FastTIMES

June 2011
Volume 16, Number 2
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Magnetic and EM Techniques

The VLF - EM16 Receiver: the Ultimate All-Terrain, All-Weather Instrument

Also in this issue . . .

- New Feature: The New Geoscience
- Tucson hosts SAGEEP 2012
- Best of SAGEEP 2011
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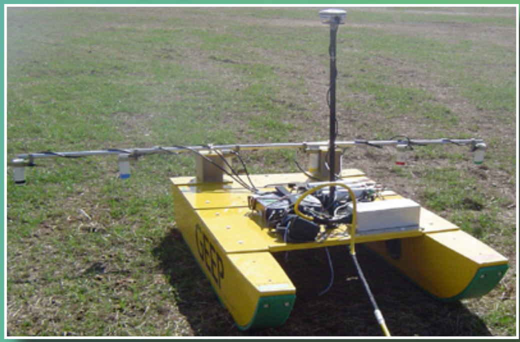
. . . and more!

Geophysical Exploration Equipment Platform



On the Cover

This issue features magnetic and electromagnetic techniques for investigating near surface features and environmental applications. **Left:** George Reynolds consucts a VLF-EM survey in subzero temperature. **Right:** EM16 survey by George Reynolds in the Sahara desert.

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 application of geophysical techniques for earthquake research. ***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 August 21, 2011 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.

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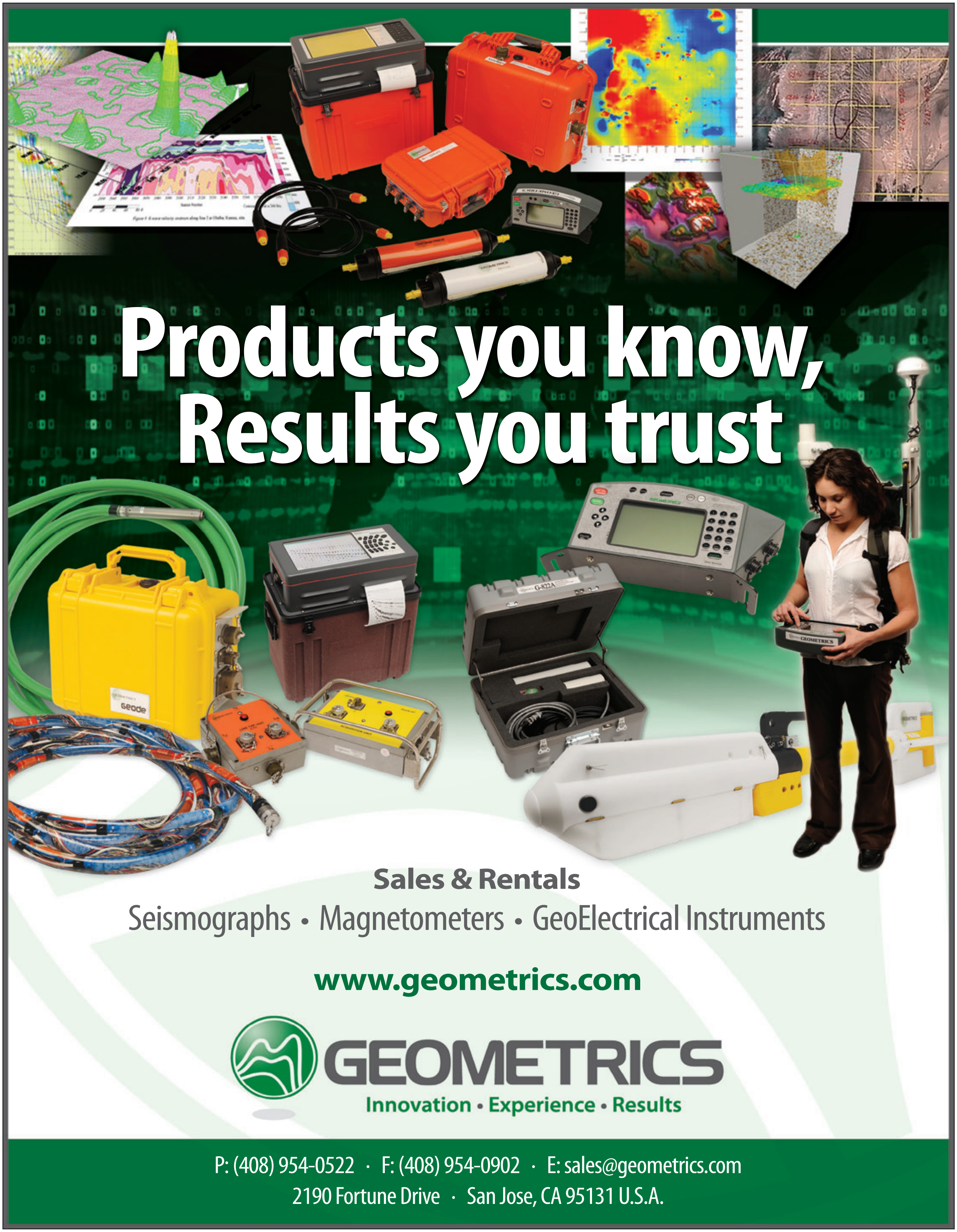
FastTIMES is published electronically four times a year. Please send articles to any member of the editorial team by August 21, 2011. Advertisements are due to Jackie Jacoby by August 21, 2011.



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Calendar

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

2011

June 22–24	*International Workshop on Advanced Ground Penetrating Radar 2011*: presents a wide range of scientific and technical information of high standard to scientists, engineers and end-users of GPR technology. Aachen, Germany
June 28–July 7	*IUGG General Assembly*: International Union of Geodesy and Geophysics (IUGG) General Assembly, Melbourne, Australia
August 21	Deadline for submission of articles, advertisements, and contributions to the September issue of *FastTIMES*
August 23–26	*4th IASPEI / IAEE International Symposium*: will cover diverse topics from the state of the art of ground motion research and practice, Santa Barbara, CA
September 12–14	*Near Surface 2011*: 17th European Meeting of Environmental and Engineering Geophysics, Leicester, England
October 9–12	*GSA 2011 Annual Meeting*: Archean to Anthropocene: The past is the key to the future, Minneapolis, Minnesota
November 20–23	*10th SEGJ International Symposium*: features the interdisciplinary integration of geosciences for better understanding and modeling of invisible underground structures and processes, Kyoto, Japan
November 21	Deadline for submission of articles, advertisements, and contributions to the December issue of *FastTIMES*
December 5-9	*2011 AGU Fall Meeting*. San Francisco, CA

2012

January 15–17	*International Conference on Earth Sciences and Engineering*: brings together academic scientists, leading engineers, industry researchers and scholar students to exchange and share their experiences and research results about all aspects of Earth Sciences and Engineering, Zurich, Switzerland
February 26–29	*22nd ASEG*: the conference theme 'Unearthing New Layers' recognises that transformational change in our industry can still occur, Melbourne, Australia


Exploring the World
Choosing the Right Magnetometer
Magnetic applications in near surface geophysics are broad: mineral exploration, archaeology, environmental & engineering, geological hazards, UXO detection. It is important to choose the right solution.
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President's Message: Get involved!

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

Reno, 1997, my first time in Nevada. I rented a car, the cheapest one possible, and headed straight from the airport down Route 395. Out of Truckee Meadows, through Carson City, a right on Route 50, and I was rising into the mountains of western Nevada. All four cylinders of that not-so-mighty chariot gave their best to carry me up the steep road to Lake Tahoe. I pressed the accelerator to the floor and 18-wheeler trucks with their trailers full and hazard lights flashing still passed me heading up the slope. It wasn't much of a car, but the trip was well worth it. Lake Tahoe is truly a beautiful sight. The deep blue water set against green evergreens, the splendor of peaks, and white of melting snow are an image that remains clear in my mind. After circling the lake and with my first goal accomplished, I headed back to Reno on the Mt. Rose Highway. I wondered if the rest of my travels would also be worth my trip to Nevada. Brian Milner, from my company, had convinced several managers to bring me to SAGEEP. How would this SAGEEP conference turn out?

Over the next days, I learned new concepts, heard case history presentations, and took notes. I spoke with instrument manufacturers about new innovations and how to best tweak settings for various applications. Just as important, what I discovered while in Reno was that the SAGEEP conference is the gathering of a tightly knit professional community named EEGS. As Jeff Paine wrote in 2008, "… EEGS is made up of an intrepid, fearless, energetic, innovative, entrepreneurial, and hard-working mass of individuals who never cease to amaze." I couldn't agree more!

Want proof? No problem! Several years ago the EEGS Board took a big step forward and began the process of creating a foundation. The foundation committee took their charge and ran with it. They learned how foundations work, developed goals and bylaws, created a Board of Directors, incorporated as a separate entity for the purpose of supporting EEGS, obtained non-profit 501.3c status, and trained to improve their fund raising skills, and began receiving tax free donations for furthering the EEGS vision. Why go through all that hard work? Because they dare to ask the "what if" questions and consider the possibilities. What if EEGS funded students to attend SAGEEP and learn more about near surface geophysics? What if EEGS coordinated with universities to develop or support a near surface geophysical field camp? What if EEGS had on-call and trained near surface geophysicists to support disaster relief efforts? What if EEGS helped needy communities around the world find potable water supplies that improved health and quality of life? The list is long.

Here's the most exciting part: these are beginning to take shape! The EEGS Foundation joined with Geoscientists Without Borders (GWB) at this past SAGEEP to support humanitarian projects around the world. Thanks to the EEGS community, the joint luncheon was hugely successful and exceeded all hopes. Nearly 100 people attended, the Foundation donated all proceeds to GWB, and helped raise visibility for what GWB is doing.

I decided in 1997 that the rest of my Nevada trip was definitely worth the effort. Looking back now, I can say even more emphatically that the trip paid dividends that have grown in value over time. What is often most valuable isn't visible immediately. It's the opportunity to grow, get involved, and make a difference. What's your view on being involved? Send me an email, I'd like to hear your thoughts.

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:

Allen, Micki
Arumugam, Devendran
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"Guiding Technologies Today -Preparing for a World of Needs Tomorrow"

From the Editor's Desk: All the latest news!

Moe Momayez, Editor-in-Chief (moe.momayez@arizona.edu)

From time to time, EEGS makes its presence felt directly on the ground. David Nobes, our colleague and GEOPHYSICS Associate Editor and Senior Lecturer in Geophysics, Department of Geological Sciences at the University of Canterbury, wrote to us in March 2011, a few weeks after a large earthquake occurred in New Zealand. He asked us for access to the EEGS online collection while the campus was in disarray thanks to the effects of the earthquake. In less than 24 hours, our board responded by providing unlimited guest access to David Nobes and his students. We wish David and his students the best of luck and hope that the transition from lecturing in tents back into the classroom went smoothly.

Starting with this issue, *FastTIMES* will present a new feature under the title 'The New Geoscience'. We seek one or two page contributions from graduate students or recent graduates in geosciences to share news of the projects they are working on. Please forward your submission to the editors or send me an email if you have any questions.

EEGS is very pleased to welcome Rachel Berkowitz as a special contributor. Rachel will tackle current topics and issues in the field of geoscience and review recently published scientific books. She is a PhD Candidate at the BP Institute in the Department of Earth Sciences, Cambridge University, UK. She is also a freelance science journalist and has developed articles and scientific press releases for the Science magazine and a few Cambridge University publications. In her first article in *FastTIMES*, on page 34, she explores a new approach on CO2 sequestration. Her contemporary, Will Rayward-Smith studies the migration of injected fluids using a combination of analytical models and laboratory experiments. Will's article on page 37 provides an insight into the world of fluid dynamic geophysicists.

As the General Chair of SAGEEP 2012, I am very excited to report that the EEGS board has selected Tucson to host the 25th meeting of our society. The symposium will take place March 25-29 at the luxurious four-diamond Hilton El Conquistador Golf and Tennis Resort (http://www.hiltonelconquistador.com). The resort is located on 500 acres of serene, colorful high Sonoran Desert terrain, nestled right at the foot of the breathtaking Santa Catalina Mountains. The SAGEEP 2012 organizing committee is preparing a special program to commemorate a quarter century of scientific and professional accomplishments, provide a strong technical program under the leadership of Gail Heath, Senior Geophysicist at the Idaho National Laboratory, and a number of exciting field trips that showcase both the natural beauty of the southwest and groundbreaking research being conducted by the University of Arizona's science and engineering faculties. I look forward to welcoming you here in Tucson, Arizona! Save the dates on your calendar and please contact me if you are interested in presenting, participating or sponsoring an event at our symposium.

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.

Environmental and Engineering Geophysical Society

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 (March 2011, cover image at left) has been downloaded more than 11,000 times as of June 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.*

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Journal of Environmental & Engineering Geophysics

June 2011 Volume 16 Issue 2

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The Environmental and Engineering Geophysical Society

Journal of Environmental & Engineering Geophysics
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Editor's Scratch

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

EAGE's Near Surface Geophysics Journal, June 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 June issue of EAGE's **Near Surface Geophysics** journal.*

EAGE
EUROPEAN ASSOCIATION OF GEOSCIENTISTS & ENGINEERS

Near Surface Geophysics

Volume 9 · Number 3 · June 2011

Content

www.nearsurfacegeophysics.org

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Success with Geophysics

***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 electromagnetic and magnetic techniques applied to near surface investigations.*

Thirty-Five Years Surveying with the EM-16 VLF Receiver

George Reynolds, Metrics Consulting, Wicklow, IRELAND (metrics-consult@iol.ie)

Possibly the geophysical instrument with the highest sales[1], apart from the magnetic compass, the Geonics EM-16 is undoubtedly the most versatile piece of geophysical kit ever invented. It's apparent simplicity belies its complex fundamentals of operation but even these can be simplified, so it has appeal to a wide range of users, from beginners to the most advanced. But my interest in it stems from the fact that it has paid my bills and kept me in business during the twenty or so years I have been a self-employed geophysicist, as well as making many discoveries of significant groundwater and mineral resources with it. Here is the story of my love affair with this strange-looking device.

As a young research student, I was doing my MSc in geophysics at the Dublin Institute for Advanced Studies in 1972 when a colleague, David Howard, brought in a Geonics EM-16 instrument borrowed from Leicester University (UK). I had only worked with gravity, magnetics and DC resistivity equipment and this instrument was quite different from anything I had seen then. We read the manual and then switched it on. It emitted a shrill whistling and crackling sound, a cross between frying sausages and a tin whistle. Rotating it to find the null we had no luck, the noise was constant, no sign of a null. We hadn't realised that in the presence of fluorescent strip lighting, not to mention the other sources of interference in the lab, it couldn't have worked. What was even more intriguing was the plug-in tuning unit - it was marked "EWB" corresponding to the VLF transmitter at Odessa and I had just read the latest Frederick Forsythe thriller "The Odessa File". The other tuning units read like the old "world band" radios with their exotic stations on the dial, but in place of Hilversum, Droitwich and Athlone, we had Cutler (Maine) , Rugby (UK) and Bordeaux (France). A few days later, David and I took the EM-16 out in the field and ran a few profiles across a mineralised fault zone in nearby County Wicklow and to our pleasant surprise we got a "text-book" anomaly, perfectly symmetric and with the quadrature phase inverted, just like the Geonics manual had portrayed.

My next encounter with an EM-16 was in my first job as a geophysicist with Irish Base Metals. They were leasing three "Radem" units from Crone Geophysics and I had some difficulty finding out what in fact these instruments were measuring. In fact, they measured only the in-phase component and the field strength, the latter being more a function of time and geography than anything in the ground. We had already paid so much in rental that I suggested that we buy an EM-16 instead. The 16R resistivity attachment was also purchased as I thought it might give us useful information of overburden thickness to correct our gravity data. I had already trained up an IP crew so we now had only one operator for one EM-16, and the Radem units were returned to Crone.

A long series of experiments with DC resistivity sounding, the EM-16R and the EM-31, cross-checked by an Atlas Copco "Cobra" percussion drill and some diamond-drilling holes had established that the ubiquitous glacial till in Ireland varied between 0 and 20 metres in thickness and 80 to 130 Ohm-metres in resistivity generally. The EM-16R was not so useful when the till was only a few metres thick, because we found that the depth penetration was so great that we were often detecting the base of a

1 Geonics estimate about 2000 were made

particularly resistive crystalline limestone formation, the Carboniferous Waulsortian “Reef” Limestone, even at places where it was 200 metres thick! This led to the realisation that the EM-16R was more useful as a bedrock mapping tool and in turn to a mapping programme that went on for years. Till thickness determinations were too imprecise to allow corrections to be made to gravity data, even with DC soundings, so that idea was scrapped.

The EM-16R operators walked over much of rural Ireland as Irish Base Metals held a large block of prospecting licences (PLs) and they were an interesting bunch of guys, mostly from farming backgrounds and able to relate to farmers they encountered and obtain permission for other geophysical and geochemical surveys. They were keen prospectors too and brought back mineralised float and noted outcrops, so the EM-16R mapping programme was of immense value, even if those guys were paid the lowest rates in the company. They also recorded the EM-16 in-phase and quadrature data as a routine and over the years we tested many low-resistivity/high phase angle anomalies with the drill-rig.

The most interesting anomaly was where the apparent resistivity dipped below 100 Ohm-m and the phase angle rose about 45 degrees signifying that there was something more conductive than till underneath the till. Sometimes this was glacial clay or marl formation but we also drilled sulphides. One such sulphide anomaly at Charlestown, Co. Mayo, in the NW of Ireland almost became a copper mine. The operator there, Tom Greaney, had walked across a very difficult stretch of peat bog and found a classic VLF-EM “crossover” anomaly and a large resistivity “low” with high phase angles. This area had been covered by various surveys, including in-house deep sampling geochemistry and airborne INPUT (Transient EM) flown by Geoterrex, without any anomalies being detected. A combined IP/Resistivity sounding clinched it as we found a strong chargeable bedrock conductor under 20 feet of peat and underlying sand and gravel deposits. It was drilled and an Ordovician copper sulphide body was outlined, unfortunately cut off at depth by a thrust fault. Otherwise it might have made sufficient tonnage for an open pit operation. What was of geologic interest was a fossil gossan under the overlying Silurian sediments with fragments incorporated within the overlapping Carboniferous basal conglomerates. We looked at the deep geochemical samples and realised that the sampling had not penetrated the glacial deposits, but the coarse fractions showed a few pyrite grains. Had this become a mine, it would have been attributed 100% to the EM-16/16R combination.

This technical success resulted in several EM-16/16Rs being purchased, not only by Irish Base Metals but by rival exploration companies who had heard about our “secret weapon”! Another unintended consequence of all this activity was an accident where Tom reversed his car accidentally over the EM-16 which he had left on the grass while having his lunch, and smashed it. We claimed the cost of a replacement on the company insurance and I kept the remains for spare parts. Tom argued that he should get to keep it, but I was the boss! On an impulse, I sent it to Geonics asking for a quotation to repair the damaged unit as many of the components were more or less intact, the damage being mainly mechanical although the antenna was destroyed. The box arrived before my letter and Geonics had repaired the unit before they realised I was looking for a quotation first! We agreed on a price and I was now the proud owner of a fully-reconditioned unit which has served me well for over thirty years.

I left Ireland in 1983 to work for Billiton Española, based in Madrid but with projects in the Pyrite Belt and elsewhere in Spain. Gravity and EM were the main techniques in use in the Pyrite Belt and the huge Neves-Corvo deposit had been discovered just over the border in Portugal. An on-going programme of gravity and multi-frequency horizontal-loop ground EM using the Apex Parametrics “Max-Min” was in progress as a follow-up to an airborne INPUT survey. The Max-Min required a full-time crew of four people (two operators and two line cutters/surveyors) and I subsequently discovered later that it found nothing that we could not detect with one operator and an EM-16. The INPUT survey likewise discovered nothing. Then, working on a new hypothesis we embarked on a programme of gradient-array IP and transient EM using a large fixed-loop (600 x 300 m) and the Geonics EM-37, and made the discovery of the Aguas Teñidas polymetallic sulphide body at a depth of 300 metres.

When Billiton began to shed jobs in 1987, I set up on my own with the EM-16/16R as my only asset. Thanks to some loyal colleagues, I soon had work on a variety of projects in mineral and groundwater exploration as well as geotechnical work. It wasn't long before the EM-16 had marked up a number of minor successes, locating deposits of celestine, talc, bentonite, gold in shear zones, groundwater in fracture zones and re-activated karst where groundwater extraction was causing subsidence. The EM-16/16R was invariably the first technique I would use to characterise the project in terms of electrical properties of bedrock and overburden, and was often the only technique necessary.

In later years, as I carried out projects further afield in Europe, Africa and the Philippines, yet again the EM-16/16R was the first and often the best technique to be used, given its extraordinary cost-effectiveness. The list of successes grew steadily, uranium, nickel and groundwater in Sweden, gold in the Philippines, groundwater in Ireland, Bulgaria, France and Germany, and more recently uranium associated with fracture zones in N. Africa. There, we had groundwater with salinity six times that of seawater, so even small but pervasive fractures over hundreds of metres of strike became significant conductors. In Ireland, I realised that the largely impermeable Carboniferous limestone formations are criss-crossed by fracture zones which provide fracture permeability along narrow zones with high well-yields flanked by relatively poor or non-productive wells, and not at all corresponding to the concept of low permeability strata of more or less homogenous properties, beloved of hydrogeologists with a flair for using modelling software designed for horizontal aquifers with intergranular porosity. I often wonder what physical meaning the derived transmissivity values actually have in these cases.

The Transmitters

The theory of VLF-EM has been written up elsewhere and the article by McNeill and Labson (Society of Exploration Geophysicists "Electromagnetic Methods in Applied Geophysics", M.N. Nabighian, Ed., 1991: Vol. II Applications, Part B, pp 521-640) is probably the best reference and source of further references. They include a brief history of the VLF transmitters. Marconi recognised that radio transmission in the very low frequency band (3 - 30 KHz) was capable of long range reception but required large power inputs and this mode became the choice of European States with large navies and overseas colonies, hence the distribution of VLF transmitters. What I find amusing is the fact that this was a one-way communication as the colonies did not possess their own VLF transmitters to reply to any messages received!.

The transmitting antennae are enormous structures and can be seen on Google Earth. At the 1.2 MW Jim Creek WA (NLK) transmitter, the antenna wires bridge a valley. Thousands of tons of steel equivalent to a small battleship is held aloft by multiple pylons, each sitting on an insulating ceramic ball. Even the red navigational warning lights are special and have to be fed through isolating transformers. Acres of copper plates have to be buried in the antenna field to provide a ground plane and as the antenna height of about 800 feet is but a small fraction of the half-wavelength (about 19,000 feet) the antenna has to be top-loaded with capacitance to provide a greater "effective height". Even so, the effective radiated power (ERP) barely reaches 30% of the power input to the transmitter, most of it being dissipated in heating of the ground and the antenna itself. It is said that the signal from the Annapolis Washington D.C. transmitter (NSS) can be picked up by metal fillings in nearby residents' mouths!

Gustav Paal was researching the use of EM for mineral prospecting in Sweden during the 60s and noticed interference on precise frequencies which were traced to these transmitters. Further experiments showed that they could be used as a signal source for prospecting, leading to the EM-16 patent by Vaino Ronka in 1965. These transmitters were also used for time signals and TV signal synchronisation, as well as for communication with submarines, which is their main function now.

For practitioners like me in the field, the location and operating schedules of these transmitters became almost a way of life. We knew that the British transmitter at Rugby (GBR) was off the air on Tuesday afternoons and this provided a welcome respite from the rigours of fieldwork. Likewise, the US station at Cutler, Maine (NAA) was off on Mondays. While the stations were still amplitude-modulated, one could hear the rapid Morse code and wonder what was being communicated to some submarine somewhere in the world. We noticed changes in the patterns days before hostilities broke out in the Middle East (the "Six Day's War") and when the Soviet Union collapsed, the Moscow transmitter (UMS) went silent a week later.

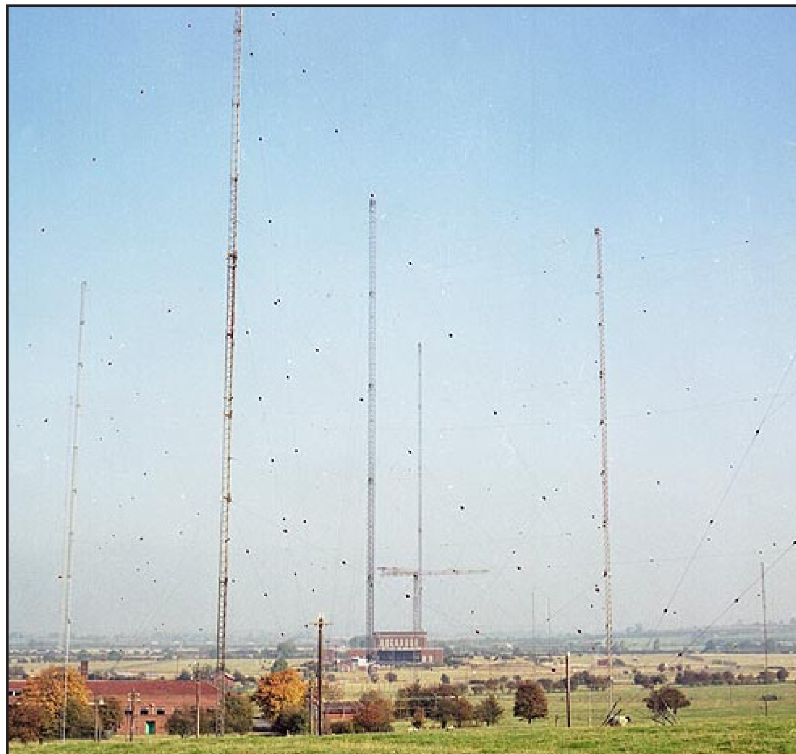

Figure 1. GBR Rugby transmitter antenna, closed down April 2003.

The end of the Cold War meant the end for some old friends like FUO and GBR, and frequency changes for others like NAA. There were concerns that this meant the end for VLF as the threat of nuclear war diminished and the need for ocean-patrolling submarine missile launchers questionable, but the renewed threat from terrorism and the fear of nuclear-equipped rogue states has given a new life to the VLF transmitter network. A few new transmitters and new frequencies has made VLF-EM prospecting somewhat challenging as operating schedules are no longer published and frequent outages and frequency changes can make fieldwork difficult. Many times I have had to change frequencies or transmitters while in the middle of a survey, wondering if I would have to change back again later.

Figure 2. Lars Kålland on the morse key of the World Heritage SAQ transmitter at Grimeton, Sweden. There is a special transmission two or three time a year to commemorate the Alexandersson Day, in honor of the inventor.

There are two very special transmitters. SAQ operating on 17.2 KHz at Varberg on the west coast of Sweden is a mechanical device, essentially a high-frequency alternator built by Ernst Fredrik Werner Alexanderson in 1924 for communication with the United States. This is powered up on a few days every year and is open to the public. The other is the portable Geonics Tx27 which can be used in places where a signal cannot be obtained from one of the military transmitters or is not in the appropriate azimuth. A wire 1000 metres long is earthed at both ends and connected to the TX27 which is tuned to resonance. This provides a useful signal from about 300m to about 3000 metres from the wire. I have used this transmitter in Ireland where there were some difficulties with the antenna wire crossing over roads, and also in the desert of Mauritania in W. Africa where it worked very well despite difficulties with earthing. We found that 20 square metres of chicken wire spread on the ground and weighed down with rocks provided a reasonable capacitative coupling although output strength was less than optimum.

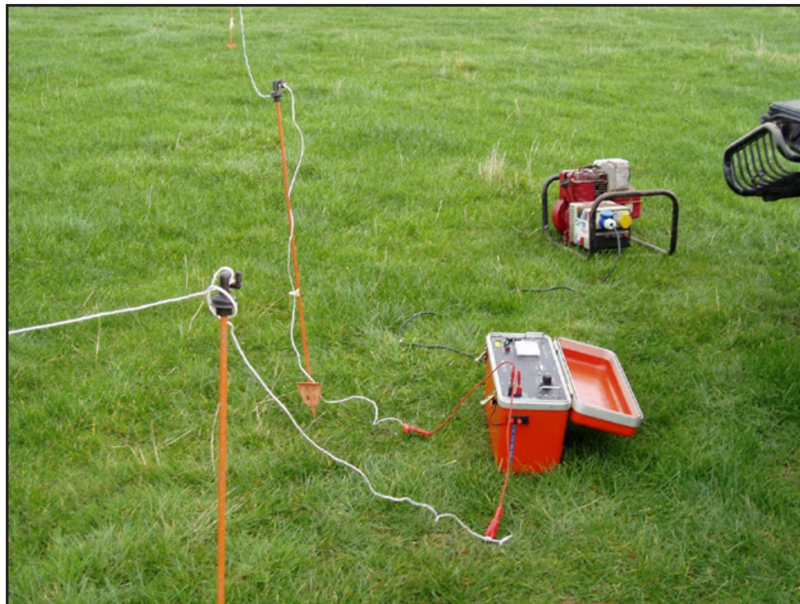

Figure 3. Tx27 (Geonics) portable transmitter with generator and wires leading to 1 km antenna.

The present-day VLF transmitter schedules are somewhat of a mystery. It is possible to monitor them using simple software and an audio soundcard with a coil of wire plugged into the microphone jack of a laptop computer. I use an audio spectrum analyser software designed for animal sound studies (bats mainly) and this works fine with a 100-turn 30 cm diameter loop. A radio ham enthusiast colleague in Germany, Wolfgang Buscher, has his own spectrum plotter software with filters and the facility to use two orthogonal loop antennas to locate the azimuth of the transmitter without having to rotate it. By logging the on and off periods of certain transmitters as well as their frequencies, it is sometimes possible to get a fair idea of when they are likely to be on, or more importantly, when they might be off the air!

Using the EM16 in the desert produced some other challenges. The strong constant wind pushed me about and made reading the clinometer scale difficult. The wind whistled in the little tube that acts as a loudspeaker and I had to use headphones. There was interference from handheld GPS units which had to be tied on a lanyard and allowed to hang down almost to the ground before the interference disappeared. But the lack of a digital LCD display in 40°C heat was a boon as the more modern digital instruments succumbed to the heat - the EM16 was the king!

Rivals

The EM-16 was not without its rivals. These included the Scintrex “Scopas” which incorporated a magnetic compass in the display, the Crone “Radem” which had a field-strength meter on the display, the ABEM “Wadi” which had an automatic line-reversing feature which was very useful for field operations as well as an on-screen Karous-Hjelt inversion for interpretation of conductors in the field! Later instruments included the Iris Instruments “T-VLF” which could measure the field components from two

Figure 4. VLF-EM in Mauritania. Here I am, enduring the 40ºC heat of the Sahara desert this time.

Figure 5. VLF-EM survey in Sweden. At -10ºC the metal clinometer is cold against my forehead!

transmitters simultaneously and the Scintrex "Envi-VLF" which could incorporate a magnetometer and a GPS unit in the backpack if so desired.

Airborne versions also exist, such as the Herz "TOTEM-2A" but variants were produced in the 70s by all the big names in geophysical instruments including Barringer and McPhar, Scintrex and Geonics.

Some other instruments use VLF signals like the Radiodetection™ pipe and cable locator tool while RFI scanners on toll roads can emit a VLF signal to interrogate the car-borne transponder for payment of the toll. Television sets were also sources of VLF signals at about 15.7 KHz from the line scan ("fly-back") oscillator. This also allowed TV licence inspectors to locate unlicensed TV sets in countries that operate this kind of tax.

Applications

The VLF-EM and VLF-Resistivity techniques are very versatile and lend themselves to many applications where near-surface geology is important and this includes many types of mineral and groundwater resource location as well as geotechnical site investigations.

These include mineral exploration for sulphide and alluvial mineral deposits, diamond-bearing kimberlites, and structurally-controlled deposits such as uranium. Groundwater-filled faults and fracture zones constitute a good target at VLF frequencies, but so do variations in the thickness and the conductivity of the soil and overburden, often glacial sands and gravels or clays. Illegal landfill sites show up as zones of extremely low resistivity (< 10 Ohm.m) and on one occasion when I encountered such readings, I noticed parts of an old TV set sticking out of the ground and I knew how to interpret those readings!

Given the sensitivity of the VLF-R method (really radio-frequency magneto-tellurics) to high resistivities where normal inductive EM methods see nothing, the VLF-R technique is particularly appropriate for karst areas and I have successfully mapped clay-filled sinkholes in such terrain.

A VLF-EM survey is little more than a walk over the area in question and if one adds some VLF-resistivity measurements and some basic geological observation, a very good understanding of underlying geology can be obtained for a relatively small effort.

Limitations and Advantages

Like any geophysical technique, the VLF method, both EM and Resistivity, has limitations. Paradoxically, these sometimes help matters by limiting the depth penetration to the zone of interest, usually less than about 40 metres.

The principal limitation is the so-called “skin depth” which is due to the attenuation of a radiowave as it interacts with a conductive ground or half-space. It is proportional to the square root of the resistivity of the ground (the more resistive the greater the depth penetration) divided by the transmitter frequency (the lower the frequency, the greater the depth penetration), both beyond the operator’s control. The range of transmitter frequencies is so narrow that choosing a lower available transmitter frequency for a VLF-resistivity survey will not result in any significant improvement in depth penetration. Usually it is the strongest Tx signal that gives the best result and that is what matters for most resistivity surveys.

The VLF method has almost no following in Australia where a combination of deep, conductive weathering and the lone VLF transmitter (North West Cape) makes the method almost useless. Africa and Asia are almost in the same position, except perhaps the arid regions of N Africa. There are a few transmitters serving S. America, Japan and India and the use of VLF - mainly EM - is growing there. It is in the glaciated regions of North America and Europe where the method finds it best uses and most loyal practitioners.

There is no direct phase reference to the transmitter and that too imposes a limit on the interpretation methods. However the very high frequency of the “very low (for broadcasting) frequency” of the transmitters means that many geological materials become effective conductors making the earth model very complicated and the interpretation of the results is always under-determined, imposing a severe limitation on any detailed interpretation.

The transmitter azimuth is often inappropriate and recourse must be made to a less-well situated transmitter or to the TX-27 portable transmitter mentioned already. This is significant for the VLF-EM technique where the expected conductor strike should be within ±45 degrees of the Tx azimuth. It is also significant (but much less so) for the VLF-R technique when operating close to a fault zone with a significant contrast in bedrock resistivity across it.

The transmitter operating schedules and frequencies present a limitation to fieldwork. As I have mentioned above, frequent frequency changes are experienced with certain transmitters, mainly in the UK and France, and the Norwegian transmitter operates a one hour on and three hours off schedule which limits productivity in the field and I have found myself running to the next measurement point to get in as many measurements before the transmitter switched off.

The EM-16 suffers from these frequency changes as a new crystal plug-in unit must be ordered to match the new frequency, which might be changed again after only a week or two in service and perhaps never again! The more modern digitally-tuned units do not suffer in this way but the frequency has to be known and the schedule has to be adhered to as otherwise one can find oneself in the field with no transmitter signal. This has resulted in me returning to the same project on several occasions in order to complete the job.

On the other hand, the VLF method has almost no equal when it comes to cost-effectiveness. It is fast, lightweight, cheap and simple to use. It provides resistivity data and a simple two-layer resistivity model is appropriate for the overburden over bedrock case where the greatest contrast in electrical properties usually occurs. The EM data provides information on geological structures and is a useful adjunct for mapping. The VLF-EM technique often proves to be as effective as other EM techniques when near-surface, steeply-dipping conductors are sought.

Interpretation

VLF-EM:

Basic interpretation methods range from “eyeballing” the plotted profiles of in-phase and quadrature components (also known as tilt angle and ellipticity, or real and imaginary phase, depending on whom you are talking to) to applying simple digital filters, either the Fraser smoothing or the Karous-Hjelt inversion, which provide an indication of the induced current density and the approximate conductor location, depth and dip. Software products to do this include “RaMag” (P. Walen, California), “IXVLF” (Interpex, Golden CO) and “Sector” (ABEM, Sweden). Earlier products like “KHFILT” (Geosoft) are still in use. Forward modelling like VLFMOD is available from ABEM and there are published nomograms and suites of model curves also, but difficult to obtain. One of the most sophisticated products is “Maxwell” (EMIT, Australia) which can model a variety of electromagnetic systems including the VLF-EM method.

VLF-Resistivity:

Many software products for 1-D and 2-D magneto-telluric (MT) interpretation can be used to invert and forward-model VLF-R data. Simpler methods such as the 1-D Bosstick inversion and the Grisseman & Reitmayr inversion (also 1-D) can be implemented on handheld programmable calculators or laptops. A more sophisticated 2D inversion routine was published by Monteiro (Portugal). Geonics provide sets of 2-layer nomograms for in-field inversion and these are essentially Cagniard 2-layer MT sounding curves of apparent resistivity vs phase angle calculated for a variety of first-layer resistivities.

Stories from the Field

Carrying out surveys in the field with the EM-16 brings about its own rich harvest of anecdotes and stories. This is probably because a survey can be carried out by one person alone and the instrument is so small it hardly looks like any serious work is being done.

Once, when I was doing fieldwork in N. Spain, a farmer approached me having observed me all day from a distance and said “you’re not Spanish!”. I asked him how he knew and he replied “because if you were Spanish, there would be three of you doing that!”.

In Ireland, farmers assume I am a water-diviner which is often not far from the truth! The warbling/whistling sound carries over long distances and some people have reported UFOs in the area. Birds in nearby trees sometimes imitate the sound which can be quite amusing. When I had a mysterious neighbour living in an adjoining house, I could tell when he was there by the VLF signal from his TV set. He made no sounds whatsoever and came and went closing his front door noiselessly - very strange indeed! Parts of the EM-16 had other uses too - the silicon rubber plug-in tuning modules served as excellent pencil erasers. I often used the clinometer on the instrument to estimate slopes and heights of cliffs and trees etc.

On another occasion in Ireland I arrived at the survey site in a remote part of the country after a long drive and was annoyed to find that the GBR transmitter had switched off. I stayed over with friends but after three days of no signal, I returned home. Two weeks later, the signal had come back so I returned and completed the survey, finding a tiny kitten on the road which I rescued as there were no houses for miles in any direction. Minou is still the family pet today, fourteen years later. He was nearly named “GBR” but my wife said no!

Figure 6. VLF-EM in Ireland. My colleague Nick is enjoying the fine weather. The upward tilt of the EM-16 signifies the presence of a conductive zone ahead of his position.

Figure 7. VLF-Resistivity in a cabbage field. Nick is doing the survey along the line of the drills so as not to damage the crop.

A few years ago I had an unique opportunity to re-enact an experiment first carried out by Gustav Paal (Luleå University, Sweden) when he observed the ability of VLF radiation to penetrate the ground. I took my trusty EM-16 down the decline of the Aguas Teñidas copper-pyrite mine in S. Spain to a depth of 300 metres below ground surface. The decline is overlain by an electrically resistive rhyolite formation and the signal remained strong as I was still within the theoretical skin depth. But when I entered the conductive shale and sulphide complex the signal disappeared altogether as theory predicted it should.

Two surveys I made with the EM-16 stand out in my memory. One was in Finland where a kimberlite pipe had been located onshore but extending under a nearby lake. Not wanting to wait until the lake was frozen in winter, I proceeded to do a profile of VLF-EM measurements using a rowing boat. I was unable to locate a buoyant rope to mark out a profile and at the time GPS was still too inaccurate for survey work due to the Selective Availability scrambling which was applied then (President Bill Clinton removed this at midnight, May 1 2000 - a boon to field geophysics!) - so what to do? Well, I developed a method of pulling once on the oars while aiming at a target tree on the far shore, taking a reading and jotting it down and then another pull. When I reached the far shore I measured the distance on the map and divided by the number of readings to get my average distance, about 15 metres I recall. The water was less than 5 metres deep and was almost pure, so not very conductive. The edge of the kimberlite pipe was easily identified by this profile.

The other memorable survey was done in the grounds of a castle converted into a luxury golf club and a water supply was needed for the planned “golf village” in the grounds. I had completed three profiles and detected several structures that I identified as water-filled fracture zones. One of these was later drilled and provided a good yield in three holes spaced 100 metre apart along one of the fracture zones. The question was then asked if these fracture zones could be traced across the golf course for an irrigation well. I replied yes, but that I would need to run a fourth profile along the length of the course parallel to the other profiles. “Not possible!” was the answer “we have golfers every day using the course”.

"Well, maybe when it is raining?" I suggested. "Nope. They play in all weathers". Not to be outdone I persisted "I'll bet they don't play at night?". "Hmmm, that's true. Can you do the profile in the dark?" I did. Using a red headlamp for night vision, a compass to keep straight and a GPS to log my positions, I set off down the line after dusk and apart from falling into a bunker, I managed to do the fourth line which picked up all the fracture zones as before.

But perhaps the strangest story of all is told by my colleague Wolf Buscher. It concerns the rock guitarist Mike Oldfield of "Tubular Bells" fame. Apparently when Mike Oldfield was recording Tubular Bells in the early 70s in the Manor studio not too far from Coventry in the UK, the recording equipment picked up the 16.0 kHz signal from the nearby GBR transmitter which did not interfere in any way with the recording and was not noticed by the recording engineers. It can be detected still on CDs but not on MP3s as the bandwidth is too narrow from the compression. It can be revealed by playing it through a spectrum analyser on a PC where the signal can be seen consisting of a series of "vees" or dot-dot-dot-dash in Morse, followed by the call-sign "GBR" repeated many times before the encrypted message begins. So the old VLF transmitter at Rugby, one of the first in the world, lives on in a rock music recording. Strange indeed!.

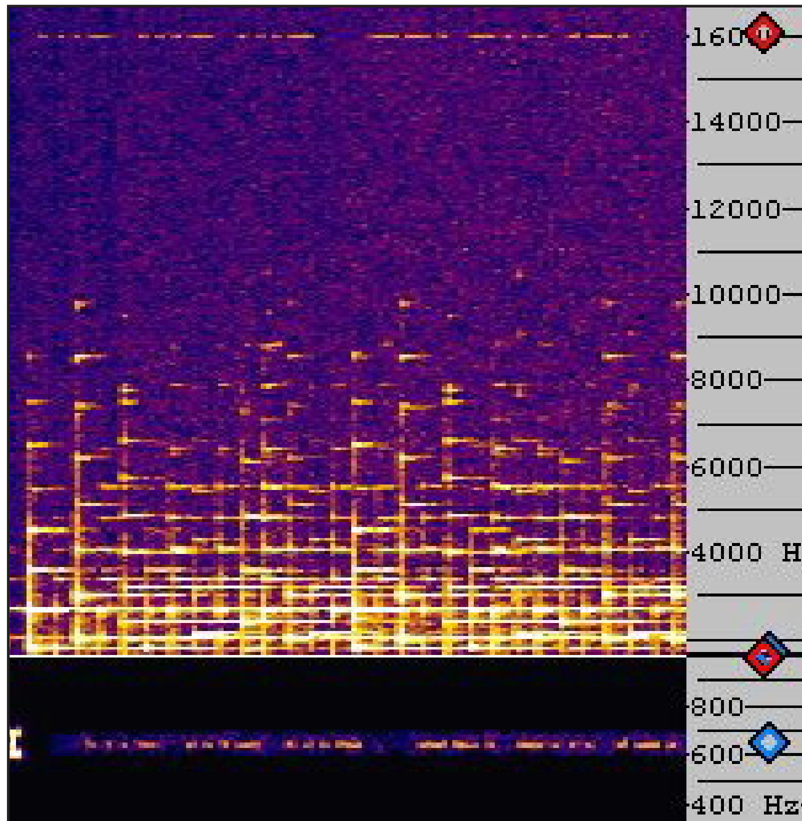

Figure 8. Tubular Bells spectrogram showing the morse code along the top of the graph at 16000 Hz. The opening 6 seconds of this classic rock music contains the repeated message "V-V-V-G-B-R" which includes the callsign "GBR" of the Rugby (UK) transmitter.

My old EM-16 likewise lives on and will doubtless outlive me. It still looks in factory condition and it is a treasured possession apart from earning its keep as a working instrument. It outdoes the modern digital instrument when it comes to training operators or teaching students as one has to rotate the antenna to demonstrate the polarisation ellipse in three dimensions and have a perception of the magnetic and electric field vectors in relation to the conductor sought. The digital instruments don't do anything apart from beeping and any monkey can press the buttons! Nearly 50 years since its invention, this technique still holds its own and EM-16 instruments are still manufactured. When I turned 60 last December, one of my birthday cards had the message "Keep the phase angle at 60" Hmmm! I wonder what that was referring to?

Author's Note

The author has referred to methods, software and instruments that he is familiar with. The items mentioned are not an exhaustive list and any omission of a brand name or manufacturer is not intentional. No endorsement of any instrument is made and the author has not received any remuneration from Geonics Ltd. or any other manufacturer to promote their products.

Repeatability of Towed Magnetic Data for Archaeological Prospection within a Sand and Gravel Mineral Deposit

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Abstract

The Geophysical Exploration Equipment Platform (GEEP) was used to survey an area of known archaeological interest in Shelford, Nottinghamshire. The site consisted of varying depths of sand and gravel deposits reaching a maximum thickness just under 10 meters, although the archaeological remains are likely to be much closer to the surface. An array of six caesium magnetometer sensors were set up at 0.6m separations on the GEEP and towed across the site. A section of the site was surveyed again the following day to determine the repeatability of the towing method used. Sand and gravel deposits in the region produced a level of background magnetic variation across the traverses and archaeological features were clearly observed outside this trend. A differential GPS system was mounted on the GEEP to provide positional data ensuring a reliable comparison between datasets was achieved. Data obtained on the repeat survey shows extreme likeness to that observed on the original dataset indicating the repeatability of the GEEP towing method for small separation magnetic surveys in sand and gravel environments. It took the GEEP operator three and a half hours to collect the original 6 hectare dataset, and an additional forty minutes to complete the repeated section.

Introduction

Magnetic surveys have been popular within the discipline of archaeological prospection for many years. With advances in instrumentation, the ability to detect the very small resolution anomalies often associated with archaeological remains is now easily achieved. In sand and gravel environments the high level of magnetic variation in the substrate, can sometimes lead to the small archaeological anomalies becoming undetectable. In order to detect small amplitude variations in the archaeomagnetic response from historical artefacts or structures, the area needs to be adequately sampled in order to prevent aliasing of the data. This often leads to very detailed surveys with line spacings commonly between 0.5 and 1m, carefully controlled by pre-defined grids. It can take many hours for one operator to complete coverage of a large area in this detailed manner even when aided by an array of magnetic sensors mounted on a hand pulled cart.

Productivity could be greatly increased if the magnetic survey was conducted by a vehicle towing multiple magnetometer sensors simultaneously, completing several lines of the walked survey line in one driven pass. The concern of implementing such a towed survey is whether the data is reliable and repeatable at the faster speed. This was tested by conducting a comparison between magnetic survey data recorded on one day with that recorded on the following day. To further display the reliability of the data it was then compared to a hand pushed cart survey conducted by English Heritage.

Site of Investigation

Shelford is a small village in Nottinghamshire, UK. It is the site of a former medieval priory and manor house situated south of the River Trent. The site lies above a sand and gravel mineral deposit which sits on top of a mudstone unit. The sand and gravel is of varied composition and exists at a depth approximately no deeper than 10m as shown by a resistivity survey carried out as part of the FASTRAC project. All data collected was in accordance with this project funded by the Aggregates Levy Sustainability Fund (ALSF) administered by English Heritage. The area of interest in this report comes from magnetometer surveys conducted over a grass field approximately 240m x 260m shown in Figure 1.

Figure 1. Site location indicated by the red shaded region.

Methodology

The survey was conducted using a Geophysical Exploration Equipment Platform (GEEP). The platform was equipped with six caesium magnetometer sensors and a differential GPS for positional recording. The platform comprises of a geophysically invisible (minimally magnetic) sledge mounted on runners which is towed by a small tractor 10m in front of the equipment, at a speed of approximately 6km/hour. The sensors were attached to an aluminium pole which was subsequently mounted on the platform giving the sensors a ground clearance of 0.3m. The GEEP system is pictured in Figure 2 and the array of magnetometers can be seen in Figure 4.

Figure 2. The GEEP (Geophysical Exploration Equipment Platform).

The GEEP was towed around the boundary of the survey section and then the area was in filled with a series of traverses along the long axis of the field. This gave area coverage of a survey line every 0.6m - as the sensors were 0.6m apart and lines were traversed at 3m spacing (Figure 3). Data is collected by the GEEP at 5Hz, which produced approximately one reading every 30cm. Tie lines and repeat lines were recorded at the end of each survey to ensure reliability of the data. Figure 3 shows an example of the tracks traversed by the GEEP. The lines seen are the plotted positions as recorded by the differential GPS, true positions for all the sensors were determined later from the azimuth, pitch and roll readings recorded by the on board fluxgate compass unit. A wireless local area network (WLAN) was set up to transfer the data from the instruments on the sledge to a stationary logging laptop pc. This allowed real time quality control of the incoming data to be carried out.

Since the area to be covered was large (6 hectares), and the survey swathe spacing required was small (3m), the area was sampled as two sections, part 1 and part 2. Both parts were surveyed on 3rd September 2007 and a central section was re-surveyed on the following day (4th September 2007) to test the repeatability of the towed magnetic survey method.

A base station magnetometer was also set up on both survey days to record the magnetic field at a fixed location in an adjacent field. This was later subtracted from the recorded sensor data to allow diurnal correction of the magnetic readings to be computed, thus ensuring the accuracy of the magnetic data to allow for interpretation of small (<1nT) magnetic variations.

Once the data had been recorded, it was processed in Microsoft Excel and imported into Geosoft Oasis Montaj where corrections were applied including that of co-ordinate projection, low pass filtering and sensor positioning. Maps were then constructed of the findings so the results could be easily compared.

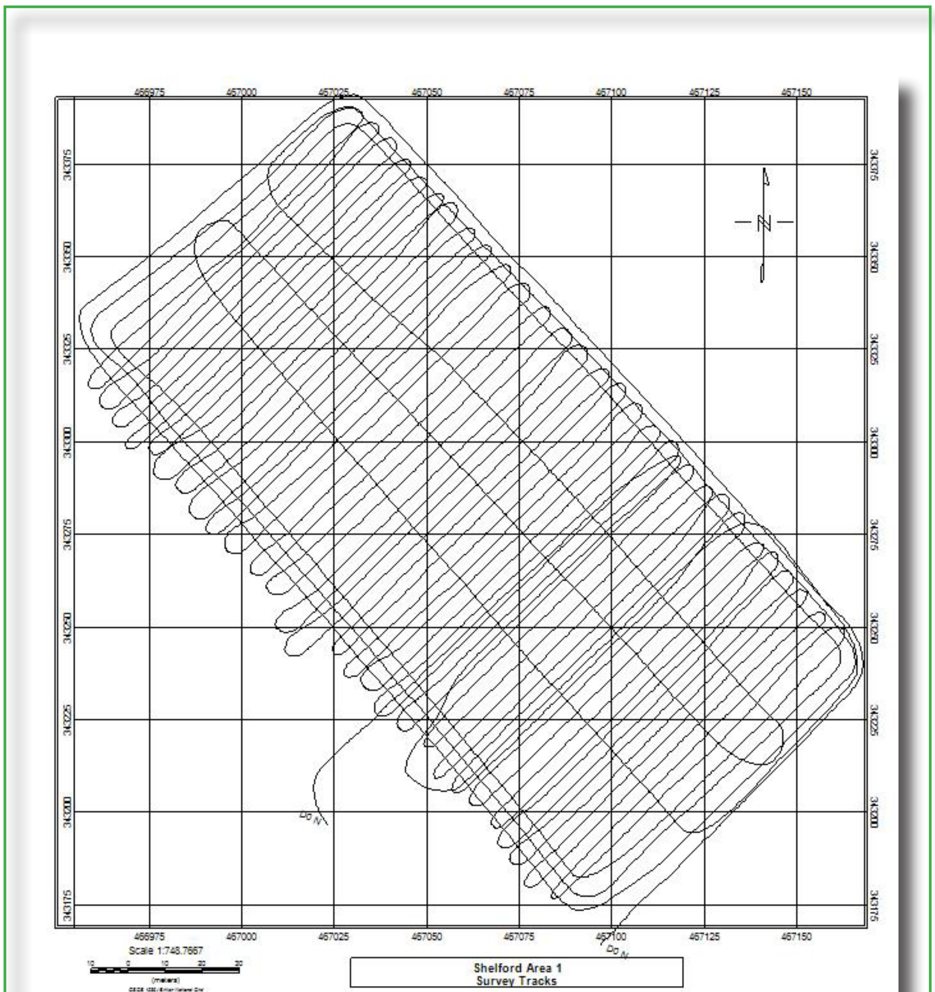

Figure 3. GEEP survey tracks from DGPS data for area 1 to highlight survey produce. The 3m survey swathes (shown here) give a 0.6m line coverage.

Data Processing

After the GEEP is used it writes the recorded data to a file which is later manipulated by the PostProcessor program to create an ASCII file containing the differential GPS, compass data, sensor X, Y, and Z offsets and magnetic readings for the six sensors. It was first important to ensure each sensor was comparable to the other and that each was positioned in the correct location relative to the GPS position, so the data set was imported into Microsoft Excel. Each of the sensors was located by a series of offsets relative to the position of the GPS. These offsets were represented as X, Y, and Z directions from the GPS with all the sensors having common X and Z measurements of -1.1m and -0.9m respectively (Figure 4). Y distances started a 1.5m for the port most sensor, and increased at intervals of 0.6m until the starboard sensor at -1.5m (Figure 4). The offsets were than calculated using the

X, Y, Z positions and the compass azimuth, pitch and roll values. The resulting easting and northing offsets could then be added to the projected GPS co-ordinates to produce correctly positioned magnetometer sensors allowing the results to be correctly plotted. Height offsets were not computed as the survey area was relatively flat and height was not used in the final data set.

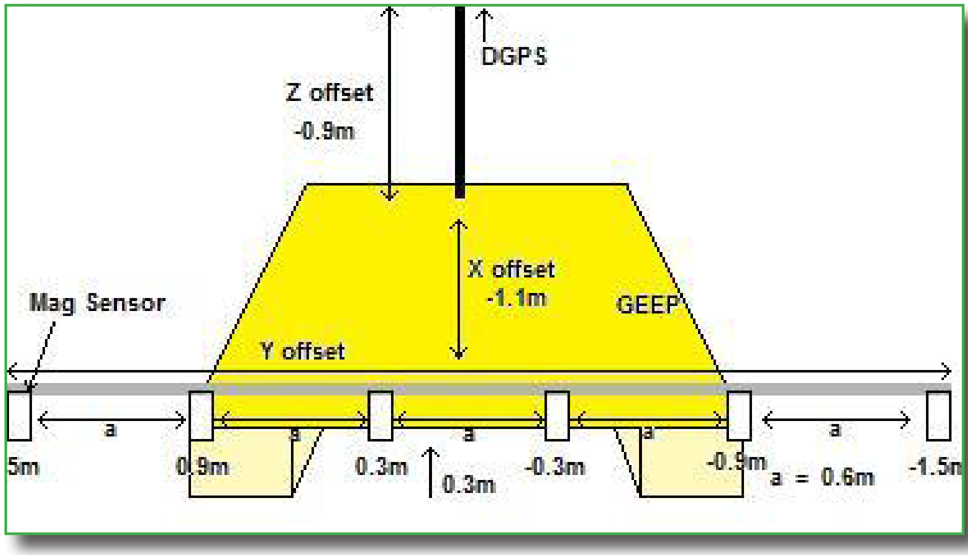

Figure 4. Positions of the magnetometer sensors.

Each of the magnetometer sensors produced a slightly different magnetic base level signal which needed to be corrected for to ensure the sensors could all be plotted simultaneously without creating false anomalies. This was achieved by calculating the average reading from each individual sensor and subtracting this average from each of the sensors results in turn.

Once the true sensor offsets had been calculated and the sensor readings were comparable, the data-set was imported to Oasis Montaj for further manipulation and plotting. An important processing stage was to project the co-ordinates from WGS84 to the local OSGB1936/British national grid co-ordinate system. This was carried out utilising the pre-existing co-ordinate projection modules within Oasis Montaj which converted the latitude and longitude positions to easting and northing locations. The sensor offsets calculated previously, were then added to these projection positions to give accurate data positions relative to the GPS position in a localised positional grid.

Now that each reading had an individual location, the data set was corrected for diurnal drift by using the math.gx function to subtract the magnetometer base station value from its corresponding sensor value. Small background noise errors and slight heading errors noticed on two of the sensors were smoothed out by applying a low-pass filter. The column which held the magnetic data for each data set (area 1 and area 2) was then gridded against the easting and northing values to display grids of magnetic amplitude in nT. Joining together of the two areas was then achieved by implementing the Grid Knitting function in Oasis Montaj and the whole data set was presented as a grey scale shaded map, complete with legend, scale and north arrow.

The same processing procedure outlined above was then carried out for the repeat data section completed on the second day. To ensure the datasets could be easily compared a polygon mask was drawn and applied to both the original data set and the repeat dataset. Once again the cropped data grids were displayed as grey scale shaded relief maps.

Results and Analysis

Figure 5 shows the total coverage of the survey area, the black lines indicate the areas covered on the 1st survey day and the red lines indicate the repeat section. The survey lines shown are for individual sensors (not driving tracks) and it is clear that on a whole the area is covered to a high density,

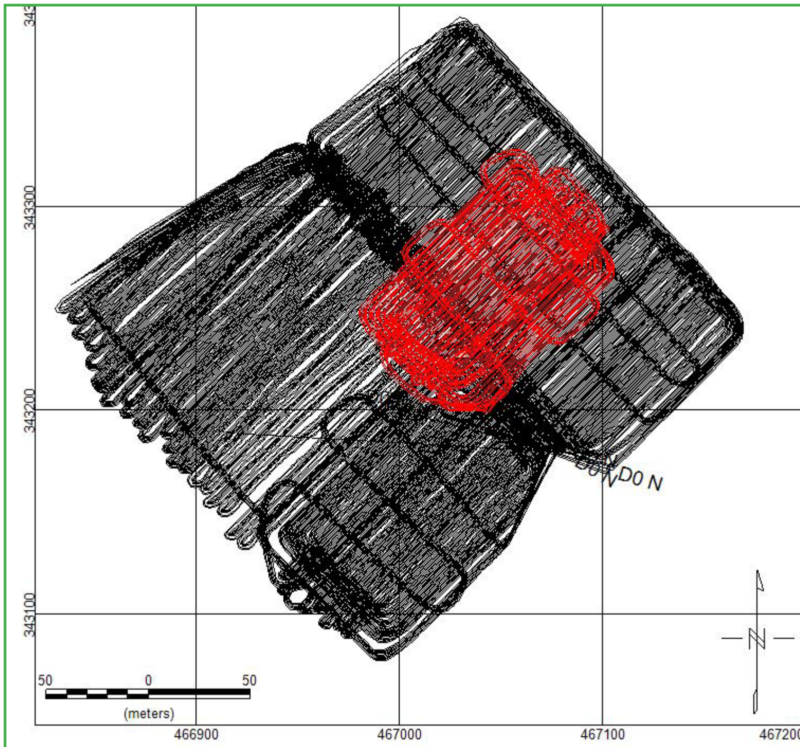

Figure 5. GEEP sensor coverage (all sensor positions) of the Shelford site. Surveys carried out on day 1 indicated with black lines, repeat survey carried out on day 2 indicated by the red lines.

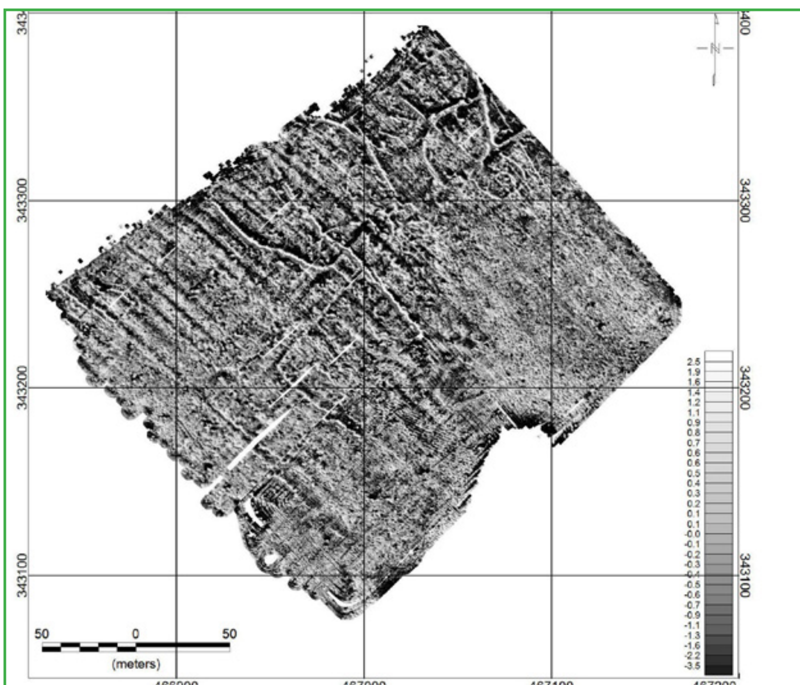

Figure 6. GEEP magnetometer results, whole site, day 1 Shelford.

however, it is apparent that some gaps are generated in the data. These gaps occur because areas of the field were covered by rough tractor wheel grooves making the vehicle hard to keep in line with the display on the drivers line map. Problems with the WLAN meant that area 2 could not be completed in one survey and had to be finished with a third survey but all areas (1, 2 and 3) are plotted as one dataset.

The whole site data set for Shelford (Figure 6) shows a number of distinct magnetic anomalies which are described below and compared in following sections. It is beyond the purpose of this paper to provide full archaeological interpretation of the results. The data set shows a range of magnetic values across the field varying from 2.5nT to -3.5nT for the largest anomalies against a background ranging between -0.5nT to 0.5nT. The dataset took 3.5 hours to collect at a rate of approximately 40mins per hectare.

Figure 6 shows that a number of ditched enclosures can be seen in the Shelford survey area. The most prominent feature is the large enclosure dominating the north west edge of the field and the associated north west – south east trending lineation. A large rectangular anomaly can be seen to the south west of this line with smaller rectangular responses in the north west corner. The north east corner shows strong linear anomalies with near circular attachments and a faint circular response can be seen to the south west of these. North west – south east broad parallel linear anomalies can also be seen across much of the area. These anomalies occur perpendicular to the direction of survey traverses and are, therefore, not striping due to heading error, and can be interpreted as ridge and furrow, a medieval farming method.

Repeat results (Figure 7) show a similar range of magnetic values to those recorded on the previous day. Anomaly amplitudes are seen to be 2.3nT or -3.0nT while the background values range between 0.3nT to -0.5nT.

This second data set shows a very strong linear anomaly to the south western edge which blends with less distinct responses to the northern end. Circular anomalies can be seen in the north east corner and the top of one of these is also apparent in the southern most corner. Other small circular responses can be seen across the area, which are thought to be surface rubbish material from a previous recreational use of the field.

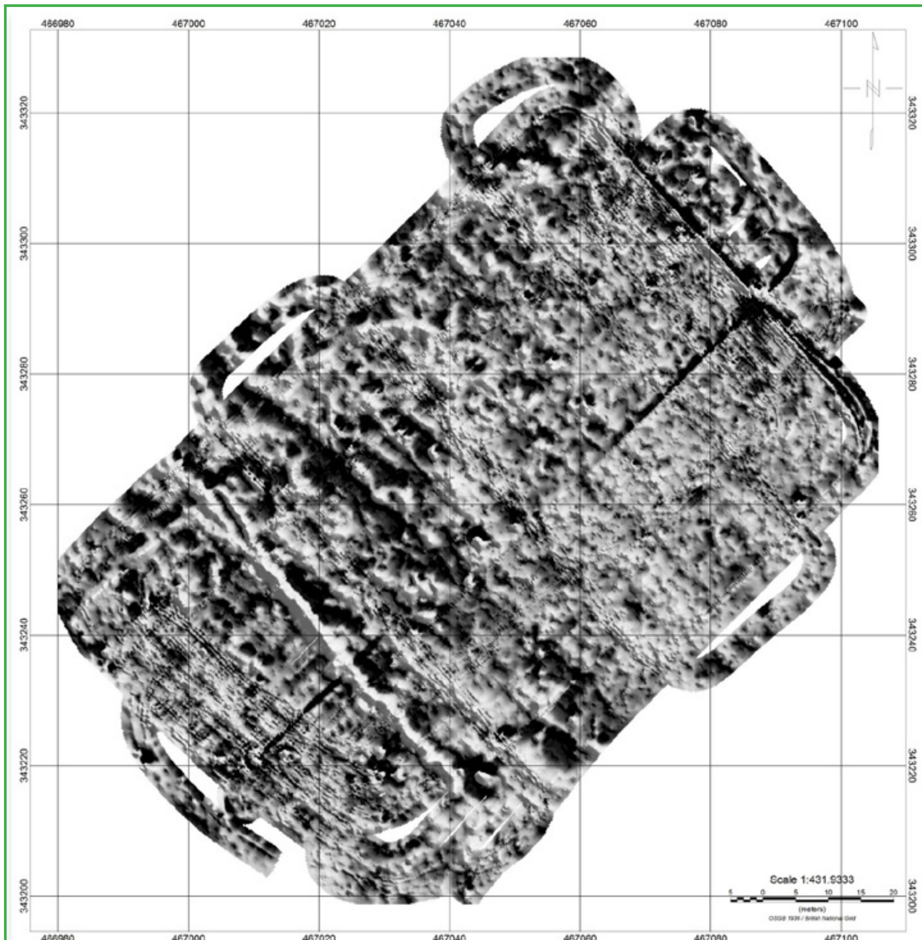

Figure 7: GEEP magnetometer results, repeat section, day 2 Shelford.

Anomalies detected on both surveys days are only a few nano Tesla (<4nT) above the background noise level as are likely to be associated with disturbance of the soil and not large ferrous artefacts. These small variations in the earth's magnetic field would not have been as easily detectable at larger measurement spacings. Modern agricultural debris, such as horse shoe nails, nuts and bolts, can cause isolated dipole anomalies and increase the levels of background noise (Breiner 1991).

Comparison

A comparison between the data acquired on both survey days over the Shelford site was carried out to test the repeatability of towed archaeomagnetic data. Data sets were first cropped to ensure unwanted values were masked and both datasets were plotted using the same colour scale (Figure 8).

It can be clearly seen that the data showed the same anomalies on both survey days. An exception occurs when looking at the south easterly extent of the linear response as it appears to lengthen in the results from the second day. The reason for this difference is due to the position of the tracks on the first day as the GEEP was turned around over the feature, thus interfering with the true magnetic response. This highlights an important survey procedure when using a towing vehicle. It shows that the instruments must pass clearly over areas of interest before a turn is completed at the end of a traverse, and highlights the importance of real time quality control displays of the data.

To further support the repeatability of towed magnetic data, Figure 9 shows the results from an English Heritage survey carried out across the area where clear comparable features can be seen. The English Heritage survey was conducted using a hand pushed cart mounted with 4 modified caesium magnetometer total field sensors (Linford et al 2007) ensuring a coverage of the area at 0.5m line spacing and took 15 hours per 6ha of coverage in the field. Only minimal post acquisition processing was applied to the data, including the setting of each instrument traverse to a zero mean to minimise any directional sensitivity of the array. Anomalies are represented on a similar grey scale compared to the GEEP survey and positive magnetic anomalies appear in lighter (white) tones above the background response.

Conclusions

Two surveys were conducted on consecutive days using a six sensor magnetometer array attached to a GEEP system and towed at 6km/hour across a 240m x 260m field. The data collected underwent many processing stages including removal of base magnetic values, filtering and sensor positioning. Data displayed in the final maps showed a clear repeatability of the towed method as indicated by near identical anomalies in both amplitude and geometry. In one case a linear anomaly was clearer on the repeat section than on the first survey due to the proximity of the underlying feature to the turning circle of the GEEP. This caused the values in this region to become disrupted indicating the importance of fully passing over areas of interest in a survey.

When comparing the datasets obtained with the GEEP to those collected with the hand pushed English Heritage cart, it is clear to see that the cart produces less noisy results as the survey speed is slower. It is felt, however, that for large sites that would take many days to survey, the fast speed of the tractor towed vehicle (GEEP) can still resolve the majority of significant anomalies as the slower method. Poor coverage of the area in parts meant that anomalies were occasionally miss-represented. This goes to highlight the fact that surveying with a faster towed method is only accurate if adequate coverage is achieved across the entire area.

Towed magnetic data shows good repeatability even in an area where anomaly amplitudes are small and background total field values are varied. Both the GEEP and English Heritage towed cart provide reliable towed magnetic data for the Shelford area. The slower hand cart method (2.5 hours per hectare)

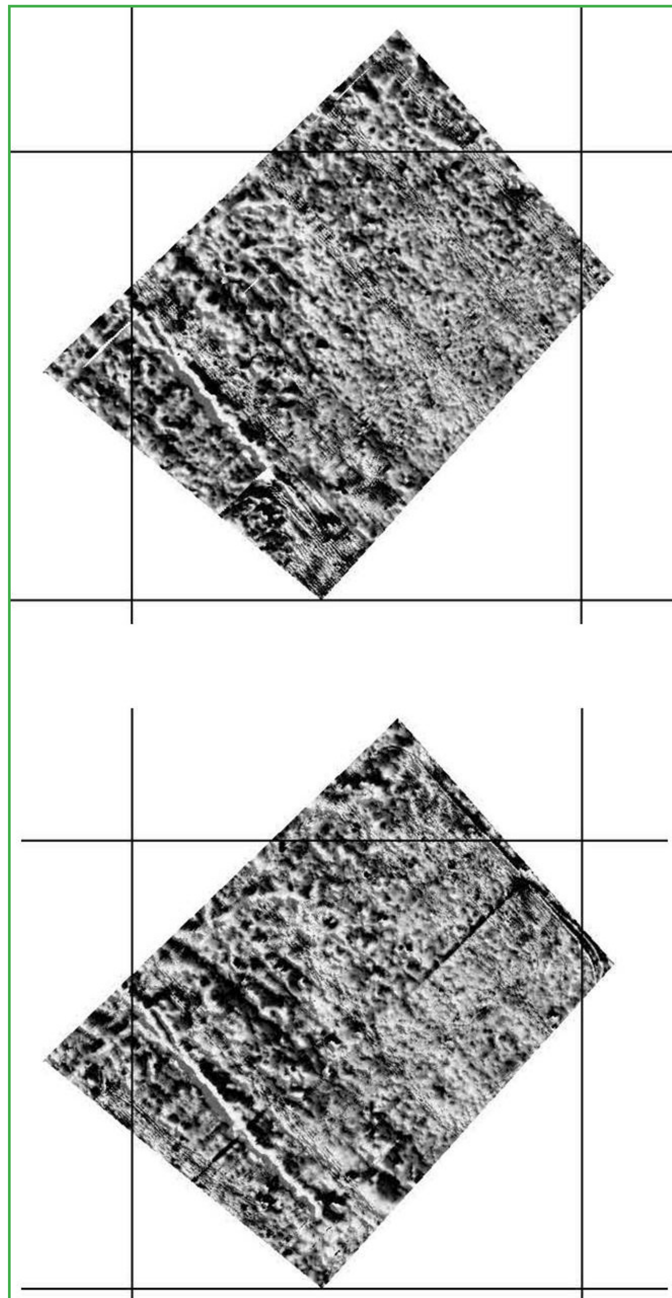

Figure 8: Comparision of day 1 (top) and day 2 (bottom) GEEP magnetometer results.

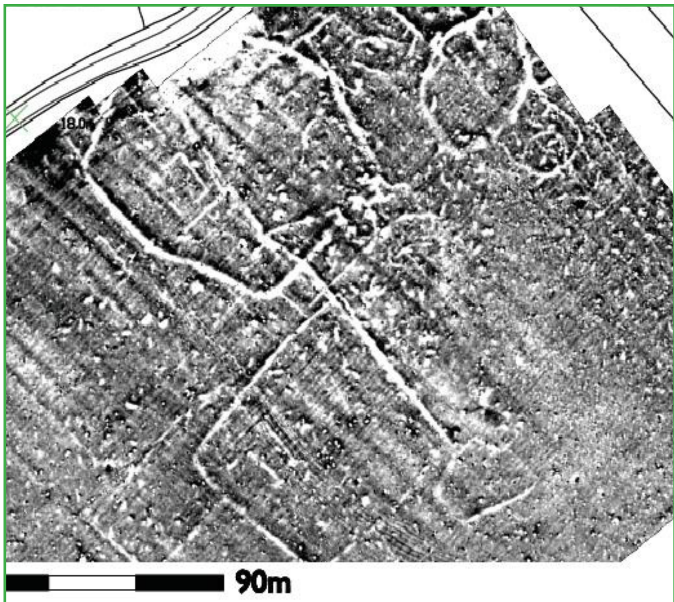

Figure 9. Extract from the English Heritage caesium magnetometer survey conducted at Shelford for comparison with the GEEP data set. The scale used in this figure (black = -3nT, white = 3nT above the background field). © Crown copyright. All rights reserved English Heritage 100019088 2007.

with a 0.5m line coverage, allowed for very clean data evenly spread across the area. The GEEP provided more rapid coverage of the area (0.6 hours per hectare) at 0.6m line coverage, although this created slightly increased levels of noise. These sensor array towed methods provide an increased productivity rate when compared to a hand-held single (or dual) sensor magnetometers (approximately 4ha per day at 1m line coverage), and clearly provide a reliable and repeatable archaeological prospecting tool which can be used in many situations especially when a large area needs to be covered.

Acknowledgments

I would like to thank English Heritage, the Aggregates Levy Sustainability Fund (ALSF) and the University of Leicester for the use of the data supplied in conjunction with the project titled A Whole-site First-assessment Toolkit for combined Mineral Resource and Archaeological assessment in Sand and Gravel deposits (FASTRAC), (PN 5366).

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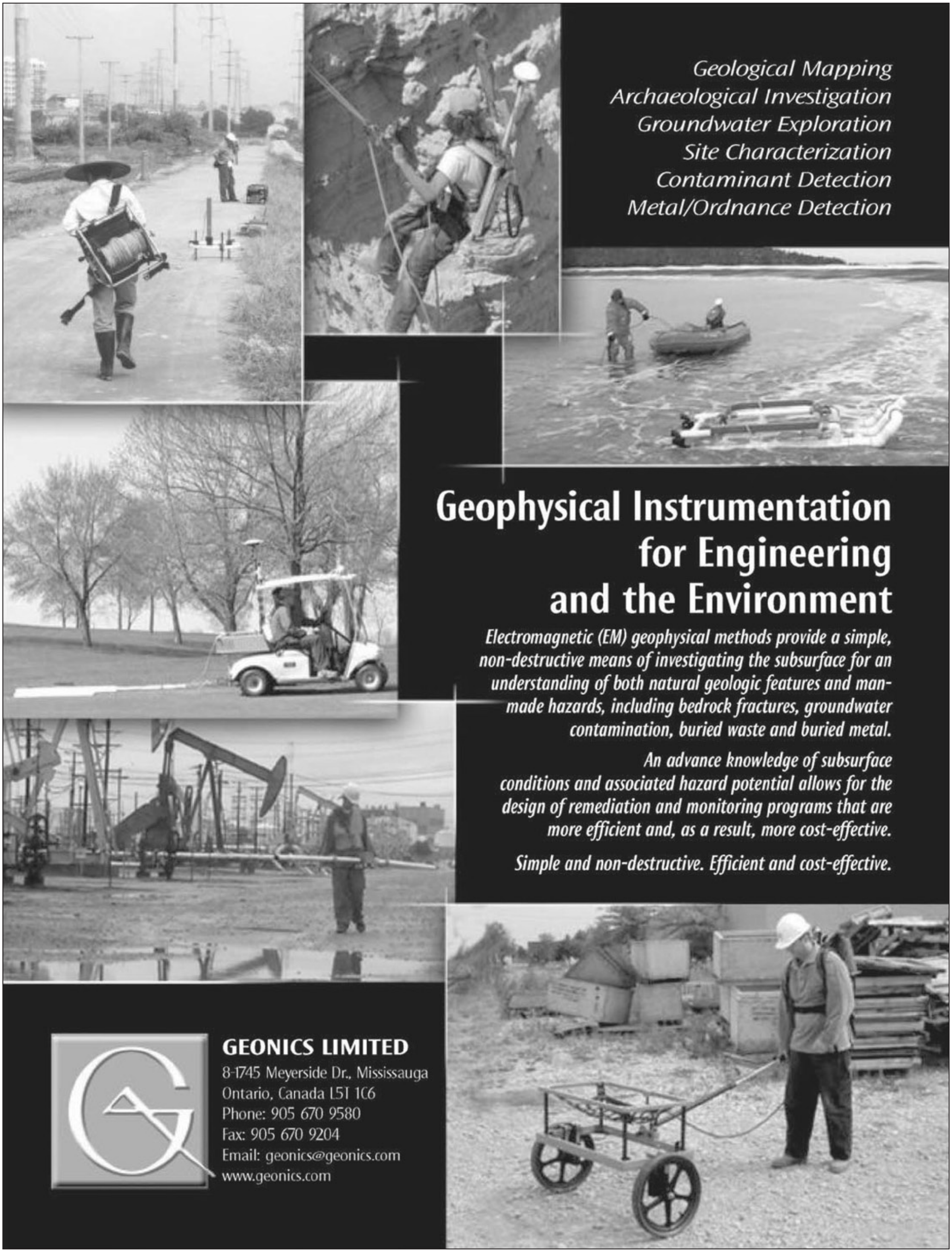
Linford, N, Linford, P, Martin, L and Payne, A 2007 'Recent results from the English Heritage caesium magnetometer system in comparison to recent fluxgate gradiometers'. Archaeological Prospection, 14 (3), p. 151-166.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FastTIMES presents short articles from young geoscientists investigating some of the more challenging problems related to the Earth's resources and environment. Graduate students or recent graduates are invited to send the editors descriptions of research topics and findings for possible inclusion in future issues.

Cold Water Geysers: A Fountain of Information for CO2 Sequestration Models

Rachel Berkowitz, BP Institute, Cambridge University, UK (rachel.berkowitz@bpi.cam.ac.uk)

As human consumption of fossil fuels continues to increase, so does the rate at which CO2 is being pumped into the atmosphere. To avoid the climatic damage now known to be associated with this increase, it is proposed that CO2 be trapped and stored for centuries. One of the most exciting plans is to inject it deep into porous geological formations. However, an understanding of how it will react with the rock that will hopefully keep the CO2 trapped underground will be a critical piece of information to ensure that the proposed sequestration will be done safely and effectively.

Crystal Geyser near Green River, Utah, was created when an exploratory oil well was drilled into a fault zone above a natural CO2 reservoir, and may provide useful information for understanding the sequestration problem. The chemical composition of the water from this cold water geyser and its evolution can be used to place constraints on the rates and potential controlling mechanisms of mineral-fluid reactions under elevated CO2 pressures in a natural system.

Crystal Geyser eruption, driven by CO2 degassing upon decompression. Ref: M. Bickle, Geological carbon storage, Nature Geoscience 2, 815-818 (2009); photo Niko Kampman.

A cold water geyser is a periodically erupting aquifer system driven by CO2 bubbles rather than steam. In Crystal Geyser, CO2-laden water pools in the confined Navajo aquifer. The borehole drilled through the natural confining layer into the aquifer provides a path for pressurised fluids to reach the surface. The water column provides enough pressure to keep the CO2 in solution at depth, but a decrease in pressure causes the CO2 to expand or "boil," starting the eruption. Because of degassing, the composition of the erupted fluid that can be sampled at the surface has a different chemical makeup to that found underground.

"Knowing the composition of CO2-saturated fluids tells us about their likelihood to react with minerals of the host rock" says Benoit Dubacq, a geologist at the University of Cambridge Earth Sciences Department in Cambridge, England [http://www.esc.cam.ac.uk/]. Possible CO2 injection sites are carefully chosen, such that when stored underground (often) in sandstone formations, CO2 is contained by a layer of clay-like cap rock, preventing it from leaking out of the aquifer. “The integrity of the caprock is a key parameter for ensuring the long-term safety of CO_2 injection sites – and thus their public acceptance,” Dubacq explains. Knowing the composition of underground CO_2-rich fluids not only provides constraints that can be used to predict how the brine might corrode cap rocks and fault seals, but also to assess the possibility of minerals releasing heavy metals when leached by CO_2-rich fluids.

It’s tricky to measure the huge amounts of gases being vented at the surface as Crystal Geyser erupts, so Dubacq and his colleagues use carbon and oxygen isotopes of the emitted fluid to calculate the amount of degassing and “have an idea of the composition of the fluid in the aquifer.” Back in the laboratory, mass spectrometers measure major and trace elements.

During a geyser eruption, water level rises in the well as it recharges from the groundwater. When overflow starts (See PICTURE 2, A), the few bubbles rising with the liquid begin to decrease the hydrostatic pressure at the top of the well and any slight density change progresses down the well. The vapour flash point--the level at which bubbles start to form--drops deeper into the well and more gas is released (A-B). Bubbles coalesce to form long slugs of gas, leading to larger eruptions (B-C), with almost all of the fluid in the well contributing to the release of CO_2 gas. At this stage, the fresh supply of fluid that is recharging the well cannot provide the gas required to maintain the slug flow because the fluid pressure is too high for gas to come out of solution (C-D). So the water level in the well falls quickly, with the hydrostatic pressure rebuilding as the incoming fluid rises. The flash point curve (describing where boiling will occur) moves upward as well (D-E). The eruption repeats when the water level reaches the wellhead and bubbles begin to again decrease the hydrostatic pressure.

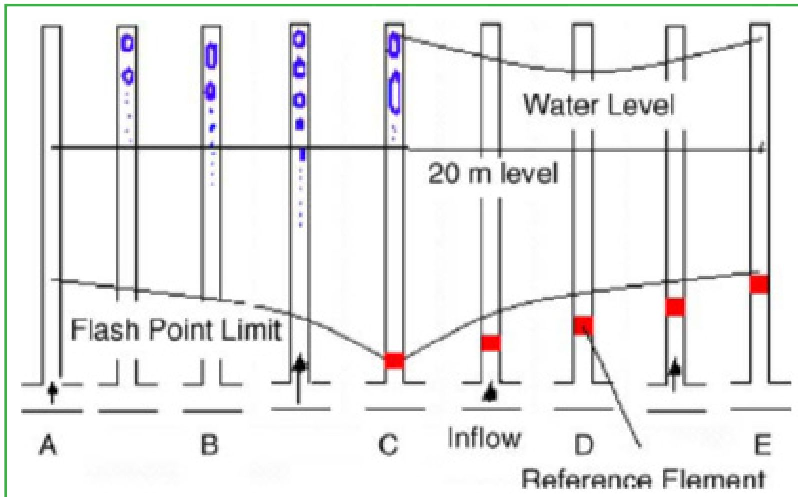
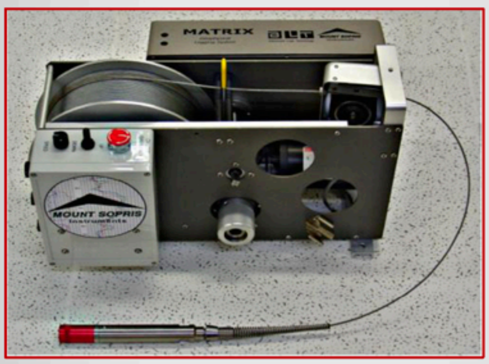
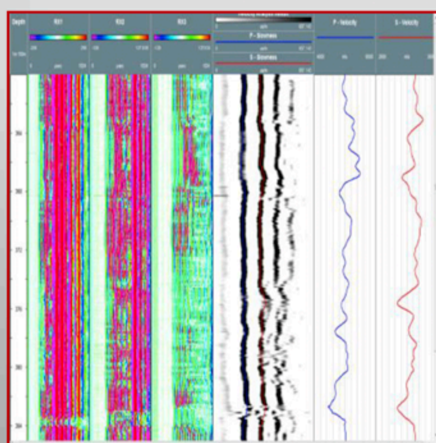


Diagram of the physical processes in the well leading to geysering cycles. Horizontal axis represents sequential snapshots in time. Vertical axis is depth, with bars extending up to the surface of the modeling domain and vertical arrows representing water coming in from below. Blue circles indicate bubbles and erupting fluid. Ref: X. Lu et al., Measurements in a low temperature CO_2-driven geysering well, viewed in relation to natural geysers, Geothermics 34, 389-410 (2005).

One recent study by Niko Kampman, also of Cambridge University, measures the rate at which plagioclase and feldspar dissolve from Crystal Geyser groundwater studying variations of compositions between fluids issued from wells sampling the same aquifer at different locations. Variations in saturation levels, on which reaction rates depend, are caused by the mixing of CO_2-rich fluids originating from another aquifer and naturally injected into the Navajo aquifer. The resulting acidic under-saturated fluid promotes the dissolution of minerals rich in silicon and aluminium such as feldspars. Solutes are thus being released in the fluid as dissolution progresses, and Kampman studied this progression by sampling different wells along the flowpath.

“We are also interested in the isotopic composition of these gases and brines and their evolution over time,” adds Dubacq. Watch this space for new results as the Cambridge team proceeds with large-scale CO_2 injection tests to determine rate laws and model the long term chemical and mineralogical responses.





Buoyancy-Driven Flow and the Energy Challenge

Will Rayward-Smith, BP Institute, University of Cambridge, UK (will.rayward-smith@bpi.cam.ac.uk)

As Carbon Capture and Storage (CCS) rapidly becomes the centre of attention for many geophysical researchers, there is growing interest in understanding the buoyancy-driven migration of fluid injected into rocks.

We have an obligation to future generations to pass down an energy infrastructure that relies less on exploiting fossil fuels. It is also critical to decrease our green house gas emissions to minimise anthropogenic climate change. This set of priorities is known as the energy challenge and geophysical fluid dynamicists are working to meet this challenge.

The capture of greenhouse gas carbon dioxide from point sources, such as the flue gases of fossil fuel power stations, and then storing this carbon dioxide underground appears to be an attractive option, but reliable prediction of the subsequent migration of injected carbon dioxide beneath the ground will be key to its wide-scale deployment.

Researchers at the University of Cambridge use a combination of analytical models and laboratory experiments to explore the buoyancy-driven migration of injected fluid which differs both in temperature and composition from local fluid in the formation, with the aim of providing fundamental understanding that will inform this technology.

Our first publication (ref: Rayward-Smith and Woods 2011a) highlights that for CCS, the injected CO2 typically arrives at a colder temperature than the formation and this has significant consequences on the migration of the CO2. As the cold CO2 flows through the rock, local thermal equilibrium manifests a thermal front, behind which the rock and CO2 are cold. As the CO2 temperature adjusts across this thermal front, it becomes less viscous and more buoyant, and so the flow changes from a deep, slow flow upstream to a shallow, fast flow downstream.

While the increased depth of the cold region near the injection point increases the storage potential of the rock, it may enhance drainage (and potential leakages) into the seal rock where the current is deep enough to exceed the capillary entry pressure.

Understanding buoyancy-driven flow in porous media is not only important for the deployment of CCS, but also for other technologies that aim to address the energy challenge. One example is Aquifer Thermal Energy Storage (ATES), a variant of inter-seasonal heat storage, which involves the injection of excess heat into deep rock during the hot summer months and later extraction during the cooler winter months. Knowledge of the movement of the injected hot water is essential for efficient heat recovery in the winter months and is discussed in our next publication (ref: Rayward-Smith and Woods 2011b).

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Rayward-Smith, W. J., Woods, A. W., 2011b. On the propagation of non-isothermal gravity currents in an inclined porous layer, J. Fluid Mech., Sub judice.

Postdoc position in Exploration and Environmental Geophysics

Deadline August 15, 2011

The Applied and Environmental Geophysics Group at ETH (Swiss Federal Institute of Technology) has an immediate opening for an ambitious and talented scientist at the post-doctoral or senior researcher level. The appointment will be for an initial period of two years with the possibility of extension for up to 6-8 years. We invite applicants conducting world-leading research in areas of applied geophysics including wave-equation based modeling and inversion methods and/or innovative applications in the field of exploration and environmental geophysics.

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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.*

The 10th SEGJ International Symposium

Imaging and Interpretation

November 20-23, 2011, Kyoto, Japan

The Society of Exploration Geophysicists of Japan (SEGJ) observes its vicennial anniversary in Kyoto at the Centennial Memorial Hall of Kyoto University. Under the theme "Imaging and interpretation", the Symposium's technical program presents the latest scientific and technological advances related to a broad range of geophysical applications that are used to better understand and model invisible underground structures and processes in various environmental and engineering investigations. For more information, please visit the symposium website (*http://www.segj.org/is/10th*) or contact Professor Hitoshi Mikada, General Chair at *segj10th@segj.org*.

SAGEEP 2012 - 25th Anniversary

March 25-29, 2012, Tucson, Arizona

For SAGEEP's 25th anniversary, we have chosen a very special destination for our symposium: Tucson, Arizona. This is the first time ever that SAGEEP has visited the southwest. Our host hotel, the Hilton El Conquistador, is a AAA Four Diamond resort, full of all the charm and flavor of the desert southwest. Nestled directly in the breathtaking foothills of the Santa Catalina mountains, the luxurious El Conquistador boasts 500 acres of untouched Sonoran Desert terrain, unparalled views of the mountains by day and world class stargazing at night. Plus, Tucson's colorful history and vibrant culture mean incredible excursions and day trips are just steps away. More information about the technical program and short courses is to come shortly.

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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.

Best of SAGEEP 2011

April 10-14, 2011, Charleston, SC

The following articles were selected for presentation at the Near Surface 2011 that will be held from 12-14 September 2011 in Leicester, England.

MULTI-SCALE MONITORING OF ECOHYDROLOGICAL PROCESSES USING ELECTRICAL RESISTIVITY TOMOGRAPHY

R. Van Dam[1], D. Hyndman[1], A. Kendall[1], K. Diker[2], B. Christoffersen[3], and S. Saleska[3]

1 – Department of Geological Sciences, Michigan State University, USA;
2 – Michigan State University, USA
3 – Department of Ecology and Evolutionary Biology, Univ. of Arizona, USA

Hydrogeophysics is a growing discipline that holds significant promise to help elucidate details of dynamic processes in the near surface, built on the ability of geophysical methods to measure properties from which hydrological and geochemical variables can be derived. For example, bulk electrical conductivity is governed by, amongst others, interstitial water content, fluid salinity, and temperature, and can be measured using a range of geophysical methods. In many cases, electrical resistivity tomography (ERT) is well suited to characterize these properties in multiple dimensions and to monitor dynamic processes, such as water infiltration and solute transport.

In recent years, ERT has been used increasingly for ecosystem research in a wide range of settings; in particular to characterize vegetation-driven changes in root-zone and near-surface water dynamics. This increased popularity is due to operational factors (e.g., improved equipment, low site impact), data considerations (e.g., excellent repeatability), and the fact that ERT operates at scales significantly larger than traditional point sensors. Current limitations to a more widespread use of the approach include the high equipment costs, and the need for site-specific petrophysical relationships between properties of interest. In this presentation we will discuss recent equipment advances and theoretical and methodological aspects involved in the accurate estimation of soil moisture from ERT results. Examples will be presented from two studies in a temperate climate (Michigan, USA) and one from a humid tropical location (Tapajos, Brazil).

INTEGRATING HYDROLOGY AND GEOPHYSICS TO EVALUATE THE IMPACT OF ARTIFICIAL RECHARGE ON GROUNDWATER IN RURAL INDIA

S. Moysey[1], D. Matz[1], S. Gangrade[1], C. Guha[2], R. Ravindranath[2], and M. Choudhary[2]

1 – Clemson University, USA;
2 – Foundation for Ecological Security, India

The monsoonal climate of India coupled with the complex geology and low storage capacity of the Deccan basalts contribute to water scarcity in central India during the dry season. One of the primary tools proposed to manage this problem is the artificial recharge of runoff captured during the monsoon to enhance groundwater availability throughout the year. One common approach for artificial recharge is the construction of small dams to generate percolation ponds, as exemplified by a small reservoir in the Salri watershed of Mahdya Pradesh, India. We use this specific example to illustrate how the integration geophysical and hydrologic data can be used to understand the influence of the dam on groundwater in the watershed. Electrical resistivity and electromagnetic induction surveys are used to assist in developing a geologic conceptual model for the watershed consisting of a thick sequence of basalt flows overlain in the lowland portion of the watershed by weathered basalt and alluvium for a depth of up to 10m. This geologic model has guided our understanding of the local flow system. A shallow flow system in the near-surface weathered basalts and alluvium is the primary source of water for agriculture. In contrast, vertical variability in the competent basalt flows is expected to create a highly anisotropic flow system with high horizontal permeability and low vertical permeability. As a result, the geophysical data help to form a conceptual model where the dam primarily impacts the shallow aquifer and has limited impact on deeper regional flow systems. To assess this hypothesis and quantify the impact of the dam on the overall hydrology of the watershed a hydrologic monitoring program was implemented. By integrating the geophysically-based conceptual model with this hydrologic data we are able to provide a quantitative assessment of the role of the dam within the watershed.

ASSESSING WATER STORAGE CHANGES ON THE FIELD SCALE COMBINING SUPERCONDUCTING GRAVIMETER OBSERVATIONS WITH AN HYDROLOGICAL MODEL

B. Creutzfeldt[1], A. Güntner[1], H. Wziontek[2] and B. Merz[1]

1 – German Research Centre for Geosciences, Germany;
2 – Federal Agency for Cartography and Geodesy, Germany

Information on water storages is crucial for many applications, like agricultural production, groundwater recharge or transport of contaminants. Limitations of observation techniques and high spatio-temporal variability make the estimation of water storage challenging, especially for deeper zones. Temporal gravimeter observations are significantly influenced by water storage changes (WSC) at the field scale and hence may provide valuable information about the state of the hydrological system.

In this study, we assess the benefit of temporal gravimeter measurements as an integral signal for hydrological application by evaluating a hydrological model using residuals time series of a superconducting gravimeter (SG). A simple conceptual model is used to estimate local WSC in the snow, soil, unsaturated saprolite, and saturated aquifer storage. The model is calibrated and evaluated against SG data on the one hand and several groundwater and/or soil moisture data on the other. The model is validated against independently estimated WSC derived from a state-of-the-art lysimeter.

The results show that using an SG as calibration constraint improves the model results substantially in terms of predictive capability and variation of the behavioral model runs in comparison to classical hydrological point measurements. Gravity measurements integrate over different hydrological storage components and the sampling volume is several orders of magnitude larger than that for the point measurements. The general problem of specifying the internal model structure or individual parameter sets can, however, not be solved with gravimeters alone. Additionally, the results show that also WSC in the deep vadose zone contribute significantly to the hydrological cycle, so SG might provide a tool to continuously and non-invasively monitor WSC also in this zone.

MULTI-ELEVATION CALIBRATION OF FREQUENCY DOMAIN ELECTROMAGNETIC DATA

B.J. Minsley[1], G. Hodges[2], B.D. Smith[1], and J.D. Abraham[1]

1 – U.S. Geological Survey, Crustal Geophysics and Geochemistry Science Center, Denver, Colorado, USA
2 – Fugro Airborne, Mississauga, Ontario, Canda

The ability to make quantitative inferences about subsurface properties is an important component of interpreting frequency domain electromagnetic (FDEM) data. Systematic data errors caused by imperfect instrument calibration can lead to inversion artifacts or, in some cases, best-fit models that are inconsistent with the measured data. Factory and in-flight internal system calibrations have helped to reduce, though not always eliminate, calibration errors in modern FDEM systems. A number of methods have been developed to calibrate data after it has been acquired, but these are primarily based on having auxiliary information about subsurface properties from well logs or ground-based geophysical surveys, which are not always available and may have inaccuracies of their own.

In this work, we propose a new strategy for calibrating FDEM data that does not rely on prior knowledge of the subsurface structure. This calibration procedure involves acquiring multiple datasets along a single calibration line at several different survey elevations at the beginning of a survey. Calibration parameters, consisting of gain, phase, and bias correction factors for each frequency, are derived by requiring that data from the multiple survey elevations be consistent with the same earth model at each location along the line. This is accomplished by simultaneously inverting the multi-elevation data for an earth model at each location along the profile along with a single set of calibration parameters. This joint inversion strategy recovers the combination of earth models and calibration parameters that are optimally consistent with the multi-elevation data. The derived calibration parameters are then applied to the survey data, and the calibration procedure can be repeated as necessary to correct for system drift.

Outdoor curriculum for geophysicists: DMT participating in EAGE Geophysics Boot Camp in 2011

May 9-20, 2011, Humbly Grove, England

In the real world, geophysics is an 'outdoor sport'. This fact usually gets short shrift in university studies. That is why the EAGE – the European Association of Geoscientists and Engineers – issued an invitation to its 2011 Boot Camp. There thirty-four students and six entry-level employees gained hands-on experience in the geosciences. DMT GmbH & Co. KG, a technology services company located in Essen, Germany, supported this project with modern geophysical equipment and by delegating experienced staff. It also offered two students an opportunity to attend this workshop at the company's expense.

In eleven days these fledgling geophysicists found out how to handle data acquisition instruments and run special software applications. They also learned about many additional practical details that arise when one carries out a joint project. This is why the camp is located near a known oil field. The data gathered during exploratory studies were compared with measured data and drill core information recovered previously by professionals in the same oil field.

'During last year's "Recruitment Workshop", held by the EAGE in southern France, I heard about the boot camp concept for the first time – and I was immediately excited about it,' recalls Fabian Gebhardt, Seismic Resources Manager at DMT. 'I didn't have to do much arm twisting to get DMT to loan out the required seismic equipment.' Consequently numerous state-of-the-art Sercel acquisition units and hundreds of geophones made their way to England, accompanied by personnel and an instructor.

'A real adventure was in store for us. We are working on a joint project in an international team,' reports Czech student Vaclav Kuna, whom DMT selected to take part in the project. His German colleague Benedikt Stille shares that view: 'It's very interesting, before we finish our studies, to experience for once the practical side of the fundamentals we learned at the university.' 'And that is exactly the whole purpose of the camp [...]', added Fabian Gebhardt in closing. DMT is one of several renowned companies that sponsored and supported this project.

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Membership Renewal

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About Me: Interests & Expertise

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

Classify Association

- ☐ Consultant
- ☐ User of Geophysical Services
- ☐ Student
- ☐ Geophysical Contractor
- ☐ Equiment Manufacturer
- ☐ Software Manufacturer
- ☐ Research/Academia
- ☐ Government Agency
- ☐ Other ________

Classify Interest or Focus

- ☐ Archaeology
- ☐ Engineering
- ☐ Environmental
- ☐ Geotechnical
- ☐ Geotechnical Infrastructure
- ☐ Groundwater
- ☐ Hazardous Waste
- ☐ Humanitarian Geophysics
- ☐ Mining
- ☐ Shallow oil & Gas
- ☐ UXO
- ☐ Other ________

Specific Areas Involved

- ☐ Borehole Geophysical Logging
- ☐ Electrical Methods
- ☐ Electromagnetics
- ☐ Gravity
- ☐ Ground Penetrating Radar
- ☐ Magnetics
- ☐ Seismic
- ☐ Other ____

Professional/Scientific Societies

- ☐ AAPG
- ☐ AEG
- ☐ ASCE
- ☐ AWWA
- ☐ AGU
- ☐ EAGE
- ☐ EER1
- ☐ GeoInstitute
- ☐ GSA
- ☐ MGLS
- ☐ NGWA
- ☐ NSG
- ☐ SEG
- ☐ SSA
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Interested in Participating on Standing Committees?

- ☐ Government Affairs
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Circle the desired Membership Category amount.

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NEW **Developing World Category***	$50	$100

Category Descriptions and Newly Expanded Benefits

Individual and Developing World Category Memberships:

- Access to the **online EEGS Research Collection** resource—online access to the complete *Journal of Environmental and Engineering Geophysics* (*JEEG*) and proceedings archives of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP)
- The option of receiving a printed *JEEG* or accessing an electronic issue
- Subscription to the ***FastTIMES*** Newsletter
- **Preferential** registration **fees** for **SAGEEP**
- **Networking** and continued **communication** on issues of interest to the organization

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- Includes all the benefits of the Individual Membership
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- A link on the EEGS Website
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- 10% discount on advertising in the *JEEG* and *FastTIMES*

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- Ability to insert marketing materials in the SAGEEP delegate packets
- A link on the EEGS website
- Listing with corporate information in *FastTIMES*
- 10% discount on advertising in the *JEEG* and *FastTIMES*

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- Two exhibit booths at the Symposium on the Applications of Geophysics to Engineering and Environmental Problems (SAGEEP)
- Ability to insert marketing materials in the SAGEEP delegate packets
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- 10% discount on advertising in the *JEEG* and *FastTIMES*

Foundation Contributions

Founders Fund

The Founders Fund has been established to support costs associated with the establishment and maintenance of the EEGS Foundation as we solicit support from larger sponsors. These will support business office expenses, necessary travel, and similar expenses. It is expected that the operating capital for the Foundation will eventually be derived from outside sources, but the Founder's Fund will provide an operation budget to "jump start" the work. Donations of $50.00 or more are greatly 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.

Foundation Fund Total: ____________________

Student Support Endowment

This endowed fund will be used to support travel and reduced membership fees so that we can attract greater involvement from our student members. Student members are the lifeblood of our Society, and our support can lead to a lifetime of involvement and leadership in the near surface geophysics community. Donations of $50.00 or more are greatly 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.

Student Support Endowment Total: ____________________

Corporate Contributions

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.

Corporate Contribution Total: $ ____________________

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Membership Renewal
Developing World Category Qualification

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

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Belize
Benin
Bhutan
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Central African Republic
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	0029	2010 (CD-ROM) ****NEW****	$75	$100
	0026	2009 (CD-ROM)	$75	$100
	0025	2008 (CD-ROM)	$75	$100
	0023	2007 (CD-ROM)	$75	$100
	0020	2006 (CD-ROM)	$75	$100
	0018	2005 (CD-ROM)	$75	$100

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

SAGEEP Short Course Handbooks

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

Miscellaneous Items

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

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Member Rate: $15

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