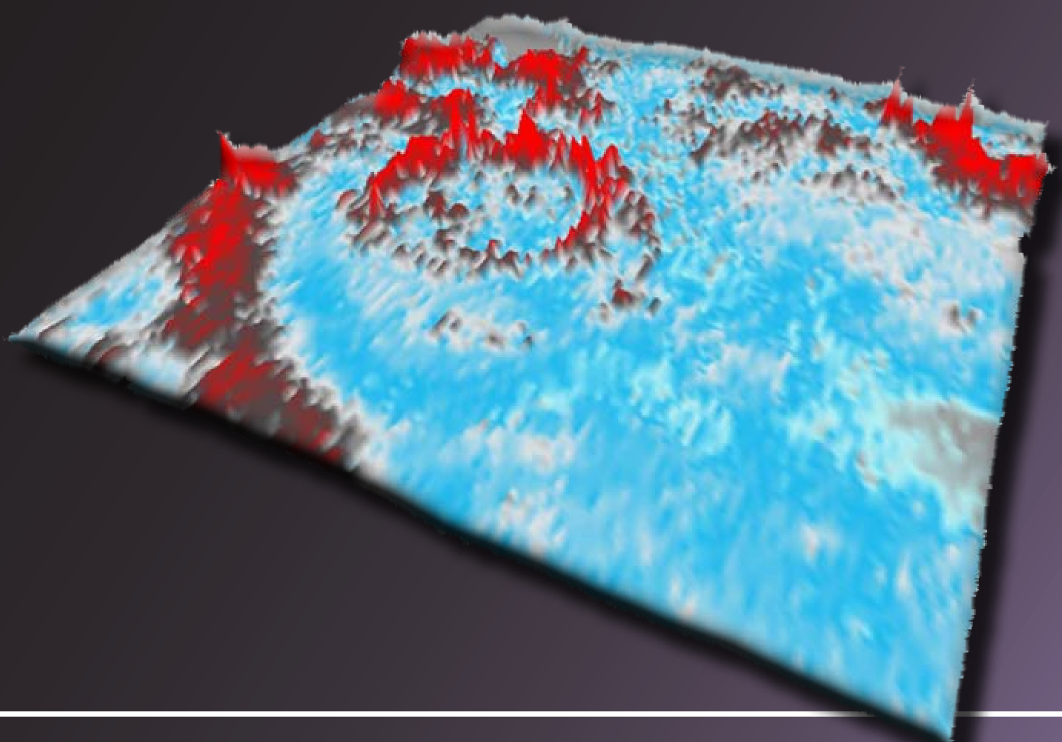
ELECTRICAL TECHNIQUES



In this issue . . .

- Tucson Hosts SAGEEP's 25th Anniversary
- Workshop on Seismic Refraction
- New! Workshop on Hydro-Fracking
- EEGS-SEG-NSG Cooperation

. . . and more!

SAGEEP 2012 - Tucson, Arizona

On the Cover

This issue features the application of electrical techniques to near surface investigations. Cover image reproduced with permission from Target (www.target-geophysics.com).

What We Want From You

The ***FastTIMES*** editorial team welcomes contributions of any subject touching upon geophysics. The theme for our next issue will be the development and application of geophysical techniques for proximal soil sensing. ***FastTIMES*** also accepts photographs and brief non-commercial descriptions of new instruments with possible environmental or engineering applications, news from geophysical or earth-science societies, conference notices, and brief reports from recent conferences. Please submit your items to a member of the ***FastTIMES*** editorial team by February 21, 2012 to ensure inclusion in the next issue. We look forward to seeing your work in our pages.

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Contents

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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 retired member $20 for a student membership, $50 developing world membership, and $650 to $4000 for various levels of corporate membership. All membership categories include free online access to JEEG. The membership application is available at the back of this issue, or online at *www.eegs.org*. See the back page for more information.

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

Managing Director
Jackie Jacoby
staff@eegs.org

FastTIMES Submissions

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

Editor in Chief
Moe Momayez
moe.momayez@arizona.edu
520.621.6580

Associate Editor
Barry Allred
allred.13@osu.edu
614.292.9806

Associate Editor
Jeffrey G. Paine
jeff.paine@beg.utexas.edu
512.471.1260

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

Jackie Jacoby
staff@eegs.org
303.531.7517

FastTIMES is published electronically four times a year. Please send articles to any member of the editorial team by November 21, 2011. Advertisements are due to Jackie Jacoby by November 21, 2011.

Calendar

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

	2011
Nov 29 – Dec 1	*SERDP and ESTCP Partners in Environmental Technology Technical Symposium & Workshop* "Meeting DoD's Environmental Challenges", Washington, D.C.
December 5-9	*2011 AGU Fall Meeting*. San Francisco, CA
	2012
January 15–17	*International Conference on Earth Sciences and Engineering*: brings together scientists, engineers, and students to share their experiences and research results about all aspects of Earth Sciences and Engineering, Zurich, Switzerland
February 21	Deadline for submission of articles, advertisements, and contributions to the March issue of *FastTIMES*
February 26–29	*22nd ASEG*: the conference theme 'Unearthing New Layers' recognises that transformational change in our industry can still occur, Melbourne, Australia
March 5-8	*DGG Meeting 2012 in Hamburg* 72nd annual meeting of the German Geophysical Society, celebrating its 90th anniversary, Hamburg, Germany
March 25-29	*25th Anniversary Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP)* "Making Waves: Geophysical Innovations for a Thirsty World", Tucson, AZ
May 21	Deadline for submission of articles, advertisements, and contributions to the June issue of *FastTIMES*
June 15~18	*5th International Conference on Environmental and Engineering Geophysics*, Changsha, China
August 21	Deadline for submission of articles, advertisements, and contributions to the September issue of *FastTIMES*
September 23-26	*First EAGE Workshop on Dead Sea Sinkholes*: Causes, Effects and Solutions Hydrogeological Workshop on Dead Sea Sinkholes, Amman, Jordan
November 21	Deadline for submission of articles, advertisements, and contributions to the December issue of *FastTIMES*

President's Message: Invitation to Tucson

Mark Dunscomb, President (*mdunscomb@schnabel-eng.com*)

While at the barber's shop this past weekend, a group of carolers stepped in off the brick sidewalk and sung several tunes for us. There I sat getting my hair cut along with a young boy about seven years old, surrounded by bundled-up serenaders all singing their part in harmony. It was a scene right out of a Norman Rockwell painting and was a clear reminder to me that the end of the year is almost upon us.

This year was a good one for EEGS. Members produced many original ideas, put on a great SAGEEP conference in Charleston, SC, rolled out a new and more powerful website (*www.eegs.org*), partnered with Geoscientists Without Borders via the EEGS Foundation, and the society is financially sound, which is saying something in the present uncertain climate. Beyond the 2011 year, 2012 marks the 25th Anniversary of the SAGEEP conference – a milestone that you should be very proud of and we'll be celebrating at this year's meeting in Tucson, Arizona. With this as a backdrop, it's a great time to think about what's in front of us.

One thing we can say with some certainty, the world is becoming more urbanized daily and that growth generates a need to understand the near surface. Land containing more inherent challenges is being developed, maintaining and redeveloping infrastructure are critical, brownfield sites are being reused, and the list goes on. One of the largest challenges is managing and finding potable water sources. It can't be overstated, water impacts every aspect of society and according to the Washington Times recently, almost 900 Million people currently don't have access to clean water. Although there are no simple answers, near surface geophysics provides needed information to generate suitable and effective solutions.

SAGEEP will be in Tucson this year from March 25 to 29 and the topic, "Making Waves: Geophysical Innovations for a Thirsty World," addresses the present need and how geophysics fits into the water solution (see). We're excited to have award-winning author William deBuys as our keynote speaker. Check out his most recent book that was released this past October, "A Great Aridness: Climate Change and the Future of the American Southwest."

Another item we can be sure of is that coordinating our efforts as a profession will greatly enhance our ability to grow, share information and resources, enhance outreach, and pursue initiatives. With that in mind, we have formed a joint task force with the Society of Exploration Geophysicists and Near Surface Geophysical Section (SEG-NSGS) to investigate how we might enhance our combined efforts (see notice inside this FastTimes and more information to come) while maintaining the special culture that makes EEGS so special. We also continue to build on our relationships with other organizations and see that as a vital aspect and benefit to EEGS and the near surface community as a whole.

A professional society is much like a group of carolers singing in harmony. One part may sound somewhat odd all by itself but, combined with all the parts and the power of many voices, the result is a creation that makes sense. It's music. A bit hokey… ok, but the point is this, we need and look forward to your voice to add to the harmony. I look forward to seeing you at SAGEEP this March.

EEGS Foundation makes great strides in its first years.

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

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

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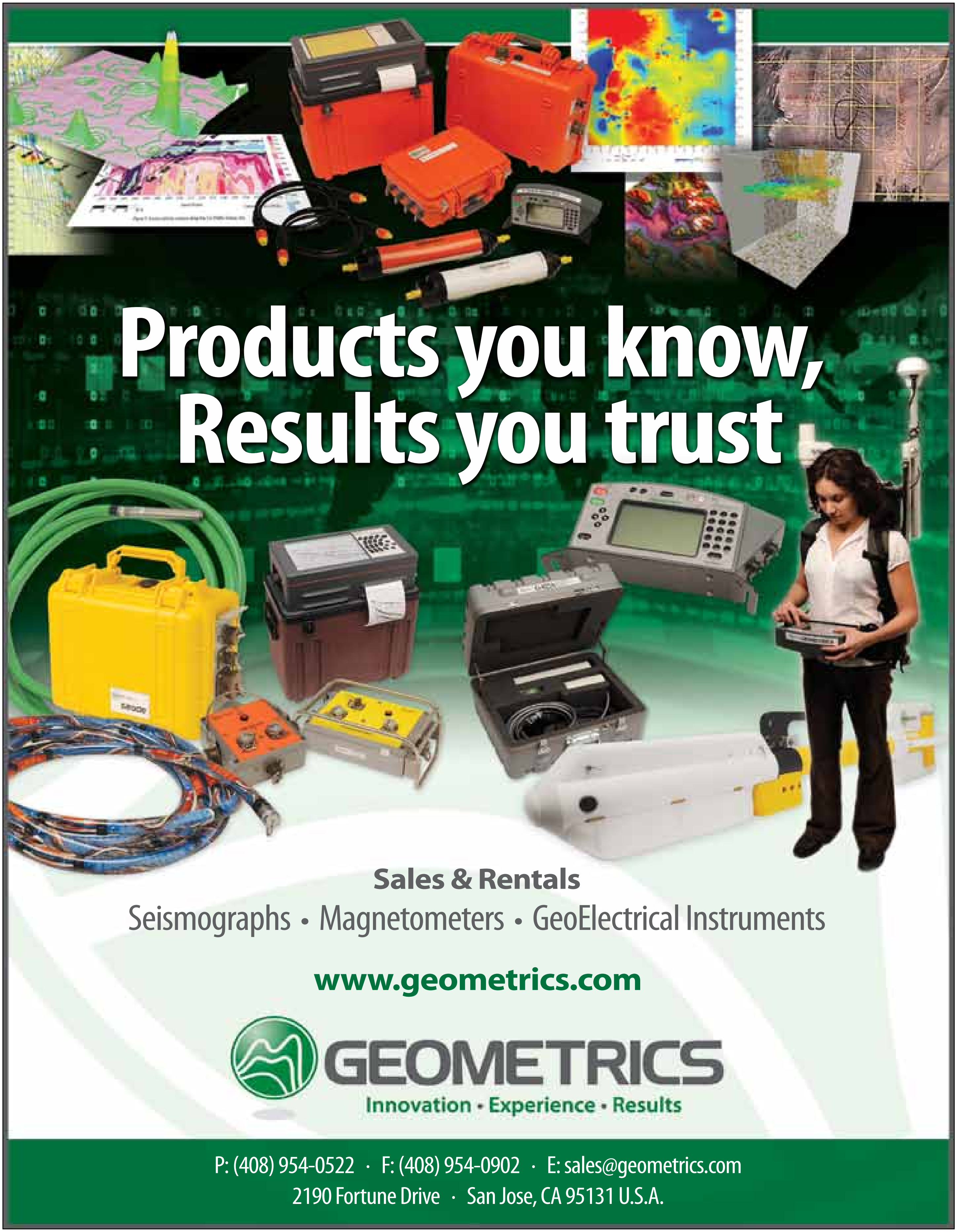
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Renew your EEGS Membership for 2012

Be sure to renew your EEGS membership for 2012! In addition to the more tangible member benefits (including the option of receiving a print or electronic 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. Members can renew by mail, fax, or online at *www.eegs.org*.

Sponsorship Opportunities

There are always sponsorship opportunities available for government agencies, corporations, and individuals who wish to help support EEGS's activities. Specific opportunities include development and maintenance of an online system for accessing SAGEEP papers from the EEGS web site and support for the 2012 SAGEEP conference to be held in Tucson, Arizona. Contact Mark Dunscomb (*mdunscomb@schnabel-eng.com*) for more information.

Help Support EEGS!

Please Join or

Renew Your Membership

Today at www.eegs.org!

EEGS Announces Changes in Membership

It's time to renew your membership in EEGS – we've added options and increased benefits!

EEGS members, if you have not already received a call to renew your membership, you will – soon! There are a couple of changes of which you should be aware before renewing or joining.

Benefits - EEGS has worked hard to increase benefits without passing along big increase in dues. As a member, you receive a Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP) registration discount big enough to cover your dues. You also receive the Journal of Environmental and Engineering Geophysics (JEEG), the *FastTIMES* newsletter, and full access to the EEGS research collection, which includes online access to all back issues of JEEG, SAGEEP proceedings, and SEG extended abstracts. You get all of this for less than what many societies charge for their journals alone.

Dues Changes - EEGS has worked hard to hold the line against dues increases resulting from inflation and higher costs. Instead, EEGS leadership sought ways to offer yesterday's rates in today's tough economic climate. Therefore, you can continue your EEGS membership without any rate increase if you opt to receive the JEEG in its electronic format, rather than a printed, mailed copy. Of course, you can continue to receive the printed JEEG if you prefer. The new rate for this membership category is modestly higher reflecting the higher production and mailing costs. A most exciting addition to EEGS membership choices is the new discounted rate for members from countries in the developing world. A growing membership is essential to our society's future, so EEGS is urging those of you doing business in these countries to please encourage those you meet to take advantage of this discounted membership category, which includes full access to the EEGS research collection. And, EEGS is pleased to announce the formation of a Retired category in response to members' requests.

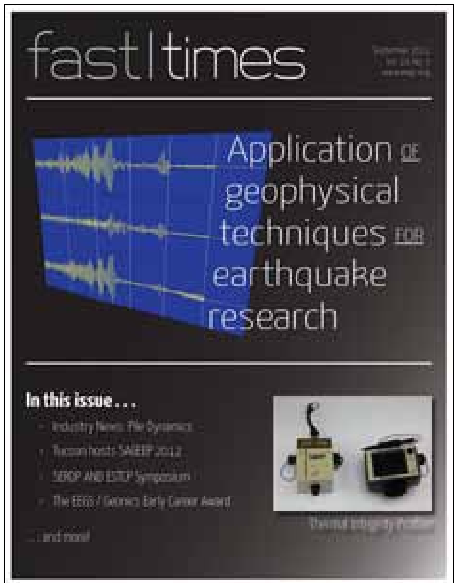
Descriptions of all the new membership options are outlined on EEGS' web site (*www.eegs.org*) in the membership section.

Renew Online - Last year, many of you took advantage of our new online membership renewal (or joining EEGS) option. It is quick and easy, taking only a few moments of your time. Online membership and renewal application form is available at *www.eegs.org* (click on Membership and then on Online Member Application / Renewal).

EEGS Foundation - EEGS launched a non-profit foundation (*www.eegsfoundation.org*) that we hope will enable our society to promote near-surface geophysics to other professionals, develop educational materials, fund more student activities, and meet the increasing demand for EEGS programs while lessening our dependence on membership dues. A call for donations (tax deductible*) to this charitable organization is now included with your renewal materials and can be found on the online Member Resources page of EEGS' web site (*www.eegs.org/pdf_files/eegs_foundation.pdf*).

Member get a Member - Finally, since the best way to keep dues low without sacrificing benefits is to increase membership, please make it your New Year's resolution to recruit at least one new EEGS member. If every current member recruited even one new member to EEGS, we could actually consider lowering dues next year!

*As always, seek professional advice when claiming deductions on your tax return.



From the FastTIMES Editorial Team

FastTIMES is distributed as an electronic document (pdf) to all EEGS members, sent by web link to several related professional societies, and is available to all for download from the EEGS web site at *http://www.eegs.org/Publications/FASTTIMES/LatestIssue.aspx*. The most recent issue (September 2011, cover image at left) has been downloaded more than 12,000 times as of December 2011, 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.

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, current and past issues, and advertising information.

The JEEG Page

*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 2011 Issue

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

EAGE's Near Surface Geophysics Journal, December 2011

*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.*

Content

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, the authors present examples of electrical techniques to near surface investigations.*

Non-intrusive estimate of the flow rate of thermal water along tectonic faults in geothermal fields using the self-potential method

A. Revil[1,2] , A. Jardani[3], J. Hoopes[1], M. Karaoulis[1], C. Colwell[4], M. Batzle[1], A. Lamb[4], and K. van Wijk[4]

(1) Colorado School of Mines, Department of Geophysics, Golden, CO, USA

(2) CNRS, LGIT, UMR C5559, Université de Savoie, Le Bourget-du-lac Cedex, France

(3) Université de Rouen, M2C, UMR 6143, CNRS, Morphodynamique Continentale et Côtière, Mont Saint Aignan, France

(4) Department of Geosciences, Boise State University, 1910 University Dr., Boise, Idaho 83725-1536

Introduction

Electrical resistivity tomography and self-potential data have been found to be complementary methods in characterizing hydrothermal systems and active volcanoes (Aizawa et al., 2009; Revil et al., 2011). Self-potential is a passive electrical potential measurement of the electrical field at the ground surface of the Earth. In geothermal fields, this electrical field results from the convective drag of the excess charge density occurring in the pore space of a porous material (Revil and Leroy, 2001). It is usually used in a qualitative or semi-quantitative way to obtain some information on the flow of the ground water (e.g., Tanguy et al., 2011; Linde et al., 2011). In this paper, we propose to invert self-potential data based on the Gauss-Newton method using some the resistivity distribution in the inverse problem. This new approach is successfully applied to two geothermal fields, one in Central Colorado (Mt Princeton Hot Springs) and the second one in Oregon (Neal Hot Springs).

Inversion of Self-Potential Data

The self-potential φ (in V) is governed by a Poisson equation (Jardani and Revil, 2009):

$$\nabla \cdot (\sigma \nabla \varphi) = \nabla \cdot (\overline{Q}_V \mathbf{u}) \tag{1}$$

which is obtained by combining the generalized Ohm's law including the advective drag of the excess of electrical charges of the diffuse layer (coating the surface of the minerals) per unit volume of pore water, $\overline{Q}_V$ (excess charge density in C m^{-3}), and the Darcy or seepage velocity **u** (in m s^{-1}). In Eq. (1), σ (in S m^{-1}) is the electrical conductivity of the porous material. The right-hand side of Eq. (1) corresponds to the self-potential source term associated with the Darcy velocity distribution and the heterogeneity in the distribution of the volumetric charge density $\overline{Q}_V$. The charge density $\overline{Q}_V$ is the effective volumetric charge density occurring in the pore space of the porous material due to the electrical double layer at the mineral / water interface (e.g., Revil and Leroy, 2001). The relationship between this volumetric charge density and the more classical streaming potential coupling coefficient *C* (in V Pa^{-1}) (Aizawa et al., 2009) is: $C = -\overline{Q}_V k \rho / \eta_f$ where $\rho = 1/\sigma$ is the electrical resistivity of the porous material (in ohm m) and η_f denotes the dynamic viscosity of the pore water (in Pa s). For pH comprised between 5 and 8, Jardani and Revil (2009) found that the empirical relationship $\log_{10} \overline{Q}_V = -9.2 - 0.82 \log_{10} k$ between the charge density $\overline{Q}_V$ and the permeability *k* (in m^2) holds for a broad range of porous rocks. The pH of the hot springs at Mount Princeton is between 7.8 and 8.6 (see Table 1), so slightly above the range mentioned previously and therefore we believe this equation can be used as a first-order approximation.

We developed a software called SP2DINV based on deterministic regularization and the Gauss-Newton method. We first need to compute the Kernel matrix that represents the relationship between the electrical current density at point M and the measured self-potential signals at a self-potential station *P*. The relationship between the electrical potential at the observation point P, $\varphi(P)$, and the current density at the source position M, $\mathbf{j}_S(M)$, is given by the integral form of the Poisson equation, Eq. (1):

$$\varphi(P) = \int_{\Omega} \mathbf{K}(P,M)\mathbf{j}_S(M)dV \tag{2}$$

where $\mathbf{j}_S = \bar{Q}_V \mathbf{u}$ is the source current density vector associated with ground water flow, dV denotes an integration over the volume of rocks (Ω represents the source rock volume in which fluid flow takes place) and **K**(*P*,*M*) denotes the kernel connecting the self-potential data measured at a set of non-polarizing electrodes *P* (with respect to a reference electrode) and the source of current at point *M* in the conducting ground. The kernel **K** depends on the number of measurement stations *N* at the ground surface, the number of elements *M* in which the source current density is going to be determined, and the resistivity distribution of the medium, which is directly taken from the electrical resistivity tomogram. For a 2D problem, each element of **K** is a Green function. The matrix **K** depends also on the boundary conditions for the electrical potential or the total current density. The ground surface is considered to be an electrically insulating boundary (Neumann boundary) and therefore the normal component of the current density vanishes at this boundary ($\hat{\mathbf{n}} \cdot \nabla \varphi = 0$ where $\hat{\mathbf{n}}$ is the unit vector normal to the boundary and φ the electrical potential). However, for the rest of the boundaries a null electrical potential is imposed ($\varphi = 0$ V). Finally, when computing the elements of **K**, one has to remember that the electrical potential is determined relative to a reference electrode located somewhere at the ground surface. As explained above, this choice is arbitrary but needs to be consistent between the display of the data and the numerical forward modeling used to compute the kernel (Jardani et al., 2008).

Property	MP	NH
T (\C)	82	87
pH (-)	8.5	7.3
σ_f (10^{-2} S m^{-1}, 25\C)	4.80	10.10
K^+	3.10	16.0
Na^+	94	190
Ca^{2+}	4.4	8.8
Mg^{2+}	0.10	0.2
SiO_2(aq)	68	180
HCO_3^-(alkalinity)	71	200
SO_4^{2-}	100	120
Cl^-	10	120
F^-	14	9.4

Table 1. Composition of the thermal waters for Mount Princeton (MP, Hortense Hot Springs, sampling: Oct. 1975, from Dimick, 2007) and Neal Hot Spring (NH, measurements made in 1972, Mariner et al., 1980).

The inversion of the self-potential data follows a two-step process. The first step is the inversion of the spatial distribution of the source current density $\mathbf{j}_S$. The second step is the determination of **u** using the distribution of $\mathbf{j}_S$ and assuming reasonable values for the charge density $\bar{Q}_V$. The self-potential inverse problem is a typical (vector) potential field problem and the solution of such problem is known to be ill-posed and non-unique. It is therefore important to add additional constraints to reduce the solution space. The criteria of data misfit and model objective function place different and competing, requirements on the models. Using the L_2 norm, these two contributions of a global cost function ψ are balanced using Tikhonov regularization (see Tikhonov and Arsenin, 1977):

$$\boldsymbol{\Psi} = \|\mathrm{W}_d(\mathrm{Km} - \varphi_d\|^2 + \lambda \|\mathrm{W}_m \mathrm{m}\|^2 \tag{3}$$

where λ is a positive regularization constant, $\left\|\mathbf{Af}\right\|^2 = \mathbf{f}^{\mathrm{t}}\mathbf{A}^{\mathrm{t}}\mathbf{Af}$ (where the superscript "t" means transpose), $\mathbf{K} = \left(\mathbf{K}_{ij}^x, \mathbf{K}_{ij}^z\right)$ is the kernel (*N*x2*M*) matrix formed from two matrices corresponding to the kernel of the horizontal and vertical vector components of the electrical source density for 2D problems, $\mathbf{m} = \left(j_i^x,\ j_i^z\right)$ is the vector of 2*M* model parameters (source current density), *N* is the number of self-potential stations and *M* is the number of discretized cells used to represent the ground (2*M* represents the number of elementary current sources to consider, one horizontal component and one vertical component per cell for a 2D problem), φ_d is vector of N elements corresponding to the self-potential data measured at the ground surface or in boreholes, $\mathbf{W}_d = \mathrm{diag}\{1/\varepsilon_1,...,1/\varepsilon_N\}$ is a square diagonal data weighting NxN matrix (elements along the diagonal of this matrix are the reciprocals of the standard deviations ε_i of the self-potential data), $\mathbf{W}_m$ is the 2(M-2)x2M model weighting matrix or regularization matrix (e.g., the flatness matrix or the differential Laplacian operator). The product $\mathbf{Km}$ in Eq. (3) represents the predicted (simulated) self-potential data. If a prior model $\mathbf{m}_0$ is considered, $\left\|\mathbf{W}_m\mathbf{m}\right\|^2$ is replaced by $\left\|\mathbf{W}_m\left(\mathbf{m}-\mathbf{m}_0\right)\right\|^2$. This Gaussian assumption on the data is used to set up the matrix $\mathbf{W}_d$. For $\mathbf{W}_m$, we use the smoothness operator (the discrete approximation of the second order derivative). At each inverse iteration step i, we compute a quadratic approximation of ψ at the current model $\mathbf{m_i}$ is minimized, yielding a linear system of equations to be solved for a new model update vector $\Delta\mathbf{m_i}$:

$$\mathbf{A}_i \Delta\mathbf{m_i} = \mathbf{B}_i \tag{4}$$

with,

$$\mathbf{A}_i = \left[\mathbf{K}^T(\mathbf{W}_d^T\mathbf{W}_d)\mathbf{K} + \lambda_i(\mathbf{W}_m^T\mathbf{W}_m)\right] \tag{5}$$

$$\mathrm{B_i} = \mathrm{K}^T\left(\mathbf{W}_d^T\mathrm{W}_d)(\varphi_d - \mathrm{Km}_i) - \lambda_i(\mathrm{W}_m^T\mathrm{W}_m\mathrm{m}_i)\right) \tag{6}$$

The update vector $\Delta\mathbf{m_i}$, when added to **m**, decreases the value of the cost function. The regularization parameter used in our approach is initially set at a large value, λ_0, and it is progressively reduced after each iteration i, until it reaches the minimum limit, λ_m, selected. In the following example, the minimum value of λ_m is set at one-tenth the value of λ_0. The value of the initial damping factor λ_0 depends on the level of random noise present in the data (Loke and Barker, 1996), with a large value for noisy data. At each iteration step, (1) we compute the inverse solution, (2) we simulate the self-potential data, and (3) we compute the data misfit contribution. If the data misfit is larger than that suggested by the self-potential noise, the value of the regularization parameter is reduced and the process repeated until the data are appropriately fitted assuring that we can find the smoothest model that fits the data. The Gauss-Newton method was implemented in a Matlab routine.

Application to Mount Princeton Hot Springs

The Mount Princeton area represents a complex system where the interaction of faults has resulted in hot springs. These hot springs include the Hortense Hot Springs, which are the hottest springs in Colorado (Limbach, 1975). The Upper Arkansas Valley is a half-graben located between the Sawatch Range to the west and the Mosquito Range to the East. The dominant faulting corresponds to the Sawatch Range Fault, a northwest trending normal fault bordering the Sawatch Range, which is composed of a relatively young (34-38 Ma) granitic batholith including Mount Princeton (Figure 1). The Sawatch fault is segmented in several places by transfer faults and accommodation zones (Miller, 1999). Here we focus on the geothermal field associated with the Mount Princeton Hot Springs. In this area, the Sawatch normal fault is segmented by a strike slip fault. The surface expression of this segmentation corresponds to the Chalk Cliffs, named for the white color of the highly fractured and hydrothermally altered quartz monzonite (Figures 1) (the white color is due to kaolinite replacing feldspar).

Geophysical data collection consisted of a series of 9 (~1.2 km-long) resistivity profiles and 2500 self-potential measurements performed in May 2008, May 2009, and May 2010. In the following, we will focus on the resistivity and self-potential data obtained along profile P3 crossing the strike-slip fault shown in Figure 1c (Fault B). The resistivity data were obtained with an ABEM SAS-4000 resistivity meter using the Wenner-α arrays and 64 stainless steel electrodes with 20-m take-outs. A current of 200 mA was generally injected in the ground for each measurement. Each measurement was repeated until the standard deviation was below 5% of the mean (a maximum of 16 measurements were stacked together). The profile P3 comprises a total of 472 measurements. The self-potential measurements were performed mainly with Pb/$PbCl_2$ Petiau non-polarizing electrodes. We used a high impedance (100 Mohm), calibrated, Metrix voltmeter with a sensitivity of 0.01 mV. The mean standard deviation of the self-potential data was 5 mV on average. Temperature was also recorded along profile P3 at a depth of 30±5 cm (see Figure 2).

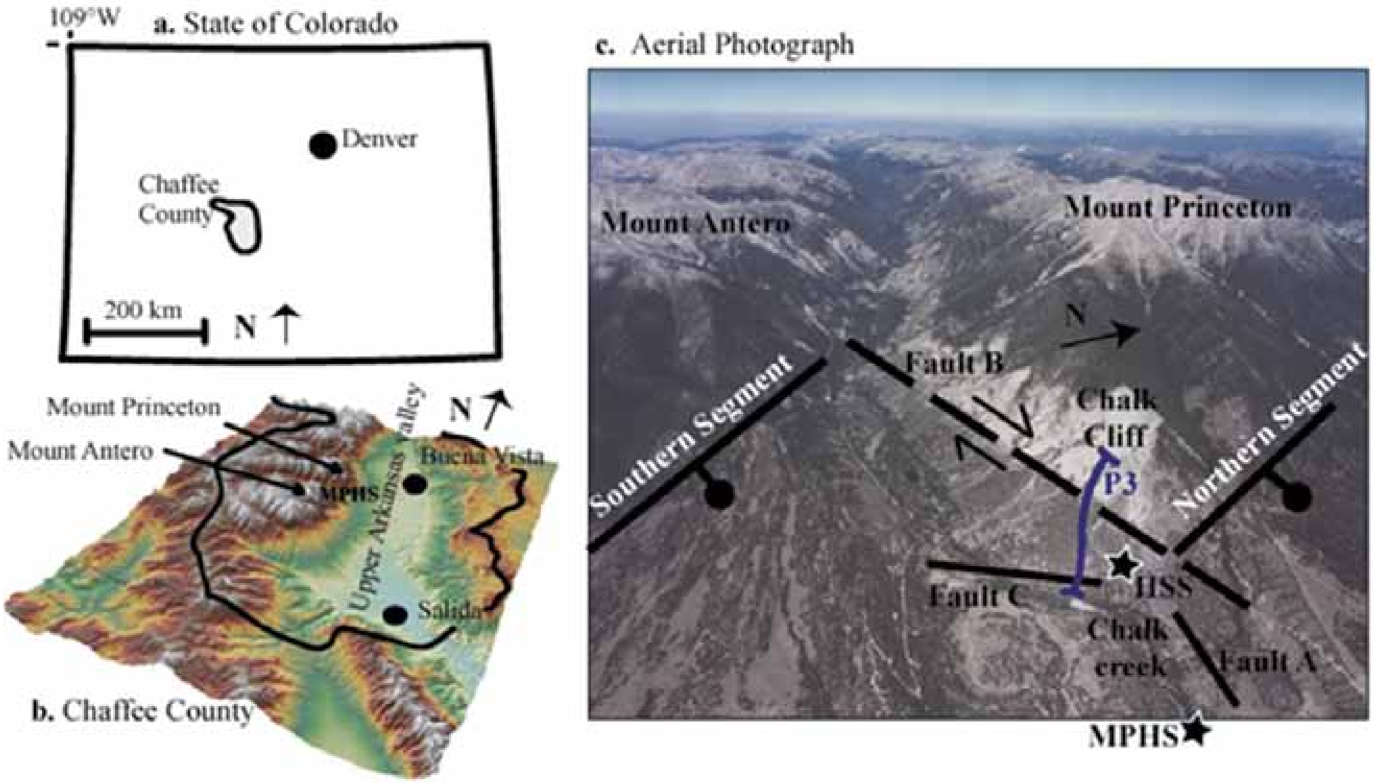

Figure 1. Localization of Mount Princeton Hot Springs: a. Sketch of the State of Colorado. b. Chaffee County. c. Simplified geological sketch c. Aerial photograph of the investigated area (courtesy from Jeffrey A. Coe, USGS) showing the position of the Profile P3 and the position of the Northern and southern segments of the Sawatch Range fault near Chalk Cliffs. Chalk Cliff results from the alteration of the quartz monzonite of the Mount Princeton batholith. HHS corresponds to the Hortense Hot Springs and MPHS corresponds the Mount Princeton Hot Springs. We have also indicated the position of the dextral strike slip fault zone (Fault B).

Resistivity data were inverted with the software RES2DINV (Loke and Barker, 1996) using a Gauss-Newton method and a finite element solver. The inverted resistivity section and the self-potential data are displayed in Figures 2. The DC Resistivity tomogram (RMS 4%, the apparent resistivity data are fitted to within 4% of the measured values) on profiles P3 (and other profiles not shown here) show a ~150 m wide, near-vertical, low-resistivity anomaly (named B3) consistent with the presence of a dextral strike slip fault zone in this area (Fault B in Figure 1). This anomaly is confirmed by additional profiles performed parallel to P3. Additionally, P3 exhibits a clear positive self-potential and temperature anomaly associated with the conductive anomaly B3. We interpret this anomaly as being due to the upwelling of thermal waters along this portion of the dextral strike slip fault zone (see *Poldini* [1938]). The thermal water upwelling along the fault plane is then flowing downslope in a shallow unconfined aquifer as evidenced by domestic wells and the shape of the self-potential signal, which increases in the direction of Chalk Creek in the center of the valley.

We use the geometry shown in Figure 2 with the material properties given in Table 2 to set up a geometry to invert the self-potential data (Figure 3). This geometry comprises three units. Unit U1 for the fault and units U2 and U3 represents the granitic basement and the shallow aquifer, respectively. The presence of this shallow aquifer is confirmed by a drill-hole (MPG-5) where a water temperature of 59°C and a water table depth of 40 m were measured (see position in Figure 2). The water table was located at a depth of 40 m. The boundary conditions are (i) impervious boundaries except at the base of the fault and at the outflow of the aquifer and (ii) insulating boundaries. We attempt to invert the self-potential measurements to determine the magnitude of the Darcy velocity using the deterministic approach proposed in Section 2. In the following, we use a constant value for $\bar{Q}_V$ in the fault because we assume a constant temperature, salinity, and lithology in the fluid flow path. Using a depth of the reservoir depth of 5 km and a mean geothermal gradient of 28°C km^{-1}, the permeability of the fault plane is estimated to be on the order of 10^{-13} m^2. This yields an approximate value of $\bar{Q}_V$ = 30 C m^{-3} using the relationship discussed in Section 2. The conductivity of the hydrothermal water is σ_f (25°C) = 0.048 S m^{-1} (Table 1). Revil et al. (2003) developed the following empirical equation between the value of the coupling coefficient and the value of the conductivity of the pore water at 25°C: $\text{Log}_{10}C = -0.921 - 1.091\ \text{Log}_{10}\sigma_f$. This gives a streaming potential coupling coefficient of ~-3±1 mV m^{-1}. Using C (in V m^{-1}) = $-\bar{Q}_V\ k\ \rho\ \rho_f\ g / \eta_f$ and $k = 10^{-13}$ m^2 (discussed above), a bulk resistivity of ρ = 200 ohm m (from the resistivity tomogram displayed in Figure 2), a mass density for the pore water of ρ_f = 1000 kg m^{-3}, a viscosity η_f = 4.6x10^{-4} Pa s (water at 60°C), and a coupling coefficient of C = -3 mV m^{-1} , we find $\bar{Q}_V$ = 7 C m^{-3}. As $\bar{Q}_V$ can vary over 12 orders of magnitude, this estimate is consistent with the previous estimate (30 C m^{-3}).

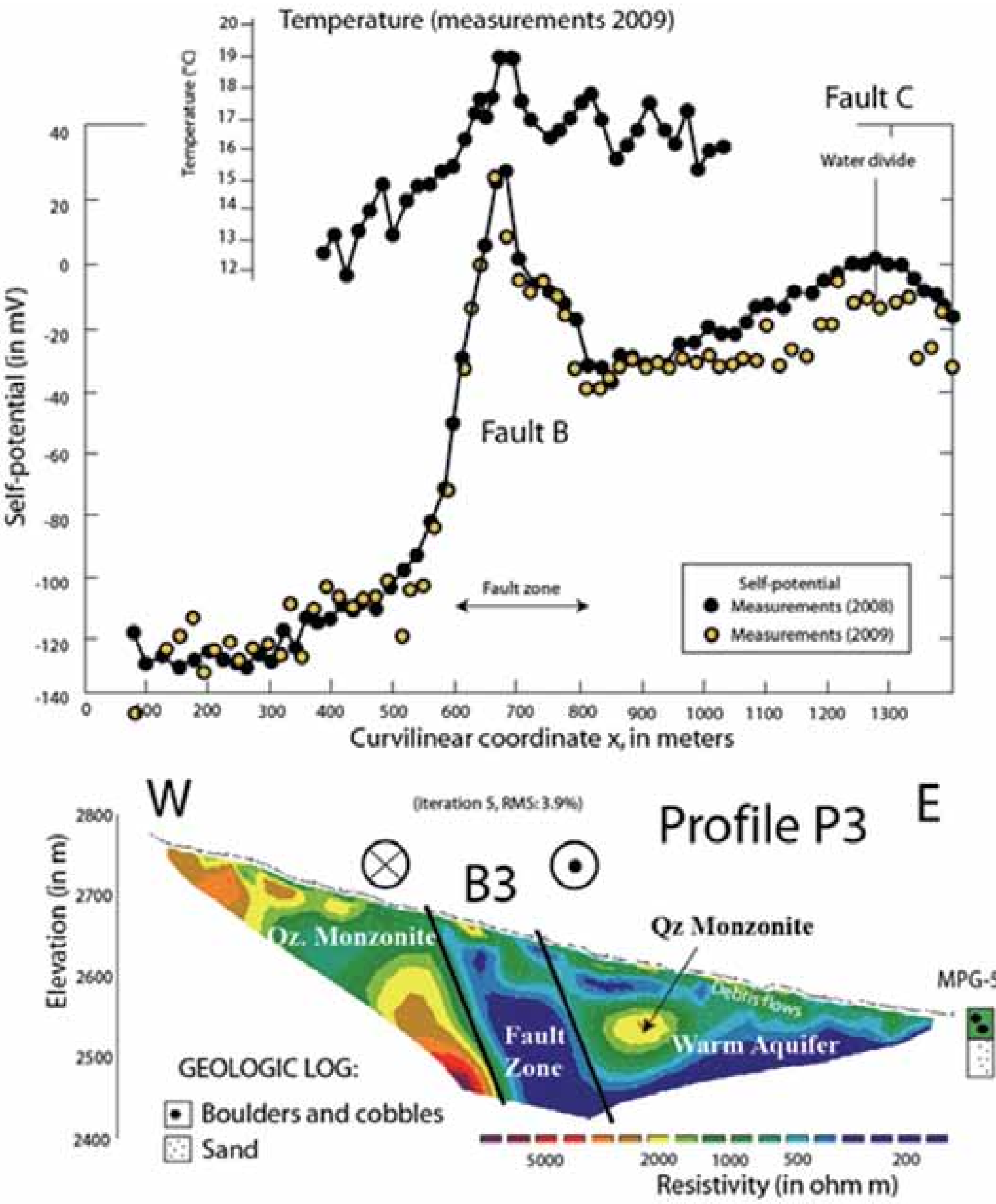

Figure 2. Resistivity tomogram (RMS Error 4%) and self-potential data along profile P3 (vertical exaggeration factor of the resistivity tomogram: 1.3). The conductive body B3 is consistent with the position of the dextral strike slip zone. The upflow in the dextral strike slip fault zone (Fault B) is associated by a self-potential anomaly of 150 mV in the self-potential signals, low resistivity values (in the range 100-300 ohm m), and an increase of the temperature at a depth of 30 cm. The positive self-potential anomaly evidences the up-flow of the hydrothermal fluids in this portion of the fault zone. Note the consistency of the self-potential measurements over a year of time interval.

In order to have a hydrogeologically reasonable model, we also use the following constraints on the direction and magnitude of the source current density in each unit:

$$\mathbf{m} = \left(j_i^x \leq 0, j_i^z \approx 0\right) \text{ in U3,} \tag{7}$$

$$\mathbf{m} = \left(j_i^x < j_i^z\right) \text{ in U1,} \tag{8}$$

$$\mathbf{m} = \left(0,0\right) \text{ in U2,} \tag{9}$$

which means that the flow is mainly horizontal in the shallow aquifer U3, vertical in the fault zone U1 and null in the basement U2. The minimization of Eq. (3) is performed iteratively by the Gauss-Newton method described in Section 2. We use the initial value of the regularization parameter equal to λ_0=0.08 on the basis of the noise level in the self-potential data.

Unit	Meaning	Permeability (m^2)	Resistivity (ohm m)	Charge density (C m^{-3})
U1	Fault	10^{-13}	200 (2)	30 (3)
U2	Basement	10^{-20}	2000 (2)	-
U3	Aquifer	10^{-12} (1)	1000 (2)	4 (3)

Table 2. Material properties of the geological units used for the numerical modelling.
(1) The high permeability of the aquifer agrees with the high permeability of the formation observed in well MPG-5 (see position in Figure 5) and composed of boulders, cobbles, aggregates, and sands. The permeability of the aquifer is only used to infer a value for.
(2) Resistivity is estimated from the resistivity tomogram.
(3) Using the relationship between the excess charge density and the permeability data.

The result of the self-potential inversion is shown in Figure 3 (61^{st} iteration, RMS Error=1.2%). This small RMS error is due to the fact that the data are relatively smooth and noise free. This will not be the case in the example shown in Section 4. Note that the value of the RMS in itself does not convey important information as better RMS can be obtained with models that that have no hydrogeological basis (i.e., not using the constraints imposed by Eqs. 7 to 9). Using the constraints described above, a converged solution gives a mean Darcy-velocity in the fault of 7±2 x 10^{-7} m s^{-1}. Taking a fault thickness of 150 m as suggested from the resistivity tomograms and an open pathway of 500 m along the dextral strike slip fault zone, a rough estimate of the water flux is 4±1 x10^3 m^3/day of thermal water upwelling along the fault plane at Chalk Cliff at a temperature of roughly 60°C.

From the pattern of hot and cold domestic wells mapped in the area, we know that the upwelling thermal water coming from a portion of the A and B-faults shown in Figure 1c is channeled in a shallow unconfined aquifer flowing toward the Mount Princeton Hot Springs. Therefore, the previous up-flow estimate (4±1 x10^3 m^3/day) based on the inversion of the geophysical data can be compared with the Mt. Princeton hot water production. This production is about (4.3-4.9) x10^3 m^3/day at ~60-65°C. This production rate does not account for six fractures leaking directly into Chalk Creek below the pool to the west end of the Mount Princeton property. It is remarkable that the two independent estimates are so close to each other.

Study	2011 (1)	1972 (2)
T (°C)	93	87
pH (-)	7.0	7.3
σ_f (10^{-2} S m^{-1}, 25°C)	9.92	10.10

Table 3. Composition of the thermal water of Neal Hot Springs.
(1) This work (sampled in May 2011)
(2) From Mariner et al. (1980).

Application to Neal Hot Springs

Neal Hot Springs are located within the tectonically complex area of eastern Oregon, in Malheur County, 90 miles northwest of Boise. This area is dominated by extension-related processes with horst graben structures. This spring is located along a region of north-striking normal faults related to the Oregon-Idaho Graben and north-west-striking normal faults of the western Snake River Plain. Heat flow averages 71 mWm^{-2} within the plain and ranges to over 105 mWm^{-2} along the margins (Brott, et al, 1978). This geothermal field is presently in development by US Geothermal Inc. They have drilled two production wells to the West of the hot springs. The first well demonstrated significant flow and a temperature of 141°C at a depth of 702 m. A second production well, completed 200 meters from the first well, intercepted a large aperture fracture possibly associated with Fault "A" discussed below (see Figure 4), and with a temperature of 141°C at a depth of 882 m. The electrical conductivity of the hot springs is slightly higher than at Mount Princeton Hot springs (see tables 1 and 3). TDS ranges from 875-882, chloride to 117-118 mg/kg, and temperature can reach 97°C. The composition of the spring water can be found in Table 1.

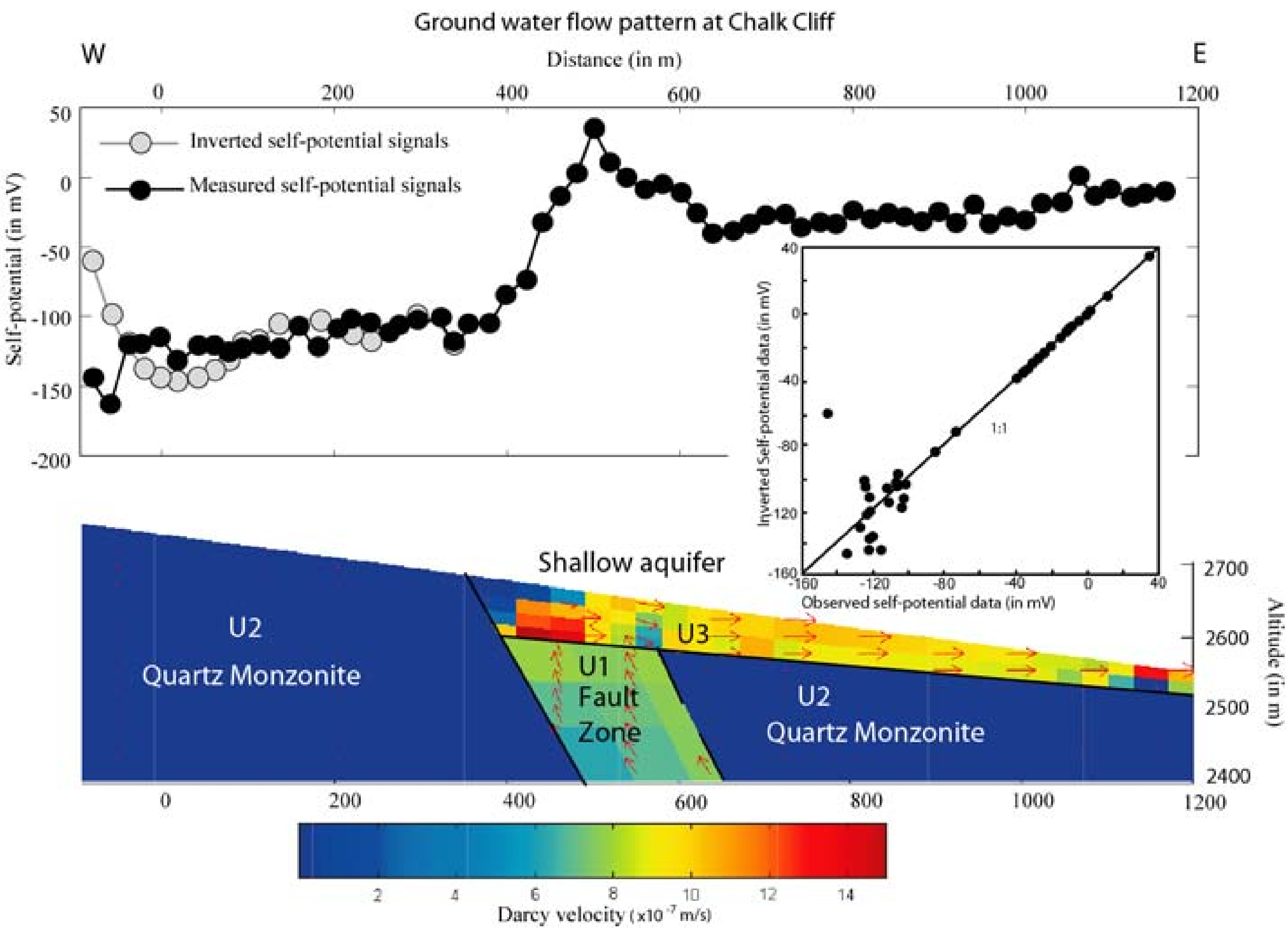

Figure 3. Ground water flow pattern as constrained by DC-resistivity and self-potential data along profile P3 (data from 2008, the end of the profile has been omitted). The unit U1 corresponds to the dextral strike slip zone, the unit U2 to the quartz monzonite basement, and the unit U3 to the shallow aquifer. The boundary conditions are (i) impervious boundaries except at the base of the dextral strike slip fault and at the outflow of the aquifer and (ii) insulating boundaries. We ignore the possibility of a mix between the thermal water and some cold water that would come from the upper section of Chalk-cliff. This may explained the discrepancy between the model and the data occurs at the top of the profile. The arrows and colors represent the direction and amplitude of the Darcy velocity, respectively. Insert: Comparison between the measured self-potential data and those resulting from the optimized ground water flow model (RMS error=1.2%).

In May 2011, we acquired five self-potential (538 measurements in total) and DC resistivity profiles through Neal Hot Springs (Figure 4; some profiles used an electrode roll). Figure 5 show the hot springs with a maximum self-potential anomaly of ~40 mV and maximum ground temperature anomalies of ~40°C. As the pore water conductivity at Neal Hot Springs (at 40°C) is approximately twice the pore water conductivity at Mt Princeton Hot Springs (at 25°C) and the self-potential anomaly is approximately half, this may imply that the Darcy velocity along the fault plane is similar for the two sites.

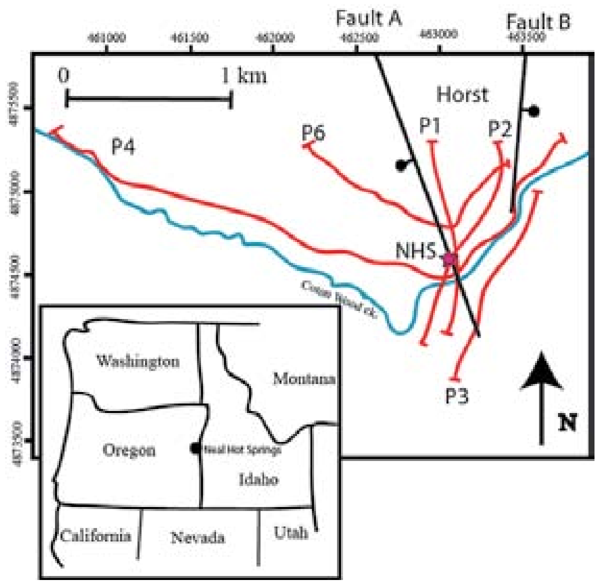

Figure 4. Position of Neal Hot Spring and position of the resistivity and self-potential profiles. Insert: position of the Neal Hot Springs (NHS) in Oregon close to the border with Idaho.

Figure 6 shows a large scale self-potential and resistivity survey crossing a basaltic horst along Profile 4 (5 km long). The P4 self-potential profile comprises 278 stations. DC resistivity measurements were acquired using a Wenner array configuration with a distance of 20 meters between the take-outs and 64 electrodes will roll-over of the electrodes along the profile. The resistivity of the basaltic horst is dependent upon fracture density and has a range of resistivities from 50 to 5000 ohm m. It is generally characterized by a positive self-potential anomaly indicating the upward flow of water through fracture network. The horst is bounded by two springs: the Neal Hot springs (~93°C) on the West and a warm unnamed spring (~40°C) on the East, suggesting that the horst is bounded by a fault on both sides. The sedimentary infilling in the two basins on each side of the horst has low resistivities (1 to 10 ohm m) due to the presence of clays (including smectite). The basins are characterized by negative anomalies that may correspond to downward infiltration of water and therefore slow recharge of the thermal reservoir at depth, but the residence time of the water in the geothermal system is unknown.

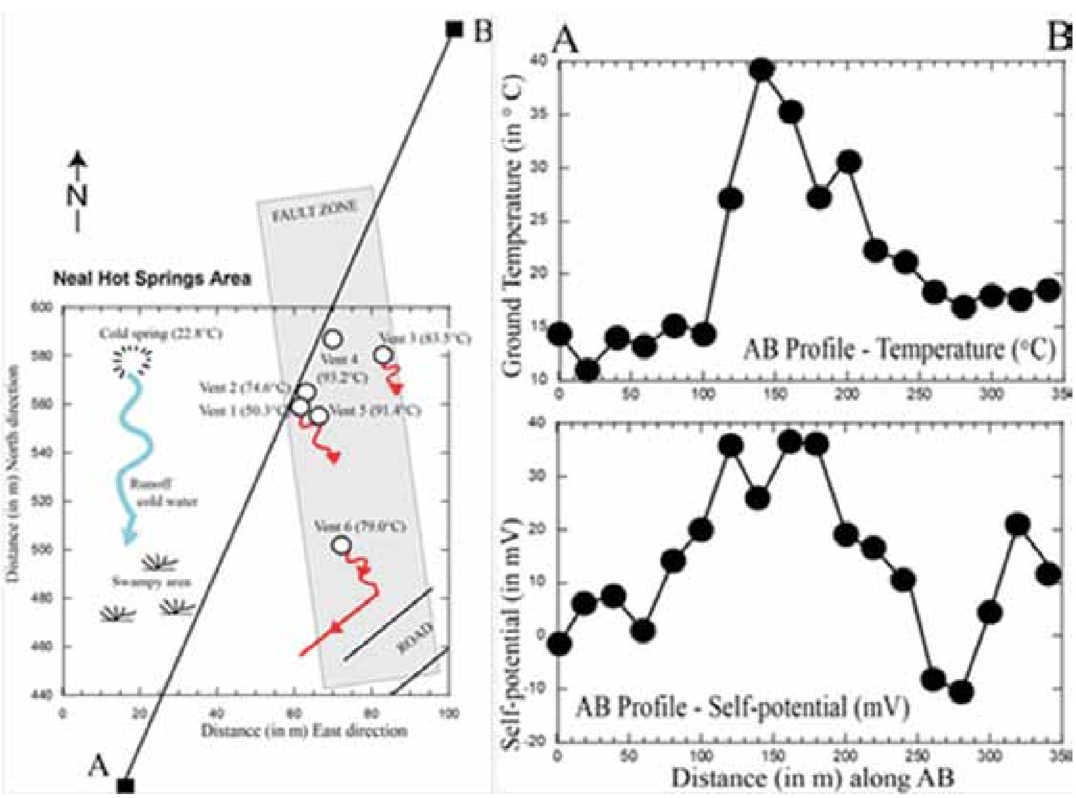

Figure 5. Sketch of the Neal hot springs. Profile AB crossed the tectonic Fault A associated with the horst graben system. The temperature is measured at a depth of 30 cm. The self-potential anomaly associated with the upflow of water along the open portion of the fault amounts to 40 to 50 mV. Note the presence of a cold spring (temperature of 22.8°C) located 50 m East from the A-fault. We have no explanation for the occurrence of this spring occurring in the hanging wall of the fault plane.

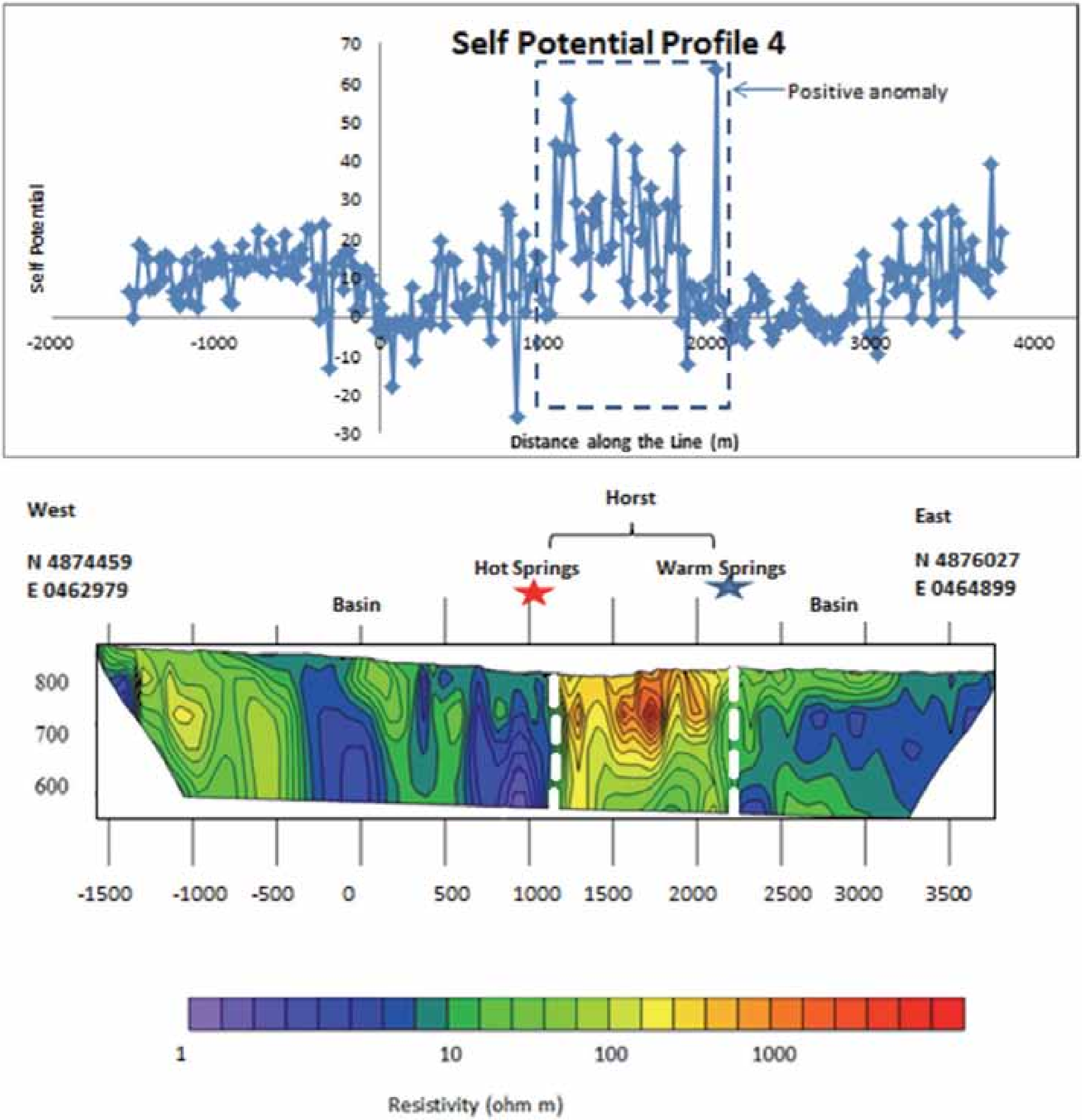

Figure 6. Large scale resistivity tomogram (altitude in meters) for the Neal Hot Spring area and associated self-potential anomalies (in mV). Note the self-potential anomalies are symmetric with respect to the position of the fractured horst (located along between 1.2 to 2.2 km). The sedimentary basins flanking the horst are associated with negative anomalies corresponding to areas of recharge. The two faults bordering the horst (A-fault on the West and B-fault on the East) are associated with the Neal hot spring on the west and a warm spring on the East side.

Figure 7 shows the resistivity distribution at a depth of 50 meters where kriging was applied to all the inverted resistivity profile data. This resistivity map clearly shows the contacts between the horst and the more conductive sediments filling the basin on each side of the horst (see the dashed white lines in Figure 7).

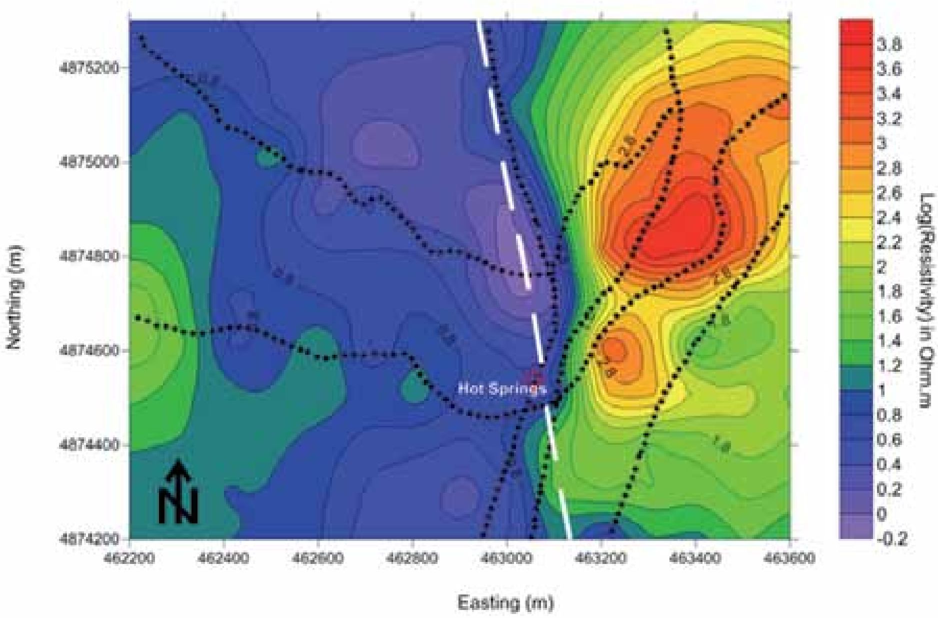

Figure 7. Result of the resistivity inversion at a depth of 50 m. The East side of this figure shows high resistivities in the range 100 to 5000 Ohm m corresponding to the horst. The West side is more conductive and corresponds to the sedimentary infilling of the graben. The filled black circles correspond to the position of the electrodes for the DC resistivity imaging. Fault A bounds the resistive volcanic rocks of the horst on the West side.

The self-potential data of Profile 4 have been inverted using the approach described in Section 2. We use 147 cells, so the number of unknowns in 2D is 294. For the initial model, we consider that the vertical component of the current density is $1x10^{-5}$ A m^{-2} and the horizontal component is null between *x* = 1350 m and 2400 m (for all depths, in the horst) and we take zero for the two components of the source current density elsewhere. The inversion converged in 5 iterations. The RMS fit of the measured self-potential data is 8%. This higher value by comparison with the Mt Princeton case study is due to the noise present in the data as shown on the self-potential profile (see Figure 6). The results are displayed in Figure 8, which shows both a comparison between the measured self-potential data and the fitted data (Figure 8a), as well as the inverted source current density distribution (Figure 8b). Figure 8a shows that the predicted self-potential data follow the trend of the measurement, but to the higher frequency components are attributed to the heterogeneous resistivity of the top soil. Figure 8b shows very well that the main upflow area corresponds to the Neal hot springs. A rough estimate of the flux can be obtained as follows. Because we have inferred previously that the Darcy velocity is roughly the same with the shear zone at Mount Princeton Hot Springs, we assume a mean volumetric charge density on the order of 10 C m^{-3} (similar to the previous case study). Using this volumetric charge density and using the maximum current density determined by the inversion of the self-potential data (2×10^{-5} A m^{-2}) yields a Darcy velocity of 2×10^{-6} m s^{-1}, which is very close (as expected) to the Darcy velocity obtained at Mt Princeton hot springs (see Figure 2). Taking an upwelling area of 100 by 100 meters (100 m is the size of the cell and the lateral extension is determined by the extension of the hot springs, see Figure 5), we obtained a flux of hot water of 2×10^{-2} m^3 s^{-1} (1700 m^3/day).

Conclusions

A new methodology based on the inversion of self-potential data is proposed to quantify the flow rate of ground water along tectonic faults in geothermal areas. This methodology is based on a Gauss-Newton inversion of the self-potential data accounting for the resistivity distribution obtained using resistivity tomography. This approach is applied to a portion of a dextral strike slip fault zone at Mount Princeton Hot Springs in South Central Colorado. DC resistivity and self-potential data exhibit anomalies in agreement with the location of a dextral strike slip fault zone. The quantitative estimate of the flux of the upwelling water along the open portion of this fault agrees with an independent estimate obtained from the production of the hot water at the Mt Princeton recreational area. It is also applied to Neal Hot springs in Oregon where a listric fault bordering a horst is used as preferential flow pathway for the upwelling of the hot water. In both cases, the pattern of shallow ground water flow can be determined using resistivity and self-potential information and some rough estimates of the flow rate have been estimated.

Acknowledgements

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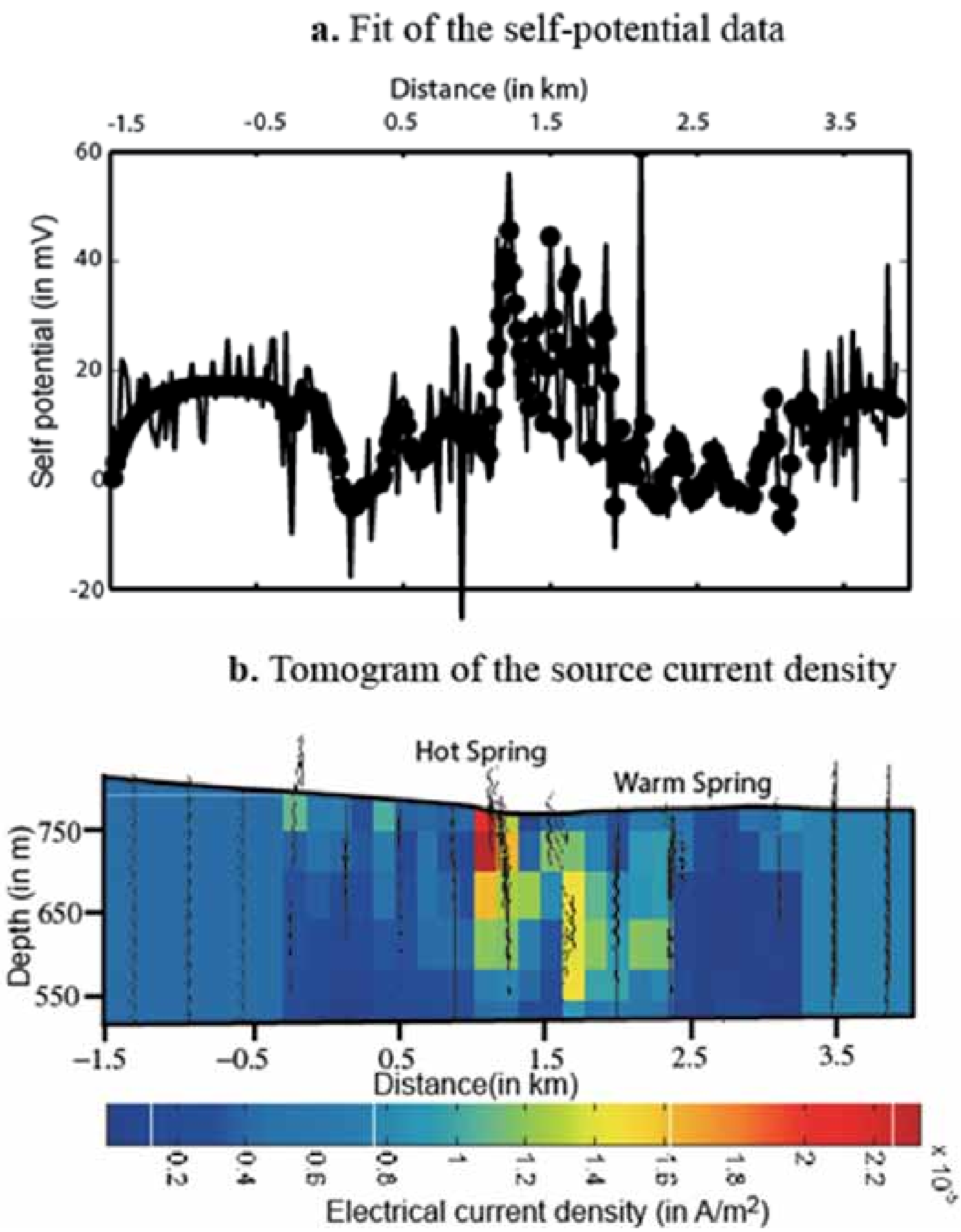


Figure 8. Result of the inversion of the self-potential data using the resistivity inversion to locate and invert the source current density distribution, which in turn can be related to the ground water Darcy velocity. a. Fit of the self-potential data (RMR error 8%). The line corresponds to the (noisy) data while the black filled circles corresponds to the reconstructed self-potential profile based on the source current model distribution shown in Figure 8b using the resistivity distribution shown in Figure 7. b. Tomogram of the source current density distribution showing the focus of the flow along Fault A volcanic rocks of the horst on the West side.

References

Aizawa, K. (2008), Classification of self-potential anomalies on volcanoes and possible interpretations for their subsurface structure, *J. Volcanol. Geotherm. Res.*, *175*, 253-268.

Dimick, N.J. (2007), The ability to predict ground water flow in a structurally faulted river valley with naturally occurring hot springs using multivariate geochemical analyses, MS Thesis, Colorado School of Mines, 93 pp.

Hase, H., T. Ishido, S. Takakura, T. Hashimoto, K. Sato, and Y. Tanaka (2003) Zeta potential measurement of volcanic rocks from Aso caldera, Geophys. Res. Lett., 30, 2210.

Jardani, A., A. Revil, A. Bolève, and J.P. Dupont (2008), 3D inversion of self-potential data used to constrain the pattern of ground water flow in geothermal fields, Journal of Geophysical Research, 113, B09204.

Jardani, A., and A. Revil (2009), Stochastic joint inversion of temperature and self-potential data, Geophys. J. Intern., 179(1), 640-654.

Limbach, F.W. (1975), The Geology of the Buena Vista area, Chaffee County, Colorado, MS thesis, Colorado School of Mines, T-1692.

Linde N.; Doetsch J.; Jougnot D. Genoni, O., Duerst, Y., Minsley, B. J., Vogt, T., Pasquale, N., Luster, J. (2011), Self-potential investigations of a gravel bar in a restored river corridor, Hydrology and Earth Science Systems, 15, 3, 729-742, Doi: 10.5194/hess-15-729-2011.

Loke, M.H., and R.D. Barker (1996), Practical techniques for 3D resistivity surveys and data inversion, Geophysical Prospecting, *44*, 499–523.

Mariner, R.H., J.R. Swanson, G.J. Orris, T.S. Presser, and W.C. Evans (1980), Chemical and isotopic data for water of thermal springs of Oregon, USGS open file report 80-737, 54 pp.

Miller, M.G. (1999), Active breaching of a geometric segment boundary in the Sawatch Range normal fault, Colorado, USA, Journal of Structural Geology, 21, 769-776.

Poldini, E. (1938), Geophysical exploration by spontaneous polarization methods, Mining Mag. London, 59, 278-282.

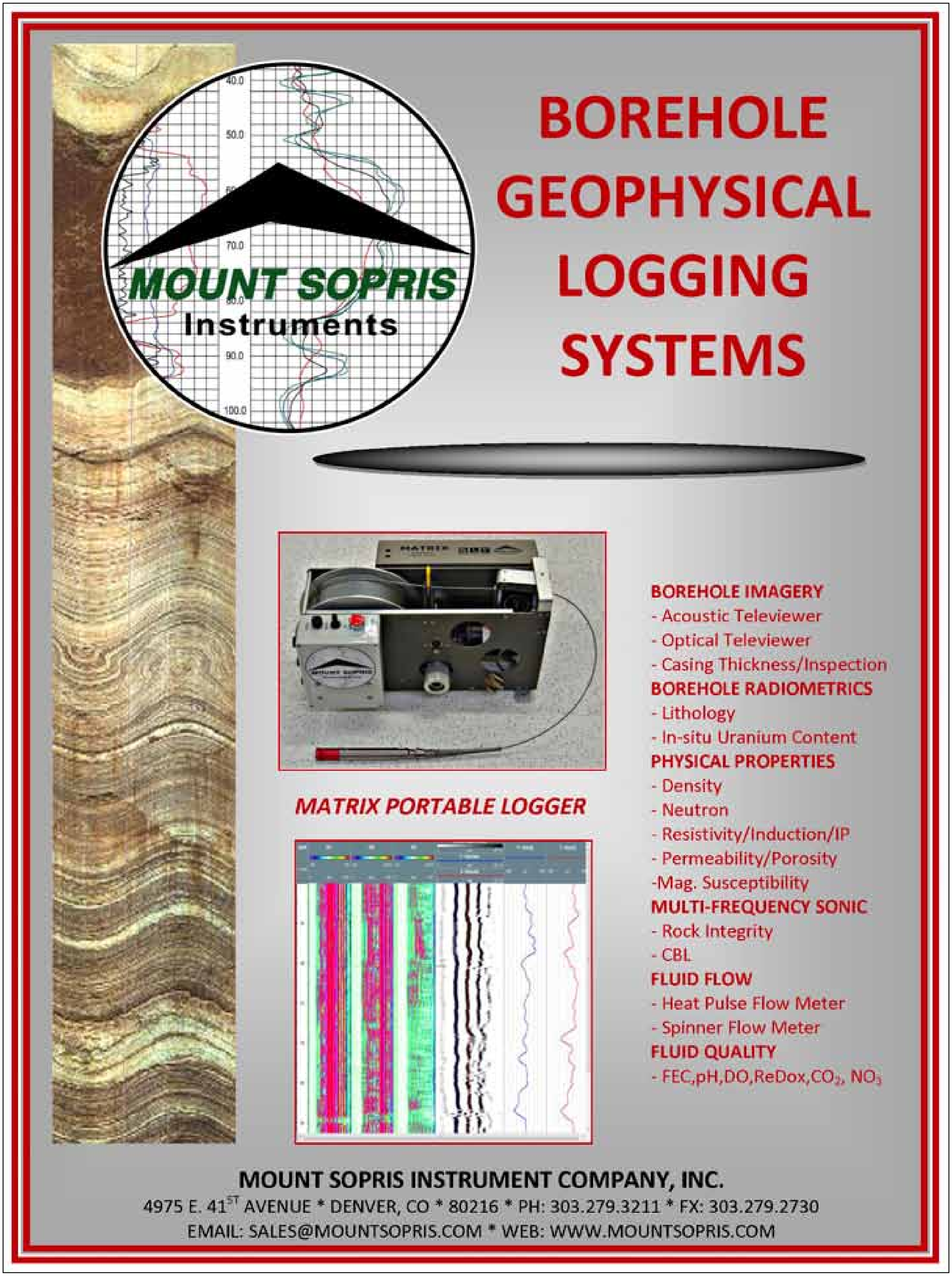
Revil, A., and P. Leroy (2001), Hydroelectric coupling in a clayey material, Geophys. Res. Lett., 28(8), 1643-1646.

Revil, A., V. Naudet, J. Nouzaret, and M. Pessel (2003), Principles of electrography applied to self-potential electrokinetic sources and hydrogeological applications, Water Resources Research, 39(5), 1114, doi: 10.1029/2001WR000916, 2003.

Revil A., A. Finizola, T. Ricci, E. Delcher, A. Peltier, S. Barde-Cabusson, G. Avard, T. Bailly, L. Bennati, S. Byrdina, J. Colonge, F. Di Gangi, G. Douillet, M. Lupi, J. Letort, and E. Tsang Hin Sun, Hydrogeology of Stromboli volcano, Aeolian Islands (Italy) from the interpretation of resistivity tomograms, self-potential, soil temperature, and soil CO_2 concentration measurements, Geophysical Journal International, 186, 1078–1094, 2011.

Tanguy, R., A. Dassargues, S. Brouyere, O. Kaufmann, V. Hallet, F. Nguyen (2011), Assessing the contribution of electrical resistivity tomography (ERT) and self-potential (SP) methods for a water well drilling program in fractured/karstified limestones, J. Applied Geophysics, 75, 1, 42-53, doi: 10.1016/j.jappgeo.2011.06.008.

Tikhonov, A. N., and V. Y. Arsenin (1977), Solutions of Ill-posed Problems, John Wiley, Washington, D.C.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A Fabricated Resistivity Apparatus Used With Other Geophysical Methods to Explore Buried Structure on the Bench and In the Field

Ahmed Lachhab & Aaron P. Booterbaugh
Department of Earth and Environmental Sciences, Susquehanna University, Selinsgrove, PA (*lachhab@susqu.edu*)

ABSTRACT

In the following study, an integration of geophysical methods and devices was implemented on the bench and in the field to identify buried structures. Electrical resistivity and ground penetrating radar methods, including the implementation of a simple constructed electrical resistivity apparatus, an Iris SYSCAL R1 Plus electrical resistivity device and a GPR with a 400MHz antenna were used. The primary goal was to identify the buried foundation of Gustavus Adolphus Hall on Susquehanna University campus and test for the accuracy and reliability of the apparatus. The Wenner array was used to investigate buried structures in a small laboratory model followed by building foundations in the field. The apparatus successfully produced consistent results on the bench revealing the location of small bricks buried under soil material and the buried remnants of Gustavus Adolphus foundation. The GPR survey and an electrical resistivity tomography survey were conducted to further explore the site. Together these methods identified the location of the foundation and proved that the low cost apparatus was a reliable tool for regular use classroom worktables and in the field.

Introduction

Geophysical prospection is useful for many applications, from investigating composition and stratigraphy to exploring objects beneath the ground surface. Geophysical investigation methods include electrical resistivity (ER), ground-penetrating radar (GPR), seismic refraction, electromagnetic surveying, and many other non-invasive techniques to explore the subsurface (Bonomo, 2010; Conyers, 2004; Leucci, 2006; Michelsen, 2008; Victoria, 2011). These methods are currently well established and are routinely and successfully used in the detection and mapping of concealed subsurface archaeological structures (Papadopoulos, 2009). In this study ER and GPR techniques were used to image buried foundations of a historical building at Susquehanna University. An electrical resistivity apparatus was assembled using simple electronic components. This study set its aim on two goals: investigate the buried foundation of Gustavus Adolphus (GA) Hall, and test the accuracy of the electrical resistivity apparatus. Proof that the apparatus could produce results as accurately as any commercial device would be beneficial because the apparatus costs a fraction of the price of a commercially produced device, making it ideal for small studies and general use in a geophysics laboratory setting. More importantly, this is an affordable tool for both instructors and students to experiment and apply theoretical knowledge both in the laboratory and in the field.

While geophysical surveys in geology typically focus on vertical changes in lithology, “archaeo-geophysical” surveys generally concentrate on shallow lateral changes in order to locate and define features (Kvamme, 2003). When lateral changes are attributed to aspects of the archaeological site, high-definition maps and images of buried remains can be produced (Conyers, 2004). ER and GPR techniques are widely applied in archaeological prospection as the rapidly collected data yield a precise image of the subsoil (Cardarelli, 2009). Furthermore, area surveying has been the dominant method, with the production and analysis of surface models (Gaffney, 2008).

Gustavus Adolphus Hall, constructed in 1895, received its name in honor of the 300th birthday of the defender of Protestantism against Catholicism in the Wars of Religion in Europe (1618-48). GA was a relatively large brick building measuring approximately 16.5 m wide by 25 m long with a 4 m by 7 m rectangular structure protruding in the front of the building (Figure 1). The foundation appears to have been constructed with either stone or bricks and all inside supports and floors are believed to have been made of wood. At least half of the basement of GA was six feet tall to allow for athletic equipment to be installed (Housley, 2007). In its lifetime, GA served many functions to Susquehanna University, including dormitories, classes, a gymnasi-

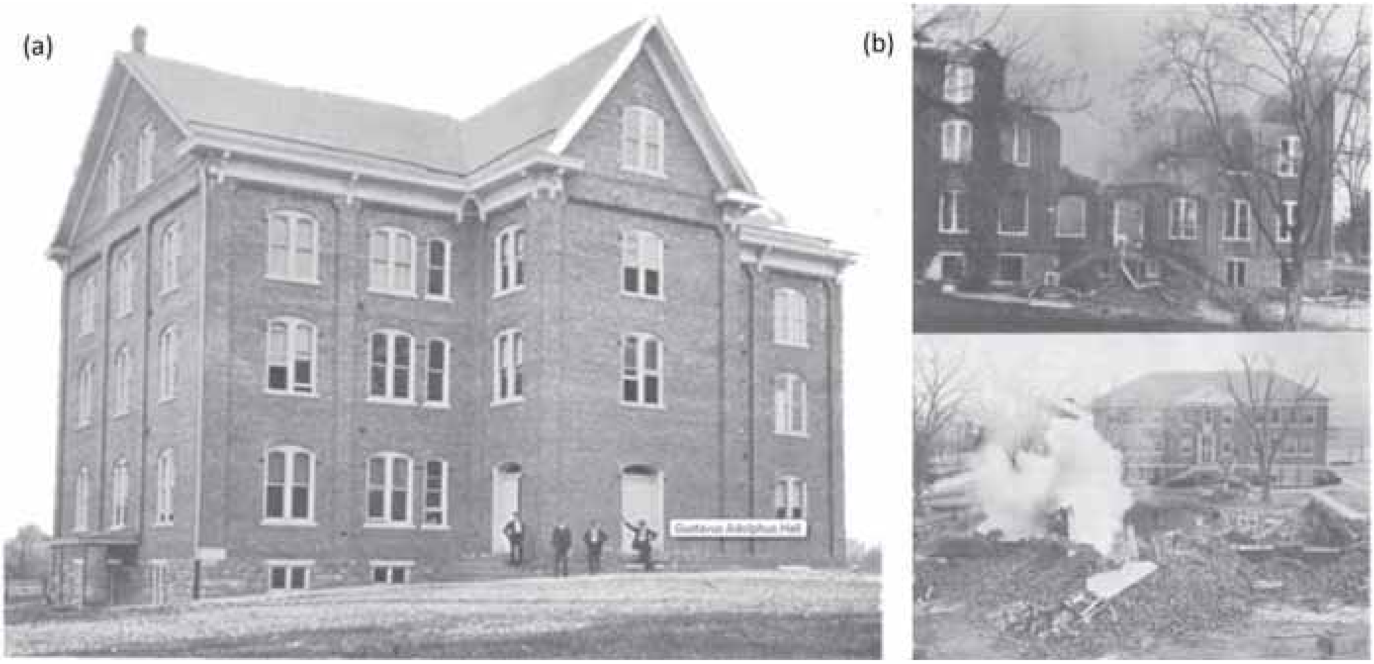

Figure 1: Undated photograph of Gustavus Adolphus Hall as it stood in the middle of campus (a) and during the fire in 1964 (b).

um, a library, a mail room, and a café. Gustavus Adolphus Hall quickly became a popular location on campus among students and for the majority of its existence was known as the student center. GA burned down in 1964 due to an accident involving an out-of-date boiler located in the basement. A large portion of the upper foundation and debris was cleared after the fire; however, some of the foundation still exists. Therefore, GA has become a good archaeological study site to implement different geophysical techniques. Photographs recovered from the Susquehanna University campus library archives portray GA before and during the fire in 1964 (Figure 1). Figure 1a shows the building as it existed before the fire, while Figure 1b shows the building during and after the fire. Figure 2 shows a campus map of Susquehanna University in July of 1962. This map was also collected from Susquehanna University campus library archives.

Materials and Methods

The primary goal of this study was to test the accuracy of the ER apparatus. The apparatus used consists of four electrodes, two EXTECH 540 multimeters, one to measure the current intensity between the outer electrodes and the other to measure the voltage between the inner electrodes. The two multimeters employ a wireless data transmission directly to a computer via a built-in radio frequency transmitter. Power was supplied by a 12 volt deep-cycle battery connected to an APS600-12 Pure Sine Power Inverter to convert the Direct Current (DC) to an Alternating Current (AC). This was done to prevent macroscopic polarization which can cause electrically charged particles to build up on the electrode, potentially leading to inconsistent results. The deep-cycle battery helps to prevent a significant loss of charge while taking measurements, although in theory, any standard battery could be used. All of these components can be purchased for as little as $1,000, making the apparatus ideal for small studies in the field and laboratory, as well as a convenient classroom educational tool. Figure 4 displays the setup of the apparatus.

Similar electrical resistivity apparatus have been used in other studies such as in Herman (2001), Avants et. al (1999). Others have used designs more closely related to a Terrameter such as in Olowofela and Jolaosho (2005). All designs provide identical results; however, the design implemented in this study is simpler and easier to assemble. This is ideal when having to transport the apparatus to the field which at times requires quick disassembly and reassembly.

The Iris SYSCAL R1+ Switch-48 was also used in this study. The device works in the same basic way as the apparatus but has many programmable features that can make data collection more accurate and efficient,

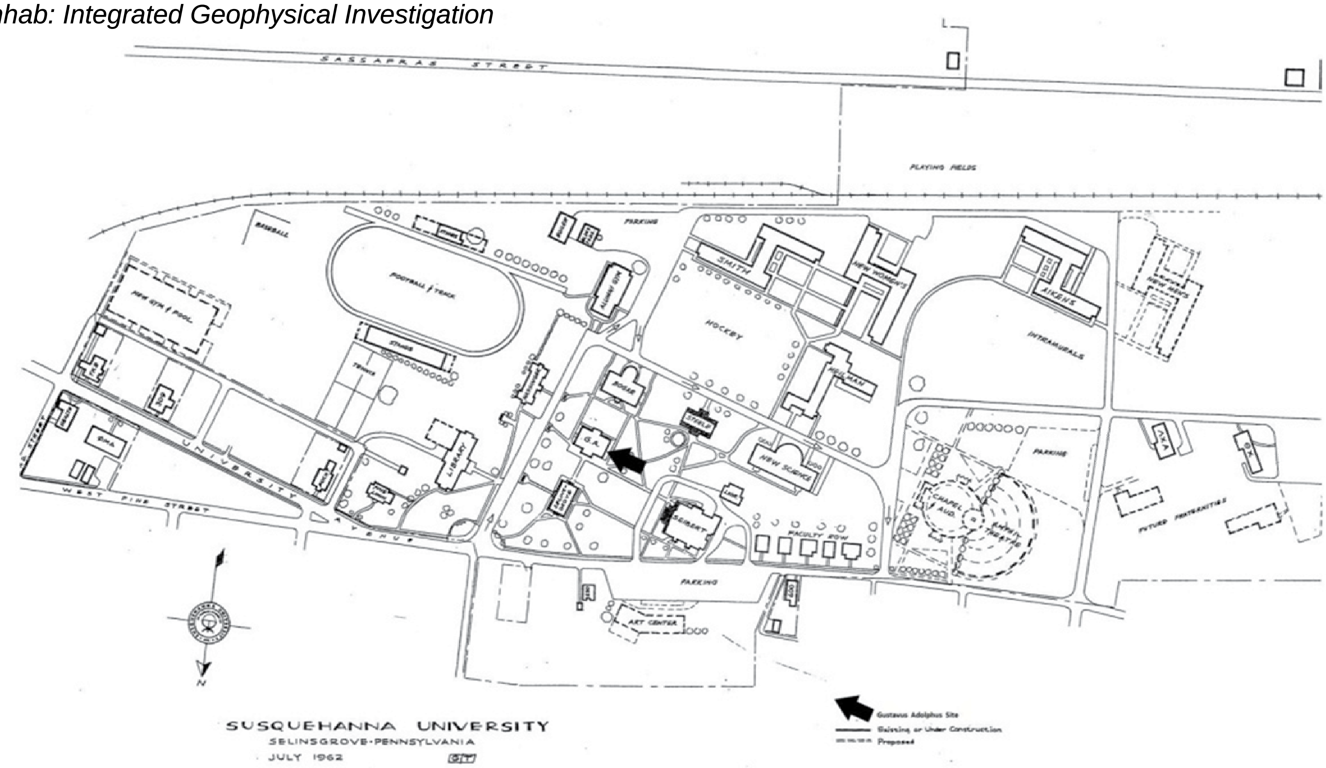

Figure 2: Susquehanna University campus map, July 1962.

including automatic ranging and switching. Another advantage is that the Iris gives an apparent resistivity measurement on site. This can be done with the apparatus but involves some calculation, as seen above. Having apparent resistivity computed on site is useful if trying to locate a specific feature quickly as well as making the entire process of collecting data quicker. Another basic difference between the ER device and the apparatus is that while the apparatus injects a continuous alternating current while data is being measured, the device sends a series of pulses of alternating current and taking an average of current intensity and potential to calculate apparent resistivity. This was found to make no relevant difference in the overall quality of resistivity data collected when investigating the shallow subsurface. Data from the device and apparatus were analyzed and imaged using MatLab.

A SIR-3000 GPR system with a 400 MHz antenna also was used to collect data. RADAN 7 software was used for the data post-processing.

Experimental Setup on the Bench and in the Field

Several tests were conducted on the bench model and in the field. Apparent resistivity mapping techniques implemented in this study are similar to that of Klasner (1981). On the bench level, bricks (2 x 2 x 8 in^3) were buried in a sandy soil leaving approximately two inches of material between the top of the bricks and the surface of the soil. Small stainless steel nails were used as electrodes. For each test conducted on the bench model, the displacement increment (*x)* was taken as 2 in and the electrode spacing (*a)* as 1 in. The soil used in the model was not consolidated and electrodes were pushed manually. Small movements during the placement of electrodes did cause some high values in the resistivity. To prevent these small variations, all nails were secured into a wood meter stick and deployed only once per transect (Figure 3). Only a quarter of an inch of the nails was inserted in the soil.

In the field electrodes were anchored to the ground by a hammer, and the apparatus was moved along the site in a yard cart. In an attempt to accurately map the GA foundation, electrode *a* spacing was set to one meter and the increment displacement *x* was set to 50 cm.

Results and Discussion

Preliminary Apparatus Tests

Three tests were performed to determine if the apparatus is a reliable tool in the field. In these tests, the apparatus was implemented in small controlled laboratory models to explore shallow subsurface wall-like

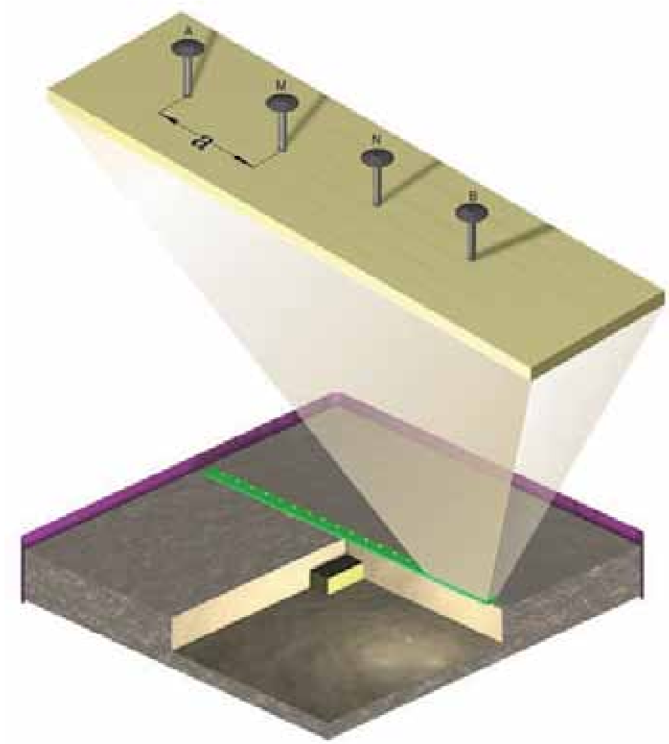

Figure 3: Block diagram showing the model with a buried brick and the wooden slab with nail-electrodes used to measure resistivity. Wenner array configuration is shown by the magnified section of the wooden slab.

structures. The success of these preliminary tests will determine if the apparatus can be applied within the scope of an “archaeo-geophysics” investigation.

Test 1 was conducted as a preliminary step, on a small scale laboratory model, where a small brick was buried beneath the soil surface (Figure 3). A single transect was performed by measuring the apparent resistivity across the location of the brick to determine whether the apparatus was working properly. Figure 5a displays the apparent resistivity versus distance along this direction. The brick was easily identified. The array was moved from a soil of lower resistivity, across a contact of higher resistivity, and returned to the lower resistivity soil. Figure 5b displays the theoretical apparent resistivity curve as an electrodes’ array was moved across a similar contact with a similar k-factor (k-factor is simply a ratio between the resistivity of the two materials [Nostrand and Cook, 1966]). Direct similarities are observed when comparing the results of Test 1 (Figure 5a) with the theoretical curve (Figure 5b).

At this point, it should be understood that for the most part ER profiling, looking for shallow lateral features, depends on the trends of the data and not necessarily the actual values of apparent resistivity. In figure 5, the *a*-spacing to object width ratio seen in the theoretical case can be directly compared to the *a*-spacing to object width ratio in the test. In other words, the object labeled “reef” in Figure 11b is approximately 20 ft wide while the *a*-spacing used in the theoretical model is 30 ft. The brick width and the *a*-spacing used in this test were both 2 in. Another explanation may be solely due to the displacement, (*x*), used. For the scope of this study, this preliminary test showed that the apparatus was performing well and was capable of producing realistic results.

For Test 2, a total of 29 transects were performed on the bench to cover the model. Each transect consisted of 30 data points. The electrode spacing, *a*, was set at 2 inches while the array displacement, *x*, was 1 inch. The goal was to assess if the apparatus was capable of observing more complex subsurface features, replicating field conditions more accurately. Apparent resistivity data was placed in a 3D surface plot using MatLab (Kattan, 2010). The apparent resistivity values were treated as heights above a reference plane to isolate the brick locations. Figure 6a displays the results from this test while Figure 6b shows the arrangement of the bricks within the model.

The location of the bricks can clearly be identified from the apparent resistivity profile. Higher peaks of resistivity values toward the edges and in some locations of the profile can be explained by fissures caused by the

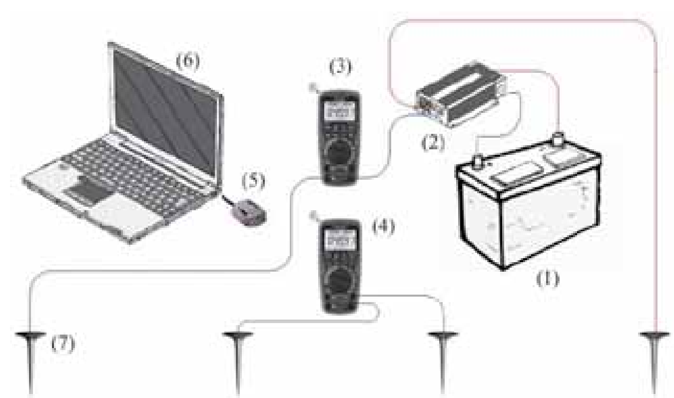

Figure 4: Sketch of electrical resistivity apparatus constructed based on the following components: (1) Car Battery (2) DC to AC inverter (3) Voltmeter (4) Ammeter (5) wireless data collection via a radio frequency transmitter from Multimeters directly to Laptop (6) Laptop and (7) Electrodes.

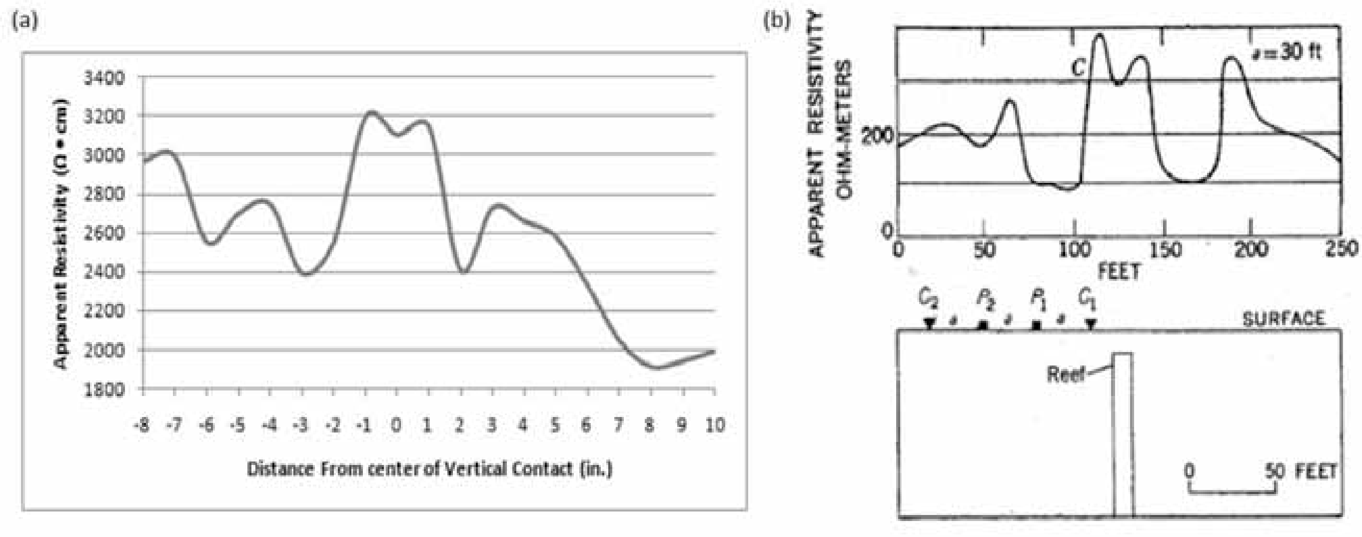

Figure 5: (a) Results from Test 1, (b) theoretical curve for the contact (reef) (Nostrand 1966).

desiccation of the soil. The fissures hinder electrical currents from traveling in the medium and therefore increase resistivity. This test conclusively revealed that the apparatus can identify complex subsurface features.

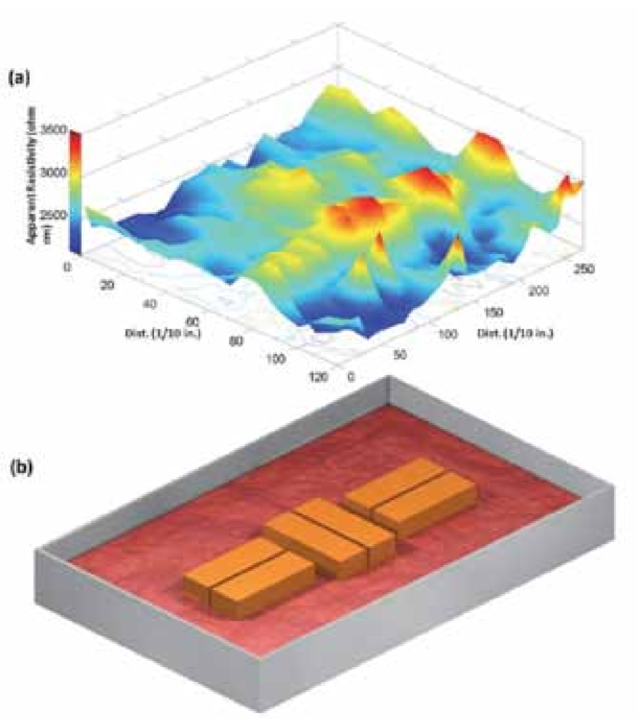

Figure 6: (a) Apparent resistivity 3-D surface plot for bench level test 2. Areas of darker shade indicated regions of higher apparent resistivity while areas of lighter shade indicate lower apparent resistivity. (b) Model diagram revealing the approximate location of bricks.

The final test was conducted before the apparatus was to be applied in the field. In this test the apparatus was directly compared to the Iris SYSCAL R1 Plus. A single transect was performed onsite using both the apparatus and the ER device. Results from this test can be seen in Figure 7. The test showed that the apparatus was capable of reproducing similar results to that of a commercial device. The apparatus recorded slightly lower apparent resistivity values than the ER device. This small resistivity difference can be explained by the difference in the frequency output of SYSCAL R1 Plus and the APS600-12 Pure Sine Power DC to AC Inverter. This shift may also be a result of the Iris ER device's ability to auto-ranging, the ability to automatically adjust the input current based on subsurface conditions. However, this slight difference between the two systems can be ignored since ER surveying relies more on the trend of apparent resistivity to reveal features rather than the direct apparent resistivity values. For ease of viewing, see dotted line in figure 7where the ER apparatus results were shifted by the average delta between the ER device results and the ER apparatus results.

Electrical Resistivity Profiling of GA site

After successful achievement on the bench level, the apparatus was implemented in the field at the GA site. A total of seventeen 42-meter transects were performed using one meter for *a*-spacing and a displacement *x* of 50 cm. Figure 8, shows a reconstruction of the site, based on electrical resistivity results, showing some of the remains of the buried foundation. The

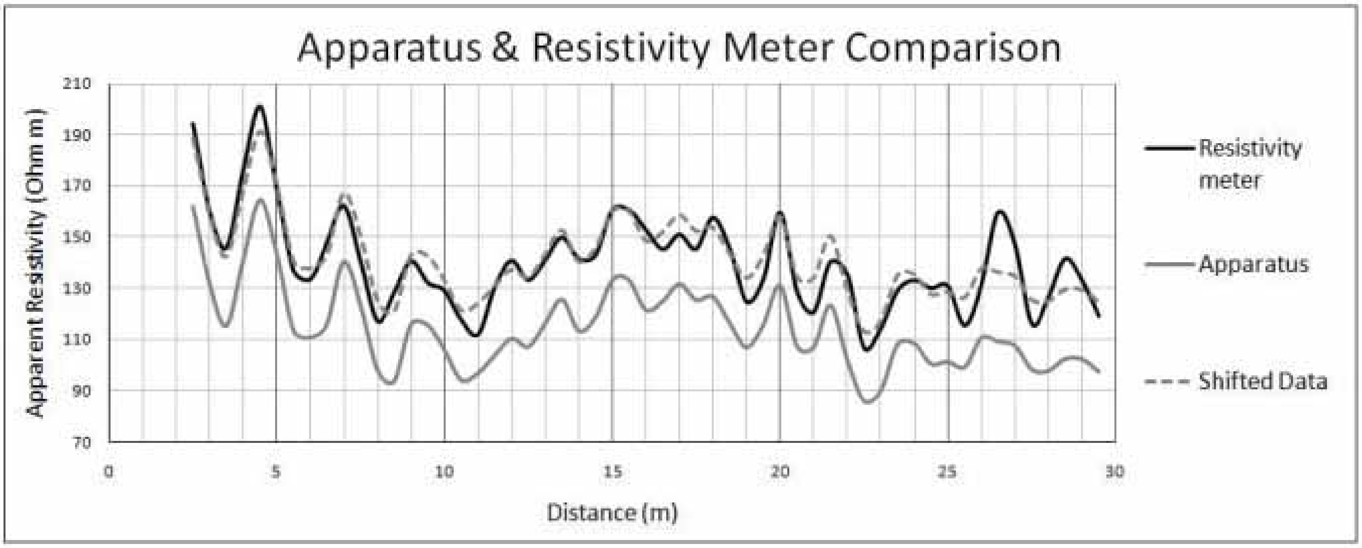

Figure 7: Comparison of ER apparatus and Iris SYSCAL R1 Plus. The data produced from both devices follow the same pattern. Dotted line indicates the apparatus results shifted by the average delta between the ER device results and the ER apparatus results.

measured data from the entire survey was plotted as a 3D apparent resistivity surface using MatLab. The trees in GA site were added to the figure because their roots affect the resistivity reading in certain areas. Additional information was taken from the campus map of July 1962 and a basic sketch of the building from the time of construction recovered from archives at Susquehanna University's campus library. The illustrated walls in Figure 8 are understandably exaggerated to better visualize the foundation of the building and how it matches the resistivity contour plot. Abnormal peaks seen in the apparent resistivity data of Figure 8 are most likely due to the root systems of the trees at the site. These trees appear to have been planted directly on the boundary limits of the foundation walls shortly after the Gustavus Adolphus fire in 1964. The roots, being highly resistant to electrical current, can heavily distort any ER data collected on the large scale. However, the apparent resistivity data collected from the survey matched well with GA dimensions collected from old aerial photos, campus maps, and historical information from Housley's book on the history of Susquehanna University.

There appear to be two possible explanations of the resistivity data collected in the survey. One is that the survey revealed the location of the higher resistivity foundation walls as illustrated in Figure 8. Under this hypothesis, an important feature to note is the "L-shape" feature seen in the apparent resistivity data and depicted in the illustration. If we refer back to the photo of GA hall and the campus map, Figures 1 & 2, it can be seen that the front of the building has a similar feature, a rectangular extension protruding from the front and back of the structure. This explanation of the data has several shortcomings; however; the location of the "walls" makes the structure look slightly larger

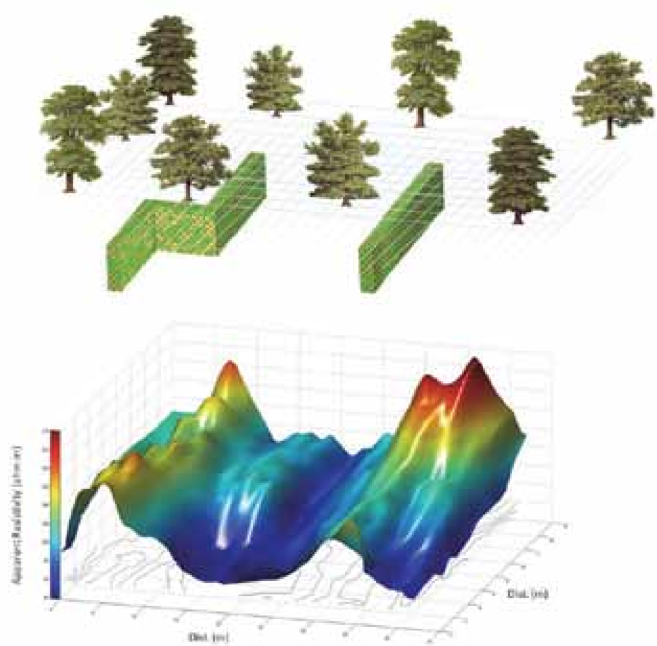

Figure 8: Apparent resistivity data in 3-D surface plot collected using ER apparatus at GA plot, Susquehanna University, Selinsgrove, PA (bottom). Location and arrangement of trees and approximate location of buried foundation in respect to apparent resistivity data.

than the outside references (mentioned previously) have indicated and, under this explanation, it appears as if the entire building was not revealed by the investigation. These shortcomings lead to a second possible explanation of the data in Figure 8, that the survey revealed the lower resistivity "cavity" left from the excavation of GA's basement. Further in the study this explanation became more favorable because this "cavity" matches nearly perfectly with GA dimensions collected from outside references, some collected after the survey took place. Another reason is that a later Electrical Resistivity Tomography (ERT) survey conducted over a segment of the foundation led to the belief that the foundation was of a lower resistivity than the surrounding medium.

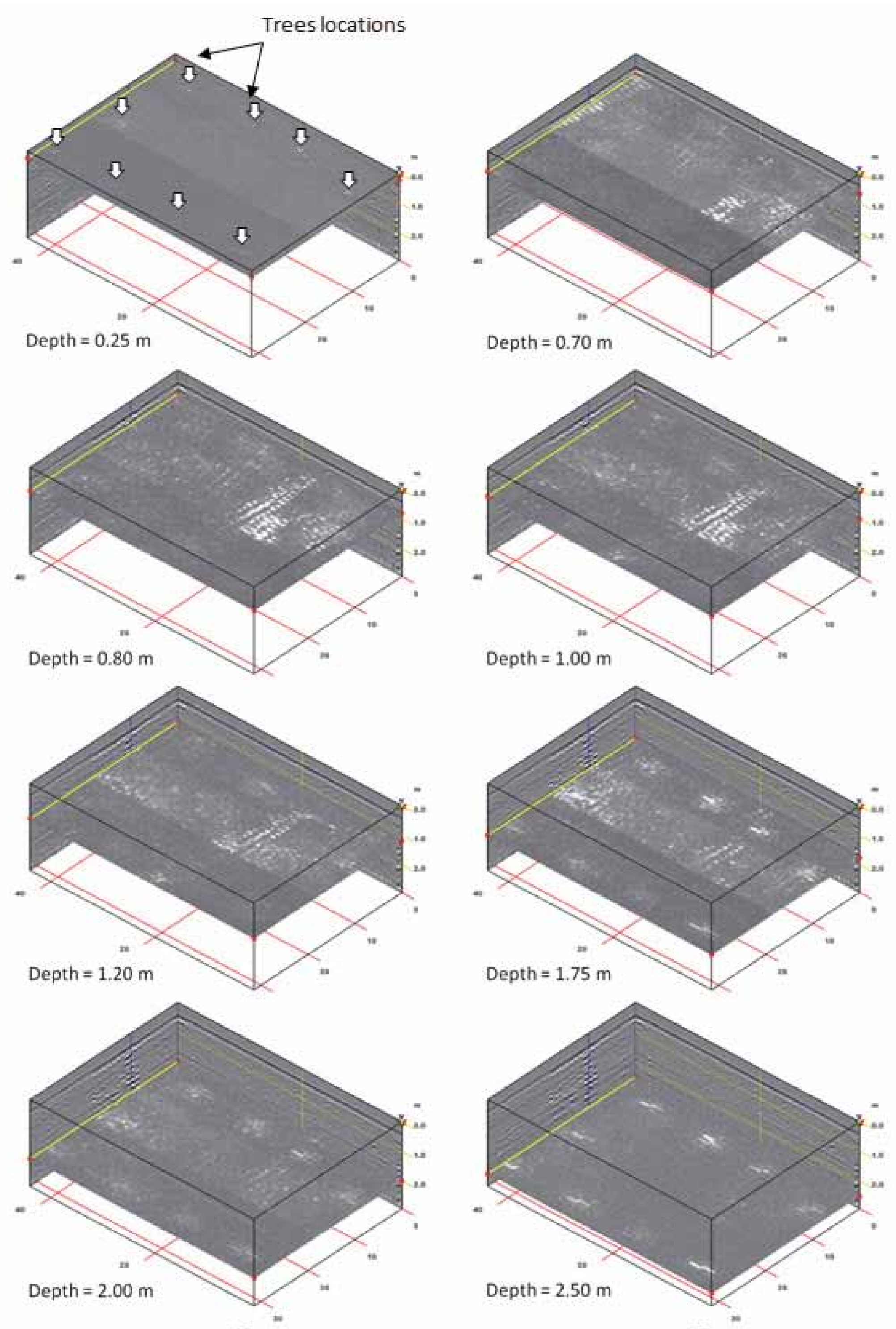

Figure 9: Apparent resistivity data in 3D surface plot from the ER apparatus at GA plot, Susquehanna University, Selinsgrove, PA (bottom). Location and arrangement of trees and approximate location of buried foundation in respect to apparent resistivity data.

Ground Penetrating Radar Profiling of GA site

To further understand the Gustavus Adolphus site and the apparent resistivity data acquired from the ER profiling done with the apparatus, a GPR profiling survey was conducted in the summer of 2011. In this effort, a 400MHz antenna was used with a SIR 3000 GPR system. GPR profiling can quickly produce high definition images if the dielectric constants of the subsurface mediums are noticeably different. A total of seventy-four 45 m transects separated by 50 cm each was conducted at the GA site. The goal of this extensive survey was to capture the entire foundation structure. Collected data was investigated through a

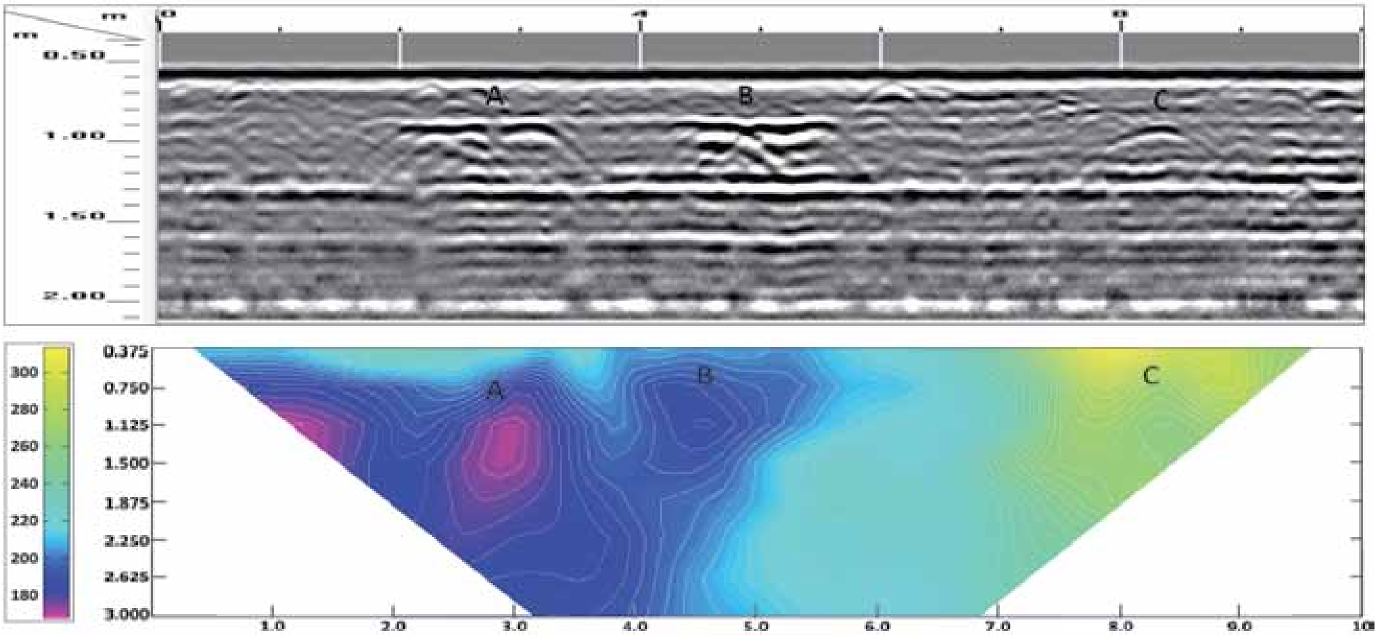

Figure 10: Ten meter transect over GA rear foundation wall. GPR transect (top) and ERT cross section (bottom). Three distinguishable features (A, B, C) can be seen in both cross sections. ERT cross section is apparent resistivity in ohm/meters. X and y axes are in meters for both cross sections.

3D analysis in RADAN 7 software and broken into slices of varying depths to reveal foundation features. Figure 9, displays the results from the GPR profiling survey of GA. Eight slices at different depth intervals were selected in order to best show the upper and lower extent of the foundation.

The GPR unit was moved around the trees in a way to make them appear as light rectangular features extending from a very shallow subsurface to a deeper level. The foundation appears at about 0.70 m of depth and continues to below 2.50 m. The foundation looks most robust between depths of 0.80 and 1.00 m (Figure 10). An important feature to note in this survey is the "L-shape" revealing the rear of the building which is not shown in Figure 1, although the general shape including this "L-shape" feature of the rear can be seen in the campus map (Figure 2). The GPR profile provided some important information on the current condition of the foundation and clues to the extent in which the foundation and debris were cleared after the fire in 1964. It appears as if the front and side structures of the foundation were either removed or broken down. The GPR profile revealed no convincing evidence that these segments of the foundation are intact as complete structures. Results from the GPR can be directly related to result from the ER profiling survey seen in Figure 8. Notice the foundation appears at 20 m along the x-axis in the GPR profile; similarly, at 20 m along the x-axis in the ER profile a depression related to a low apparent resistivity appears. Evidence from an ERT transect discussed next supports the idea that the foundation material is of a lower resistivity than the surrounding earthen material.

ERT over the Foundation Wall

Electrical resistivity and GPR profiling has, thus far, provided a good understanding of the location and condition of the GA foundation. ERT surveying, on the other hand, can give good insight into the actual resistivity and depth at which features lie. Data collected from the ERT transect was important to understand the ER profile shown in Figure 8, because it revealed that the foundation material was of a lower resistivity than the surrounding soil. Once the GPR profile clearly identified the location of the rear foundation wall (Figure 9) a 10 meter transect perpendicular to the wall was selected for an ERT survey. For this survey the ER device, Iris SYSCAL R1+, was used. The maximum electrode spacing used (a = 2.0 m) in the survey provided an estimated depth of 3 m. GPR was conducted along the same transect so that features identified through the ERT survey could be compared to that of GPR and directly related to the GPR profiling survey. Figure 10, represents the data from the ERT survey generated with MatLab as well as a GPR cross section of the same transect within the GA site. It can be clearly seen from Figure 10 that the GPR and ERT cross sections closely agree with one another. The two features seen on the left, A and B, are believed to be related to the GA foundation based on GPR profiling from Figure 8. Another feature, C, revealed by the GPR and ERT cross sections is believed to be a root or concrete pipe based on high apparent resistivity measurements of the area. It is difficult to determine exactly the nature of this feature; however, the well-defined hyperbola and its location point to a tubular feature. It can be seen that feature A, although centralized, extends at depth which would be an expected characteristic for the foundation. Feature B, on the other hand, does not appear to have this same characteristic. An explanation of this could be that the higher resistivity region surrounding feature C is distorting feature B at this depth. This explanation is feasible because as the current travels deeper it flows through a large portion of the cross section and, again, the ER device records an apparent resistivity rather than the exact resistivity of a specific location.

Conclusion

This study had two primary goals: 1) to demonstrate that the electrical resistivity apparatus was fully capable of producing results comparable to that of a commercially available ER device, and 2) to investigate a building foundation based on multiple approaches and see how comparable the results were. The apparatus succeeded on the bench level and also provided a highly detailed image of the site. The study also shows how a low cost apparatus could be valuable to researchers with low funding.

Through an integration of several geophysical methods a building foundation was successfully identified. The initial ER profiling along with data from an ERT transect revealed a potential area of low resistivity left from the excavation of the GA basement. GPR data clearly identified the rear wall of the foundation and conclusively revealed that a large portion of the foundation was either removed or destroyed after a fire in 1964. It was found that, in the scope of this study, GPR was best suited for quickly identifying the foundation; however, electrical resistivity data should not be overlooked because they can provide valuable insight into the composition of features where GPR does not. The use of multiple geophysical methods best contributed to the knowledge of the site. Similar results may also be obtained at other archaeological sites.

Acknowledgements

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References

Avants, B. & others, 1999. Measuring the electrical conductivity of the earth. American Journal of Physics 67:7

Bonomo, N., Osella, A., and Ratto, N., 2010. Detecting and mapping buried buildings with Ground-Penetrating Radar at an ancient village in northwest Argentina. Journal of Archaeological Science 37:3247-3255

Cardarelli, E. & Di Filippo, G., 2009. Integrated geophysical methods for the characterization of an archaeological site. Journal of Applied Geophysics 68:508-521

Conyers, L., 2004. Ground-Penetrating Radar for Archaeology. Rowman &Littlefield Publishers, Inc., New York

Gaffney, C., 2008. Detecting Trends in the Prediction of the Buried Past: A review of geophysical techniques in archaeology. Archaeometry 50,2:313-336

Herman, R., 2001. An introduction to electrical resistivity in geophysics. American Journal of Physics 69:943-952

Housley, D., 2007. Susquehanna University, 1858 – 2000: A goodly heritage. Rosemont P&P Corp. 93-332

Kattan, P., 2010. Matlab for Beginners. Petra Books

Klasner, J. & Calengas, P., 1981. Electrical Resistivity and Soil Studies at Orendorf Archaeological Site, Illinois: A Case Study. Journal of Field Archaeology 8,2:167-174

Kvamme, K., 2003. Geophysical Surveys as Landscape Archaeology. Soc. American Archaeology 68,3:435-457

Leucci, G. & others, 2006. 3D image of seismic refraction tomography and electrical resistivity tomography survey in the castle of Occhiola. Journal of Archaeological Science 34:233-242

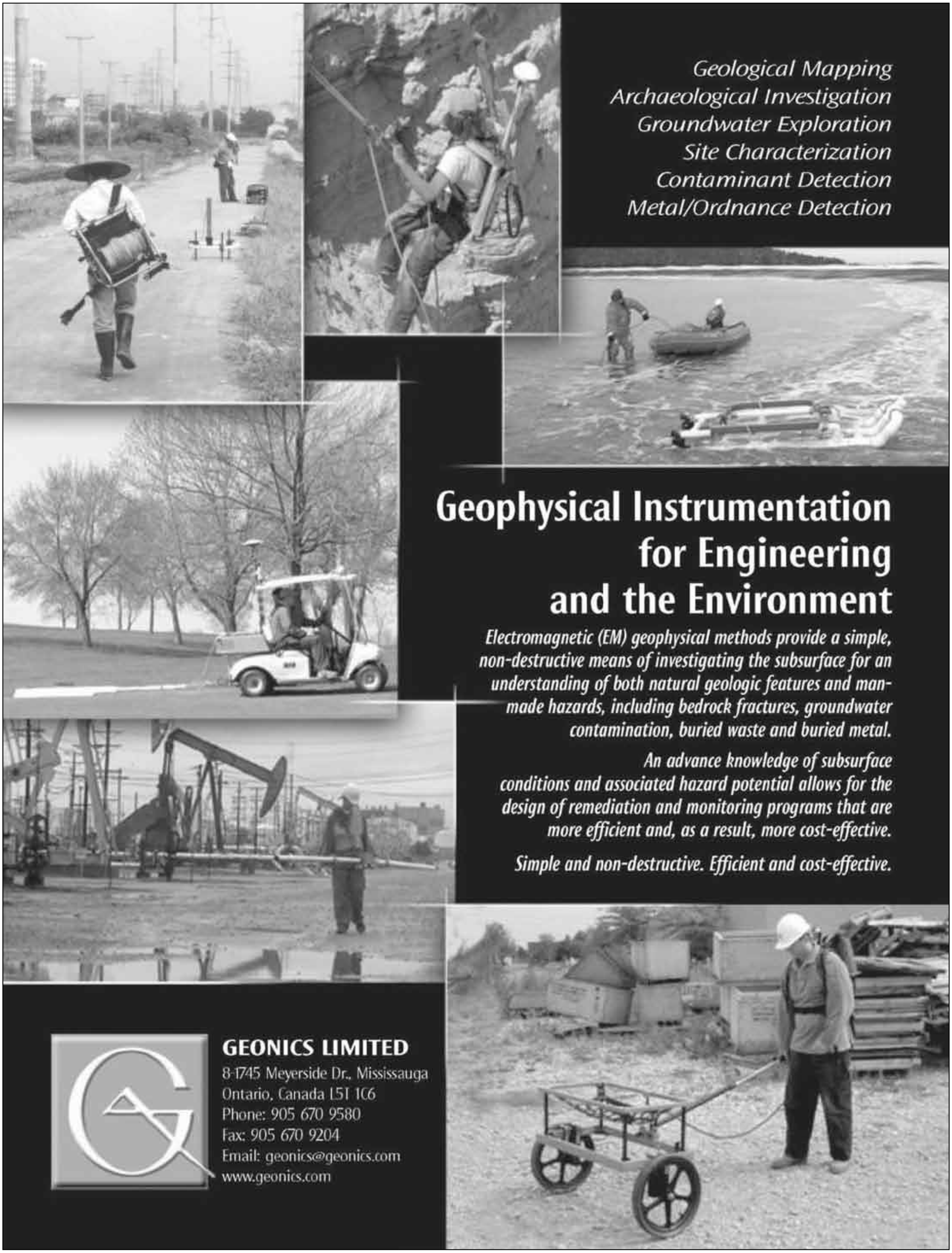
Michelsen, F., & Sachpazis, C., 2008. Application of GPR to Archaeological Site Characterization. AOA Geophysics

Olowofela, J., & others, 2005. Measuring the electrical resistivity of the Earth using a fabricated resistivity meter. European Journal of Physics 26:501-515

Papadopoulos, N., & others, 2009. Geophysical investigation of tumuli by means of surface 3D Electrical Resistivity Tomography. J. Appl. Geophys. 70:192-205

Van Nostrand, R.G. and Cook, K.L., 1966. Interpretation of Resistivity Data. US Department of the Interior

Victoria, B., de la Vega, M., and Nestor, B., 2011. Contribution for the resistivity method to characterize mud walls in a very dry region and comparison with GPR. Journal of Archaeological Science



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EEGS and SEG/NSG Discuss Increased Cooperation

The spring of 2012 will mark the 25th anniversary of the SAGEEP conference and the 20th year of existence for EEGS. Both EEGS and the Near Surface Geophysics (NSG) Section of SEG have served the near surface geophysics community during a period of significant growth and technological advancements. These two organizations have had significant overlap in membership and mission. In recent years, these two organizations have worked together for the benefit of the discipline and their members. Examples include:

- Joint publication of at least two significant resources, the 2005 Near Surface Geophysics volumes and the recent “Advances in Near-Surface Seismology and Ground-Penetrating Radar” volume
- Online release of current and past issues of the Journal of Environmental and Engineering Geophysics and SAGEEP proceedings, through the EEGS Research Collection of the SEG Digital Library
- Board-level support (“Level 3”) from SEG for special joint sessions at the 2011 and 2012 SAGEEP conferences
- EEGS Foundation’s support of the SEG Foundation’s Geoscientists Without Borders® program through a special luncheon at SAGEEP and other promotional activities.

Over the years, there have been numerous discussions between the two organizations about how to best serve the needs of the near-surface geophysical community. Recently, EEGS and the SEG have jointly created a task force to formally consider how the two organizations might better accomplish this. The committee has begun meeting and will make recommendations to their respective society board of directors and members. The committee members have been selected and sanctioned by the leaderships of both organizations. They are:

Peter Annan, Sensors & Software

John Bradford, Boise State University

William Doll, Battelle

Mark Dunscomb, Schnabel Engineering

Doug Laymon, Tetra-Tech

Rick Miller, Kansas Geological Survey

John Nicholl, URS

Peter Pangman, SEG

Bruce Smith, USGS

John Stowell, Mount Sopris

The committee has agreed that the first priority must always be to make recommendations that are in the best interest of the members and near surface geophysical community, as opposed to prioritizing organizational interests. As such, they will initially consider several key aspects of what makes an excellent near-surface organization, and review how these can best be addressed for the furtherance of the overall near surface geophysics community. These aspects include governance, publications, meetings/conferences, membership, student services, professional development, management, and finances. Several possible recommendations to members might result from the committee’s assessment, for example: 1) no change from current level of interaction; 2) identification of new joint initiatives between the two organizations; 3) sharing responsibility for existing publications or meetings; 4) greater use of SEG by EEGS for publications or management; 5) formal reorganization of the relationship between EEGS and SEG/NSG, perhaps including some form of “merger”. Each of these possible outcomes carries potential benefits and compromises that must be weighed carefully by the committee and by the members of each organization.

The committee has had short meetings at SAGEEP 2011 in Charleston and at the 2011 SEG Annual Meeting in San Antonio and has held several conference calls. A weekend meeting is scheduled for December 3-4 in Denver. We encourage members of both organizations to contact any of the committee members listed above to voice their opinions and offer suggestions to the committee.

24 October 2011

POSITION FOR GEOPHYSICIST

Open Ground Resources and Global Geophysical specialize in the application of geophysical techniques for the characterization of the near surface with a strong focus on engineering and environmental applications. We have a position for an experienced geophysicist who will be based at our offices in Pretoria, Gauteng, South Africa. This position is available immediately.

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The geophysicist will be mainly responsible for data processing, interpretation and the writing of high quality reports. Field work may also be required from time to time and the applicant must be willing to travel.

Skills required:
Strong interpretation and report writing skills
Working knowledge of specialized software applications and the ability to learn new software tools rapidly (For example, Radan, GPR-Slice, Encom PA)
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Ability to work independently and as part of team

Minimum Requirements:
B.Sc (Hons) Geophysics
3-5 years experience, preferably in engineering, environmental and geotechnical geophysics with knowledge in the application and interpretation of the gravity, magnetics, seismic refraction, electrical resistivity and ground penetrating radar techniques
Strong reporting writing skill an absolute requirement
South African resident or in possession of valid work permit (We can assist applicants with obtaining work permits)

Detailed CV's may be submitted to alten@openground.co.za to the attention of Alten du Plessis. The closing date for applications is 15 January 2012.

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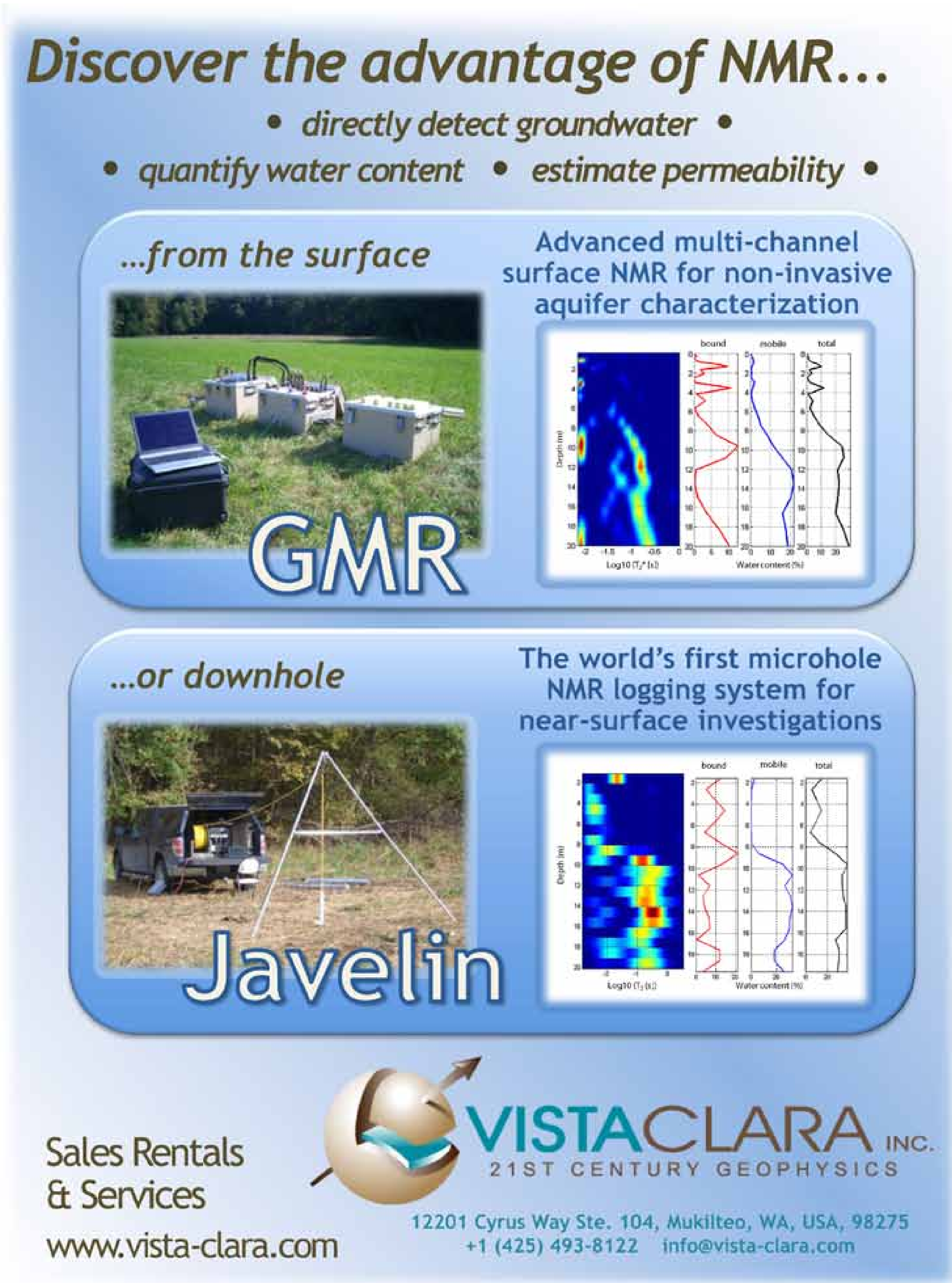
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http://www2.fz-juelich.de/icg/icg-4/index.php?index=2

and/or contact: Dr. Sander Huisman, e-mail: s.huisman@fz-juelich.de

Payment will correspond to salary grade 13 (75%) of the Collective Agreement for the Civil Service (TVöD). The implementation of equal opportunities is a cornerstone of our staff policy at Forschungszentrum Jülich, for which we have received the “TOTAL E-QUALITY” accolade. Applications from women are therefore particularly welcome. We also welcome applications from disabled persons.

Please send your application with the relevant documentation (giving the names of referees) quoting the reference code D095/2011ZT, until January 6th, 2012, to: Institute for Bio- and Geosciences (IBG), Mr. K. Beumers, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany.

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.

SAGEEP 2012 Workshop

Seismic refraction methods - Unleashing the potential and understanding the limitations

Thursday March 29, 2012, Tucson, Arizona

We would like to extend an invitation to all interested individuals to attend or contribute a paper for a workshop on seismic refraction methods.

Seismic refraction tomography is widely used to address a broad range of near-surface problems. Many practitioners hold tomographic methods in high regard, because these approaches typically yield a velocity model that is simple (smooth) and that is thought to be more representative of near-surface structures than blocky or layered models. Some have raised concerns with smooth models and suggest that a layered model is more appropriate. Others focus on starting models, and contend that the use of simple or otherwise inappropriate starting models can bias the outcome of the inversion. Still others believe that the best approach is to apply different inverse methods in order to elucidate the range of model nonuniqueness.

During the first portion of this full day workshop we will discuss concerns regarding tomographic analysis and we will describe algorithms that address these issues. In addition, we will explore emerging opportunities for improved refraction solutions, including full waveform and three-dimensional methods. Speakers will include Derecke Palmer (Univ. New South Wales, Australia), Julian Ivanov (Kansas Geological Survey), Priyank Jaiswal (Oklahoma State), and Colin Zelt (Rice University).

Contributed presentations will be included in the afternoon session (as oral or poster presentations), and a panel discussion will round out the day. We look forward to an informative day including lively discussion of many aspects of seismic refraction work. Those who are interested in making a contributed presentation should send a title and 200-word abstract to Seth Haines, *shaines@usgs.gov* no later than February 27, 2012. Presenters whose submissions are accepted will be notified no later than March 5, 2012. Abstracts or (optional) full papers from all presentations in the workshop will be compiled on a CD-ROM and distributed to all conference participants. This workshop is intended to mesh with and extend beyond the SAGEEP 2012 technical session on seismic refraction tomography that will be held on Wednesday March 28, allowing us to delve deeper into key questions and to engage in open discussion. For more information, contact the workshop organizers, Bill Doll (*dollw@battelle.org*), Seth Haines (*shaines@usgs.gov*) and Colin Zelt (*czelt@rice.edu*).

SAGEEP 2012 Workshop

Hydrofracking 101: What Is It, What Are The Issues, and How Can Geophysics Help?

Thursday March 29, 2012, Tucson, Arizona

We invite all with an interest in hydrofracking from the industry, regulatory, water supply, and geophysical monitoring perspectives to attend this workshop

Hydrofracking is a hot-button topic among industry groups, regulators, and citizens in many parts of the U.S. where it is being used to enhance hydrocarbon production from vertical and horizontal wells. Issues of concern related to hydrofracking include ensuring an adequate water supply, monitoring of fracking operations, induced seismicity, and possible water-quality impacts, yet few outside industry understand the hydrofracking process. This workshop is intended to educate attendees on the hydrofracking process, issues of concern, and geophysical approaches to addressing those issues. Topics to be covered include an introduction, history, and description of the types of hydrofracking; possible impacts associated with injection, water use, and the fracturing process; current geophysical monitoring of hydrofracking; and geophysical approaches that could address issues of concern to regulators and the public.

AAPG's Division of Environmental Geosciences has agreed to co-sponsor this workshop on critical issues surrounding hydrofracking. Major topics include:

- Hydrofracking Impact and Policy Issues
- What is Hydrofracking?
- Hydrofracking Issues from the Industry Perspective
- Hydrofracking Issues from the Regulatory Perspective
- Regional Water Needs, Availability, and Impact
- Geophysical Microseismic Monitoring
- Induced Seismicity?
- Geophysical Case Histories
- Geophysical Approaches to Address Hydrofracking Issues

Those interested in presenting on one or more of these topics should submit an abstract of 200 words or less to the workshop conveners no later than **February 27, 2012**. Accepted presenters will be notified no later than **March 5, 2012**. Abstracts or (optional) full papers from all released presentations will be compiled on a CD-ROM and distributed to all participants. Papers will be solicited for possible special issues of DEG's journal Environmental Geosciences and EEGS' Journal of Environmental & Engineering Geophysics. For more information, please contact workshop conveners Mike Jacobs (Michael.jacobs@pxd.com), Chip Groat (cgroat@mail.utexas.edu), Jeff Paine (jeff.paine@beg.utexas.edu), and Bruce Smith (bsmith@usgs.gov).

CONFERENCE REGISTRATION OPEN

25th ANNIVERSARY

SYMPOSIUM ON THE APPLICATION OF GEOPHYSICS TO ENGINEERING & ENVIRONMENTAL PROBLEMS

SAGEEP25

TUCSON, AZ | MARCH 2012

"MAKING WAVES: GEOPHYSICAL INNOVATIONS FOR A THIRSTY WORLD"

Make plans to attend this special SAGEEP! Access the EEGS web site (WWW.EEGS.ORG/SAGEEP) for full program details, Sessions, Short Courses and Workshops listings, and conference registration information.

Conference Highlights:

Oral & Poster Presentations - Over 200 submitted

Special Sessions and Presentations

Invited Keynote Speaker: William deBuys, Pulitzer Prize finalist, presenting "Hotter and Drier: Climatic Challenges of the 21st Century Southwest"

Exhibitor Outdoor Demonstrations at Sunset Point - against a spectacular backdrop of the Catalina Mountains

Luncheon Speaker: EEGS / Geonics Early Career Award Recipient

Best of 2011 EAGE/NSGD

Field Trips: Arizona Sonoran Desert and Kartchner Caverns

SAGEEP Hospitality Events - Special Entertainment and Silversmith Presentation at Ice Breaker

Student Social Event

EEGS Foundation Luncheon

Special 25th Anniversary Conference Evening Dinner, Entertainment and Special Celebration

New! 3 Short Courses (Surface Waves/ Advanced Surface Waves and Resistivity/ IP/SP) and 4 Workshops (Seismic Refraction: Potential and Limitations, Hydrofracking 101, Trends in Shallow Resistivity and IP, and Transportation Geophysics)

El Conquistador Reservations Deadline: March 7 **WWW.EEGS.ORG/SAGEEP**

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.

ICEEG 2010 and 2012: China's Premier Forum for Near-Surface Geophysics

by Jeffrey G. Paine, Bureau of Economic Geology, The University of Texas at Austin (*jeff.paine@beg.utexas.edu*)

Figure 1. Group photograph of attendees at the 4th ICEEG on the Chengdu University of Technology campus, June 2010.

With the 5th International Conference on Environmental and Engineering Geophysics (ICEEG) just around the corner (June 2012), it is timely to give those contemplating a trip to Changsha a brief description of the 4th ICEEG, which was held in Wuhan and Chengdu, China, in June 2010. Several speakers, including Torleif Dahlin, Jan van der Kruk, Lanbo Liu, Alan Green, Maik Thomas, Janet Simms, John Bradford, Chih-Ping Lin, Jianghai Xia, and Jeffrey Paine traveled to China to give invited presentations on geophysics applied to geohazards at the conference and an associated workshop. These events, hosted by the China University of Geosciences (Wuhan) and the Chengdu University of Technology, were part of the 4th ICEEG chaired by Runqiu Huang, Xuben Wang, Jianghai Xia, Yaoguo Li, Shen Yu, and Yixian Xu. Highlights included a one-day workshop co-sponsored by SEG's Near Surface Geophysics Section at Wuhan, a visit to the laboratories on the campus of the China University of Geosciences, two days of geohazard-focused presentations at the conference, and a spectacular and sobering two-day field trip to visit the areas affected by the Great Sichuan Earthquake (magnitude 8) of May 12, 2008. The field trip included stops Beichuan town (pictured below) former community of about 20,000 that has been abandoned and left largely as it was after the earthquake as an "earthquake park" and a memorial to the thousands of residents who lost their lives during the earthquake and accompanying landslides. The total loss of life is estimated at more than 70,000; more than 4,000,000 were left homeless.

Figure 2. Landslide scarps and May 12, 2008 earthquake ruins, Beichuan, Sichuan Province, China.

Building on the success of the 4th conference, the 5th International Conference on Environmental and Engineering Geophysics will be held on the campus of The Central South University, Changsha, China (*www.csu.edu.cn*), June 15 to 18, 2012. Changsha, a city of 7 million people, is located 130 mi south of Wuhan. Be sure to mark your calendars and submit your abstract, which is due February 28, 2012. Like the first four ICEEGs, ICEEG 2012 will be a unique opportunity for all attendees to share current research results and experiences in near-surface geophysics with an international audience in a culturally and geologically stimulating environment with gracious and generous hosts. See the ICEEG website (*http://www.iceeg.cn/english/index.htm*) for details!

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- ☐ Humanitarian Geophysics
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- ☐ UXO
- ☐ Other ______

Specific Areas Involved

- ☐ Borehole Geophysical Logging
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- Subscription to the ***FastTIMES*** Newsletter
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- **Networking** and continued **communication** on issues of interest to the organization

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

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Student Support Endowment

This endowed fund will be used to support travel and reduced membership fees so that we can attract greater involvement from our student members. Student members are the lifeblood of our Society, and our support can lead to a lfetime of involvement and leadership in the near surface geophysics community. Donations of $50.00 or more are greatly apreciated. For additional information about the EEGS Foundation (a tax exempt public charity), visit our website at www.eegs.org and click on Membership, then "Foundation information". You may also access the EEGS Foundation at http://www.eegsfoundation.org.

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The EEGS Foundation is designed to solicit support from indivudals and corporate entities that are not currently Corporate Members (as listed above). We recognize that most of our Corporate Members are small businesses with limited resources, and that their contributions to professional societies are distributed among several organizations. The Corporate Founder's Fund has been developed to allow our Corporate Members to support the establishment of the Foundation as we solicit support from new contributors. As such, Corpoate Founders received special recognition for donations exceeding $2500 made before May 31, 2010. These sponsors will be ackowledged in a form that may be posted at their SAGEEP booth for years to come, so that individual members can express their gratitude for the support.

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	0012	1988-2000 (CD-ROM)	$150	$225
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SAGEEP Short Course Handbooks

	0027	Principles and Applications of Seismic Refraction Tomography (Printed Course Notes & CD-ROM) - William Doll	$125	$150
	0028	Principles and Applications of Seismic Refraction Tomography (CD-ROM including PDF format Course Notes) - William Doll	$70	$90
	0007	2002 - UXO 101 - An Introduction to Unexploded Ordnance - (Dwain Butler, Roger Young, William Veith)	$15	$25
	0009	2001 - Applications of Geophysics in Geotechnical and Environmental Engineering (HANDBOOK ONLY) - John Greenhouse	$25	$35
	0011	2001 - Applications of Geophysics in Environmental Investigations (CD-ROM ONLY) - John Greenhouse	$80	$105
	0010	2001- Applications of Geophysics in Geotechnical and Environmental Engineering (HANDBOOK) & Applications of Geophysics in Environmental Investigations (CD-ROM) - John Greenhouse	$100	$125
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	0021	Geophysics Applied to Contaminant Studies: Papers Presented at SAGEEP from 1988-2006 (CD-ROM)	$50	$75
	0022	Application of Geophysical Methods to Engineering and Environmental Problems - Produced by SEGJ	$35	$45
	0019	Near Surface Geophysics - 2005 Dwain K. Butler, Ed.; Hardcover Special student rate - 71.20	$89	$139
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ALL ORDERS ARE PREPAY

Sold To:

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

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

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

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

Merchandise Order Information:

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

SUBTOTAL – MERCHANDISE ORDERED:

TOTAL ORDER:

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

GRAND TOTAL:

Payment Information:

☐ Check #: ______________ (Payable to EEGS)

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

☐ Visa ☐ MasterCard ☐ AMEX ☐ Discover

Card Number: ______________ Cardholder Name (Print): ______________

Exp. Date: ______________ Signature: ______________

Three easy ways to order:
Fax to: 303.820.3844
Internet: www.eegs.org
Mail to: EEGS
1720 S. Bellaire St., #110
Denver, CO 80222-4303

THANK YOU FOR YOUR ORDER!

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

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