*Fast*TIMES

Airborne Geophysics:

Unmanned Aerial Systems for Agricultural Geophysics - Potential and Public Policy

Airborne Geophysics for Environmental and Engineering Applications

Airborne Electromagnetic Surveys for U.S. Geological Survey Programs

March 2014

Volume 19, Number 1

This issue is focused on airborne geophysics, with articles that highlight issues related to unmanned aerial systems (drones), give examples of airborne geophysics environmental and engineering applications, and provide an overview of airborne electromagnetic surveys that are being carried out by the U.S. Geological Survey.

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*Fast*TIMES

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ABOUT EEGS

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

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

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

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EEGS welcomes membership applications from individuals (including students) and businesses. Annual dues are $90 for an individual membership, $50 for introductory membership, $50 for a retired member, $50 developing world membership, complimentary corporate sponsored student membership - if available, and $300 to $4000 for various levels of corporate membership. All membership categories include free online access to JEEG. The membership application is available at the back of this issue, or online at www.eegs.org.

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June 19 - 20 or August 14 - 15	Multichannel Analysis of Surface Wave (MASW) Workshop Lawrence, Kansas, USA http://www.kgs.ku.edu/software/surfseis/workshops.html
June 20 - 23	6th International Conference on Environmental and Engineering Geophysics Xi'an, China http://tdem.org/iceeg2014/en (Note: Antonio Menghini, antonio.menghini@aarhusgeo.com, a JEEG Associate Editor, will be co-chairing a session on airborne geophysics. See page 46 for additional information.)
July 22 - 24	Joint Society of Exploration Geophysicists and American Geophysical Union Summer Research Workshop - Advances in Active + Passive "Full Wavefield" Seismic Imaging: From Reservoirs to Plate Tectonics Vancouver, Canada http://www.seg.org/events/upcoming-seg-meetings/
August 24 - 30	22nd EM Induction Workshop Weimar, Germany http://www.emiw2014.de
October 26 - 31	Society of Exploration Geophysicists International Exposition and 84th Annual Meeting Denver, Colorado, USA http://www.seg.org
December 15 - 19	American Geophysical Union Fall Meeting San Francisco, California, USA http://fallmeeting.agu.org/2014/

2015

February 15 - 18	Australian Society of Exploration Geophysics and Petroleum Exploration Society of Australia - 24th International Geophysics Conference and Exhibition Perth, Australia http://www.conference.aseg.org.au (Note: See page 46 for additional information.)

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

NOTES FROM EEGS
PRESIDENT'S MESSAGE

Catherine Skokan, President
(cskokan@mines.edu)

As I write this, my last President's Letter, I am preparing for the exciting SAGEEP in Boston. We will have three full days of oral presentations, poster sessions, an outdoor demo (pray for good weather), and a wonderful Gala Conference Dinner. It looks to be an excellent program in a great location. I hope to see all of you there. After SAGEEP, I turn the reins over to Moe Momeyez, and I will be the "past" president. Moe has been very active in many aspects of EEGS, including chairing SAGEEP 2012 in Tucson, Arizona. I look forward to working with him.

SAGEEP 2015 is in the planning process. Please watch e-mails and FastTimes for more details. The target site is Austin.

I am excited with the work that Barry Allred has done as our new FastTimes editor. He is planning a UXO theme for the September issue and welcomes short articles and case histories on this topic.

The talks with SEG about a merger continue. We are currently conducting a legal review ....and this kind of due diligence always take time. We will be taking this matter to a vote of the membership by summer, 2014. I encourage all of you to become aware of the issues on both sides. I also encourage all of you to join or renew your membership in EEGS so that you have a say in the outcome. If you are passionately for or against a merger, you cannot express your opinion on a ballot if you are not a member. In order to help clarify issues concerning a possible merger, there will be an information table set up next to the registration booth at SAGEEP in Boston. If you are unable to attend, or have questions after SAGEEP, please feel free to contact me via e-mail (cskokan@mines.edu).

Editor's Note: This President's Letter was prepared in mid-March, and since that time, merger negotiations between EEGS and and SEG have been discontinued.

EEGS Foundation makes great strides in its first years.

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

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

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

Sponsorship Opportunities

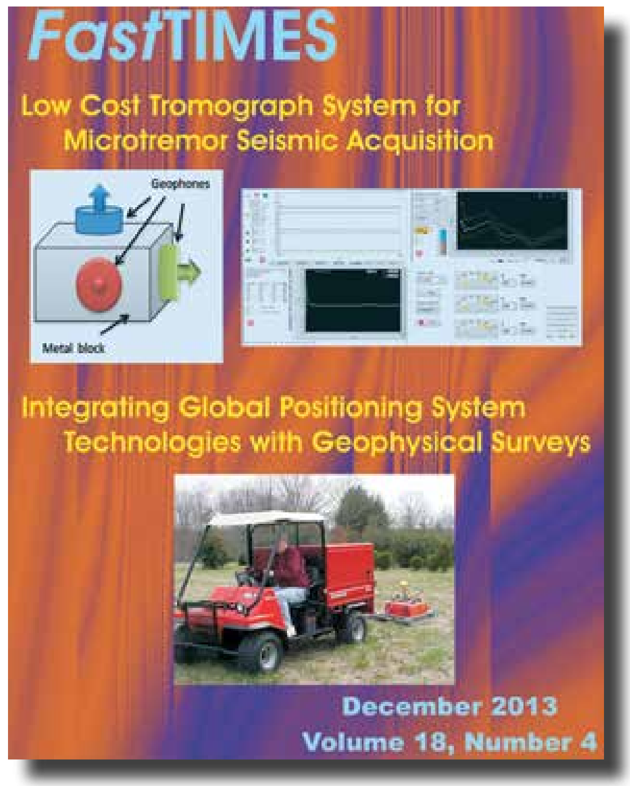
There are always sponsorship opportunities available for government agencies, corporations, and individuals who wish to help support EEGS's activities. Specific opportunities include development and maintenance of an online system for accessing SAGEEP papers from the EEGS web site and support for our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

From the *Fast*TIMES Editorial Team

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

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

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



Submissions

The *Fast*TIMES editorial team welcomes contributions of any subject touching upon geophysics. *Fast*TIMES also accepts photographs and brief non-commercial descriptions of new instruments with possible environmental or engineering applications, news from geophysical or earth-science societies, conference notices, and brief reports from recent conferences. Please submit your items to a member of the *Fast*TIMES editorial team by June 15 to ensure inclusion in the next issue. We look forward to seeing your work in our pages. Note: Plans are for the September *Fast*TIMES issue to focus on geophysical methods used for locating UXO, and submission of short articles and case histories on this topic are highly encouraged.

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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Editor's Note

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

Introduction to the March 2014 JEEG Special Issue on Time Domain Electromagnetic Applications

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The idea to propose a special issue on time domain electromagnetic (TEM) methods was based on my perception that recent innovations and developments, both in instrumentation and processing, deemed it time to perform a checkup on the state-of-the-art of the method. Many of these advancements address offshore and airborne applications rather than ground-based ones. For example, the popular use of the marine controlled source electromagnetic (MCSEM) method in the oil industry, undoubtedly a real "renaissance" for EM, marked a surge in the development of new devices and approaches, together with the continuous improvement in technology and processing of airborne EM data. As shown in this issue, the application of ground-based TEM has also grown, with advances in instrumentation, data processing, and its application.

The papers by **Xue et al.** and **Li et al.** are proof of this statement, as they show the possibility of applying TEM in challenging environments. In **Xue et al.**, "Research on the application of a 3-m transmitter loop for TEM survey in mountainous areas," they design a system for exploration in mountainous areas, where it is more convenient to use a compact system, without giving up penetration depth and resolution. The authors are able to achieve this outcome by significantly increasing the input current and still maintain instrumentation accuracy and resolution. In **Li et al.**, "Three dimensional modeling of transient electromagnetic responses of water-bearing structures in front of a tunnel face," modeling simulations show the possibility of using a given waveform transmitter and a dedicated 3-D inversion approach to detect water-filled faults and karst cavities in front of a tunnel face, a crucial issue in coal mining activities to avoid fatal accidents.

Fitterman, "Mapping saltwater intrusion in the Biscayne Aquifer, Miami-Dade County, Florida using transient electromagnetic sounding," reports a successful case history of TEM application for the study of saltwater intrusion along coastal aquifers, even in the presence of urban environments. He shows that the well-known limitation of TEM methods in noisy areas can be overcome by scrupulous specification of parameters during the acquisition process. Moreover, he highlights the incomparable ability of the TEM method to accurately image the saltwater-freshwater interface.

The capability to identify groundwater contamination is also demonstrated in the paper by **Metwaly et al.**, "Combined inversion of electrical resistivity and transient electromagnetic soundings for mapping groundwater contamination plumes in Al Quwy'yia Area, Saudi Arabia." This paper addresses the joint use of TEM and VES (vertical electrical soundings), both of which are suitable for detecting hydrogeological targets, as they sense contrasts in electrical resistivity. In this case, the pollution is caused by human activities, i.e., illegal dump sites and seepage from septic tanks, hence a relevant application of environmental geophysics.

The paper by **Sapia et al.**, "The impact on geological and hydrogeological mapping results of moving from ground to airborne TEM," completes the issue. The authors demonstrate the advantage of using airborne EM, in comparison with ground-based geophysical prospecting, when a high degree of lateral resolution is needed, as occurs in the case of the detection of narrow aquifers within buried valleys. They simulate a ground-based acquisition dataset from a real airborne EM dataset by desampling the airborne data. The authors demonstrate the high degree of focusing that comes from the dense sampling of an airborne EM survey, which is impractical to achieve using a typical ground-based campaign.

Acknowledgments
I thank the authors for their patience during the review of their manuscripts, and to the reviewers who gave their time and effort in contributing to the outcome of this initiative. I am also grateful to JEEG Editor-in-Chief Janet Simms, who gave me the opportunity to compile this special issue. Although it does not represent an exhaustive examination of the current stage of TEM methodology, it does shed light on its expanding applications and illuminates the ever more complex world of the TEM method.

SUCCESS WITH GEOPHYSICS

FastTIMES welcomes short articles on applications of geophysics to the near surface in many disciplines, including engineering and environmental problems, geology, hydrology, agriculture, archaeology, and astronomy. This issue is focused on airborne geophysics. In the articles that follow, authors discuss issues related to unmanned aerial systems (drones), give examples of airborne geophysics environmental and engineering applications, and provide an overview of airborne electromagnetic surveys that are being carried out by the U.S. Geological Survey.

UNMANNED AERIAL SYSTEMS FOR AGRICULTURAL GEOPHYSICS — POTENTIAL AND PUBLIC POLICY

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Introduction

Unmanned aerial systems (UAS - "drones") will revolutionize agriculture. Field scouting will become automated, inexpensive, and on-demand. The low-flying UAS will closely examine crops, pastures, and timberlands. Since they will see crop infestation at its very outset, farmers will be able to focus precisely on pest containment. Cattlemen will be able to monitor livestock health and pinpoint both strays and their predators, while they "ride herd" overhead using UAS thermal imaging. Geo-referenced nutrient and yield maps will become commonplace. Rapid delivery of essential, time-critical information at very low cost is the trademark of the UAS.

U.S. farmers will have access to this technology very soon; the Federal Aviation Administration (FAA) has been mandated by Congress to develop regulations to safely integrate commercial UAS into American airspace by September 2015. Many anxiously await these legal changes, since current FAA regulations severely restrict UAS deployment. Most UAS commercial applications within U.S. airspace are now prohibited. One consequence of these UAS prohibitions is that U.S. production agriculture is now at a distinct disadvantage with its global competitors in its UAS applications.

Keywords: Unmanned Aerial Systems (UAS), Federal Aviation Administration (FAA), Agriculture, Geophysical Applications.

These restrictions are particularly frustrating because, although the U.S. market for commercial UAS applications is essentially closed, the price of a UAS has significantly declined. UAS hobbyists world-wide have been driving down the cost of this technology, principally through their freely donated innovations and open-source software. Very powerful UAS mapping platforms are now available in the U.S. They can be assembled from inexpensive hobbyist kits imported from overseas. The UAS constructed from components and materials supplied for the hobbyist will cost significantly less than a UAS marketed for commercial purposes (Figure 1). In less than two years, a commercial mapping UAS first offered at $80,000 can now be assembled from $800 in hobbyist parts and deployed using free open-source software. Two UAS designs are commonplace: a winged UAS and a multi-rotor UAS. Compared to the multi-rotor UAS, the winged UAS (Figure 1) provides faster flight, longer flight times, and a more stable imaging platform. However, the multi-rotor UAS provides more maneuverability and lifting power.

Figure 1: Hobbyist mapping UAS constructed of flexible EPO (Expanded Polyolefin).

FAA Restrictions

The limits placed on the UAS by the FAA fully encompass the use of hobbyist airframes. Deploying these hobby "drones" commercially will result in cease and desist letters from the FAA, with possible stiff fines. Aerial photography for hire are the majority of these offenses. The following are the FAA regulations (2012) that address the civil use of a UAS. A model aircraft (i.e., unmanned), or an aircraft being developed as a model aircraft, can only be flown under the following conditions:

1) *the aircraft is flown strictly for hobby or recreational use;*

2) *the aircraft is operated in accordance with a community-based set of safety guidelines and within the programming of a nationwide community-based organization;*

3) *the aircraft is limited to not more than 55 pounds unless otherwise certified through a design, construction, inspection, flight test, and operational safety program administered by a community-based organization;*

4) *the aircraft is operated in a manner that does not interfere with and gives way to any manned aircraft; and*

5) *when flown within 5 miles of an airport, the operator of the aircraft provides the airport operator and the airport air traffic control tower (when an air traffic facility is located at the airport) with prior notice of the operation (model aircraft operators flying from a permanent location within 5 miles of an airport should establish a mutually-agreed upon operating procedure with the airport operator and the airport air traffic control tower (when an air traffic facility is located at the airport)).*

The FAA defines the term ``model aircraft'' as an unmanned aircraft that is--
1) *capable of sustained flight in the atmosphere;*
2) *flown within visual line of sight of the person operating the aircraft; and*
3) *flown for hobby or recreational purposes.*
The FAA may pursue enforcement action against persons operating model aircraft who endanger the safety of the national airspace system. Government public safety agencies (e.g., local police, fire, rescue, etc.), if permitted by local ordinance, are permitted to operate unmanned aircraft weighing 4.4 pounds or less when the aircraft is operated:
1) *within the line-of-sight of the operator;*
2) *less than 400 feet above the ground;*
3) *during daylight conditions;*
4) *within Class G airspace (uncontrolled); and*
5) *outside of 5 statute miles from any airport, heliport, seaplane base, spaceport, or other location with aviation activities.*
The economic cost of the FAA ban on commercial UAS application is considerable; the Association for Unmanned Vehicle Systems International estimates the U.S. economy loses $10 billion for every year UAS production sales are delayed (AUVSI, 2013). Nevertheless, many state legislatures and local governments have, or are considering, outright bans or limitations of "drones" due to privacy and property-rights concerns. Concerns of potential invasive overflights of farming operations by environmental or animal-rights activist have initiated "Ag-Gag" laws within some states.

The Potential

Flying a UAS is only a fraction of the cost of a manned aircraft, and for many operations it is much faster and safer. A UAS flying a large field, for example, can provide mapping at 2-cm resolution in 18 minutes; a job that if flown traditionally would require hours, if not days or weeks, due to aircraft scheduling. Another application is for crop insurance claims; UAS allow almost effortless documentation of land flooding, drought conditions, and crop damage. Strict U.S. government regulations on UAS use have severely limited American agricultural research and development. There are only a limited number of FAA-approved test ranges, and only those public agencies having FAA-issued Certificates of Operation (COA) are allowed to use these ranges for research. As a result of these constraints, most of the UAS research and development is taking place in foreign airspace. Companies outside the U.S. are supplying commercial UAS platforms for agricultural applications in Australia, South America, Europe, and Asia. According to the largest trade group, the Association for Unmanned Vehicle Systems International (AUVSI), Japan has an estimated 10,000 UAS vehicles deployed for agricultural use, where they do 90% of the aerial crop dusting (AUVSI, 2013). A wide breadth of countries, ranging from Uruguay, Argentina, Brazil, to Australia are also using UASs in agriculture to track cattle, survey crop health, detect harvest readiness, and as a tool for surveying the damage from drought, flooding, weeds, and pests. Since commercial use of the UAS is prohibited in the U.S., few of the UAS applications benefitting agriculture internationally can be implemented to benefit American agriculture.

One such UAS making inroads in agriculture is the Yamaha RMax helicopter, the size of this vehicle is similar to a motorcycle (Figure 2). It has a 28-kg load capacity, with a practical visual operating range of up to 400 m. The Yamaha RMax helicopter, first introduced in Japan as an agricultural UAS, was developed from Japanese government R&D funding extending back to the 1980's. Dealerships for this UAS are now opening in Australia. The liquid sprayer has two 8-L tanks, and the granular sprayer has two 13-L hoppers. It can spray cover 1.3 ha in 10 min. The manufacturer promotes a wide variety of agricultural uses that include spraying, seeding, remote sensing for precision agriculture, frost mitigation, and variable rate dispersal. In Japan, RMax helicopters are used primarily for seeding and spraying rice. Yamaha states that "the use of unmanned helicopters rapidly spread to other crops besides rice, including wheat, oats and soybean in 1992, lotus root in 1993, daikon radish in 1994, and chestnut groves in 1995." Despite the enormous contribution this vehicle could make to agriculture, its size and capability may hinder its adoption within the U.S. It can be easily weaponized, which may lead to stringent import/export restrictions.

Figure 2: UAS spraying grapes, showing maneuverability and lifting power.

Geophysical Applications

Many users of ground-penetrating radar (GPR) are aware of the restrictions placed on their surveys by the Federal Communication Commission (FCC) over the past decade. Although the lower-frequency, unshielded antennas were not banned, they can no longer be sold for domestic use. The higher-frequency GPR antennas, ground-coupled and upwardly shielded, are still sold domestically, but they now have performance restrictions and require user registration with the FCC. Mounting active geophysical transmitters, such as GPR, microwave, and EMI, on UAS platforms in large numbers will most surely initiate FCC attention. Thus for the mass U.S. market, passive remote sensing technologies (e.g., hyperspectral, multispectral, geomagnetic) have the most potential for UAS applications in the near future.

Any passive geophysical sensor that can be miniaturized in size and weight of a "Point-and-Shoot" digital camera or smart phone can become a UAS payload (Figure 3). For example, the generation of inexpensive geo-referenced digital elevation maps (DEMs) and orthomosaics with flight patterns pre-loaded within the UAS (Figure 4), are now well within the hobbyist realm. Inexpensive digital camera with GPS-capable geo-referencing can be configured to trigger automatically, or from the on-board autopilot generating pulses based upon travel velocity. Overlapped images can be processed into a mosaic, or stitched, forming stereo pairs for near-LiDAR 3-D images or point clouds (Figures 5 and 6). Many software options are available for processing UAS images from sequential geo-referenced photographs, both workstation and web based.

Figure 3: Fixed wing UAS with payload viewport.

Figure 4: Ortho imagery from hobbyist-grade UAS, nearly reaching or matching that of lower-tier commercial grade systems.

Figure 5: Near LiDAR quality imagery from hobbyist-grade UAS.

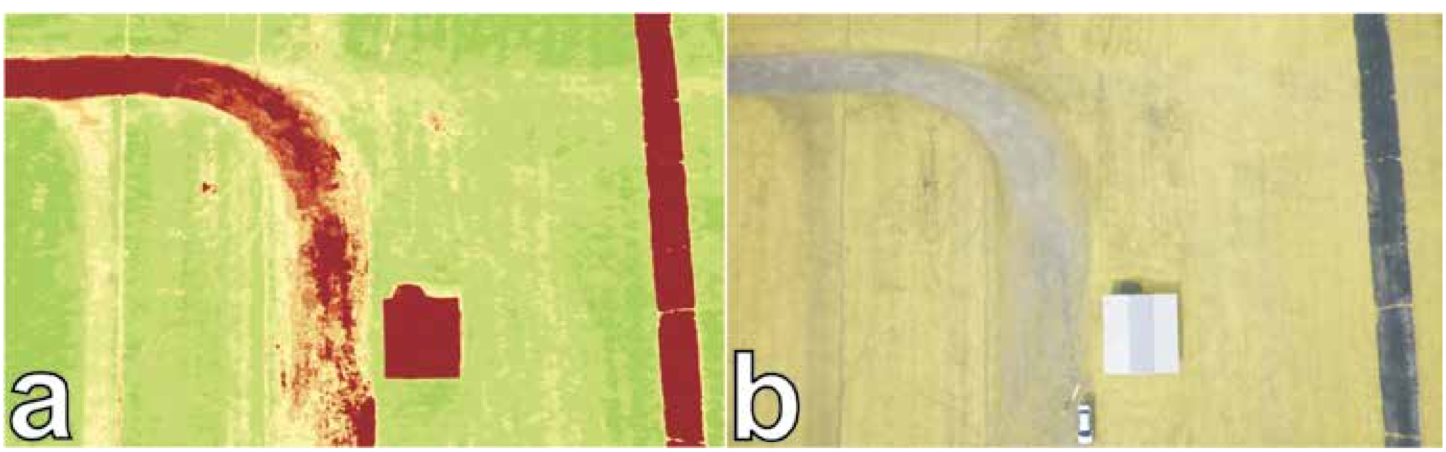

Figure 6: (**a**) NVDI image from a converted Point and Shoot digital camera, (**b**) corresponding photograph (Event38).

Supplementing Ground-Based Geophysics

The potential benefits that UAS technology can bring to geophysics is evident when considering the following application. An immediate research goal is to determine a survey methodology for the mapping of large acreages of buried agricultural drainage tile networks across the U.S. Midwest. Figure 7 shows a Google Earth image, which by happenstance, has the field moisture and crop growth stage revealing the buried tile network. One can observe that too much growth masks the network in some areas, while in lower moisture areas; the lush growth only immediately above reveals the tile network. Earlier or later in the season, the network would have remained hidden from view. On-demand aerial surveying can similarly reveal numerous other dynamic features that are influenced by time-varying parameters, such as soil moisture, cover crop, crop maturity, and season. Passive geophysical surveying from an inexpensive UAS can be an effective tool in that it helps focus more expensive, ground-based geophysical surveys. Table 1 is a tabulation of agricultural geophysics applications that are applicable to the UAS. Note that these are passive systems, rather than active, and the list will expand as UAS technology matched with miniaturized geophysics matures. The UAS has the potential to make significant contributions to agriculture. However, research and development within the U.S. is currently limited, as the implementation of UAS technology for commercial use is restricted for general agricultural operations under current FAA regulations. Experts project rapid UAS expansion in agricultural production applications when these restrictions are loosened after September 2015.

Figure 7: Google Earth image illustrating the dynamic effect of soil moisture and crop growth in revealing buried drainage tile network.

Table 1. UAS Agricultural Geophysics

Category	Target	Passive Sensor[1]
Crop		
	Chlorophyll	NDVI
	Stress	NDVI, visual
	Maturity	NDVI, visual
	Disease	NDVI, visual
	Fertility	NDVI, visual
	Population	NDVI, visual
Soil		
	Surface compaction	geomagnetic, visual
	Traffic pans	geomagnetic, visual
	Drainage	geomagnetic, visual, ortho
	Moisture	geomagnetic, visual, near infrared
	Classification	visual
Insurance		
	Flood	visual
	Drought	visual
Pests		
	Weeds	NDVI, visual
	Disease	NDVI, visual
	Insect/nematode/etc.	NDVI, visual
	Animal	Thermal, visual
Livestock		
	Health	Thermal
	Location	Thermal, visual
	Predators	Thermal

[1]Airborne geophysics may serve as an augmenting tool for traditional ground-based surveys. The reader is encouraged to conduct their own internet search on passive remote sensing of the desired category and target, as new sensors will most likely soon become miniaturized for the UAS geophysical sector. Updates will be available on http://www.ag-geophysics.org.

Free UAS Hobbyist Resources

- Personal Unmanned Aerial Vehicles. http://diydrones.com/
- Droneyard. http://droneyard.com/

References

Association for Unmanned Vehicle Systems International. 2013. The Economic Impact of Unmanned Aircraft Systems Integration in the US. Robotics Tomorrow. March. Available at: http://tinyurl.com/l5qrt8s . Accessed 25 February 2014.

FAA. 2012. FAA Modernization and Reform Act of 2012. SEC. 336. Special Rule for Model Aircraft. Available at: http://tinyurl.com/85vhakh . Accessed 25 February 2014.

AIRBORNE GEOPHYSICS FOR ENVIRONMENTAL AND ENGINEERING APPLICATIONS

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Introduction

At first glance, near-surface applications for airborne geophysics may appear limited as many of the targets are typically small and within 10 to 20 metres of the surface. Airborne geophysics has traditionally been used to locate large-scale mineral deposits at much greater depths. However, with advances in system design, improvements in the quality of data being collected, more accurate positional information, and better interpretation tools developed over the years, airborne geophysics can play an important role in the near-surface characterization of ground conditions. The information from airborne geophysical surveys can improve the interpretation from other more traditional near-surface datasets, such as those from drilling, to aid in site characterization, hazard identification and water management plans. Costs associated with other ground investigation methods can be better managed and focused with the knowledge gained from airborne geophysics.

Airborne geophysical methods include both frequency and time-domain electromagnetic, magnetic, gravity gradiometry and gamma-ray spectrometry. Airborne geophysical data have been used to help study the following:

- Foundation evaluation of levees
- Identifying aquifers in arid climates and mapping water-bearing fractures
- Mapping permafrost extents for engineering and groundwater flow models
- Mapping overburden depths and types for engineering-site evaluation, groundwater studies, and tailing pond locations
- Mapping depth and lateral extents of acid mine drainage, sub-surface salt water or other groundwater containments.
- Locating buried pipelines or well heads
- Pre-construction corridor assessment for pipelines, railway or power lines
- Identification of aggregate resources
- Bathymetry and sea ice thickness
- Locating radioactive waste
- Slope stability studies

Keywords: Airborne Geophysics, Electromagnetic Induction Surveys, Magnetic, Gravity Gradiometry, Gamma Ray Spectrometry.

Electromagnetic surveys map changes in the electrical properties of the earth to depths of 400 m or more, depending upon many factors including geology, soil type, and water content (to name a few) along with the system employed. Frequency-domain EM systems such as RESOLVE® (Figure 1) provide the highest EM frequencies and therefore the best near-surface detail and most sensitivity to very low-conductivity soils. The powerful HELITEM® system has 2.0 MAm^2 dipole moment to give great depth of penetration through conductive ground. The MULTIPULSE™ option adds a second, small, fast trapezoid pulse after the HELITEM® high-power half-sine pulse to provide better sensitivity to near-surface geology and weak conductors. MULTIPULSE™ can be surveyed from either a helicopter or fixed wing platform.

Figure 1: Multi-frequency RESOLVE® HEM System.

Magnetic surveys can help identify buried iron and steel objects such as pipes, well heads and storage tanks. Together, magnetic and electromagnetic methods can also help locate fracture zones that can control water or contaminate movement within the sub-surface. Radiometric surveys use gamma-ray spectrometers to map the emitted gamma rays from natural radioelements (potassium, uranium, and thorium) as well as man-made sources, including Co^{60} and Cs^{137} from nuclear accidents or leaks, or devices such as industrial smoke detectors. HeliFALCON™ gravity gradiometer surveys employ FALCON® sensors, purpose-built for airborne use, in a slow, low-flying helicopter to measure changes in density caused by overburden, geology, structure, and karst formations with incomparable resolution for airborne systems.

Depending on target, terrain, and weight constraints, several of the above geophysical methods can be combined in one survey. Airborne surveying provides fast coverage of an area with survey speeds ranging from 80 to 120 km/h depending on system and terrain consideration. Depending on the target, this can be equal to 800 or more hectares per hour. Since the survey is flown from an airborne platform, ground access is not required which may be advantageous if the ground is rugged or hazards make it otherwise inaccessible. However, aircraft on survey are generally restricted from flying directly over inhabited buildings. Initial survey results can be prepared within a few hours of the completion of survey flight for examination.

Ultra-Broadband Time Domain EM: MULTIPULSE™

The system was flown in the Athabasca oil sands, in Canada. Within the survey area, the overburden consists of glacial deposits of variable thickness covering the Grand Rapids formation which is composed mainly of sandstones. Below this is the Clearwater formation, a layer of marine shale and sandstone. The McMurray formation hosts the oil sands and is upwards of 150m thick and overlays the Devonian waterways foundation which is predominately comprised of shale and limestone (Figure 2). General geology from:

http://www.ramp-alberta.org/river/geography/geological+prehistory/mesozoic.aspx .

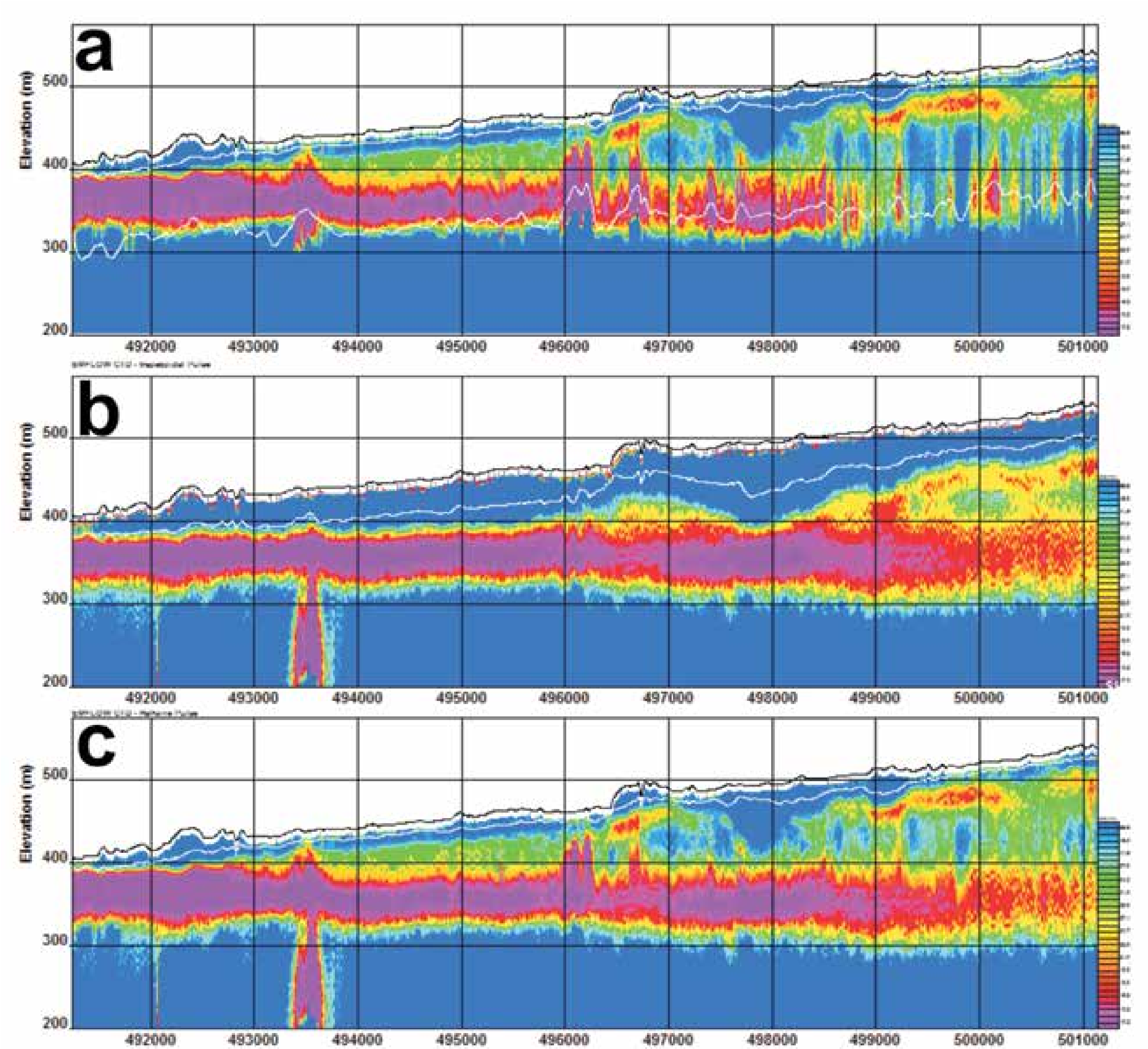

Figure 2: Resistivity-depth sections from MULTIPULSE™ data: (**a**) Small pulse provides better near-surface sensitivity; (**b**) Large pulse provides better depth penetration; (**c**) Final product retains near-surface sensitivity and better depth penetration for a more accurate and complete resistivity profile.

Mapping Overburden Thickness and Sinkholes

The Victor diamond-bearing kimberlite pipe in Canada has intruded through karstic Ordovician limestone, and prior to mine construction, all sinkholes in the area had to be identified. There was some ground geophysics on the site of the sinkhole (known from exploration drilling) and about twelve other drill holes in the area. A RESOLVE® airborne EM survey was conducted to measure resistivity across the area of the planned mine infrastructure, and the overburden thickness was estimated by inverting the EM, constrained by the drill and ground geophysical data (Figure 3).

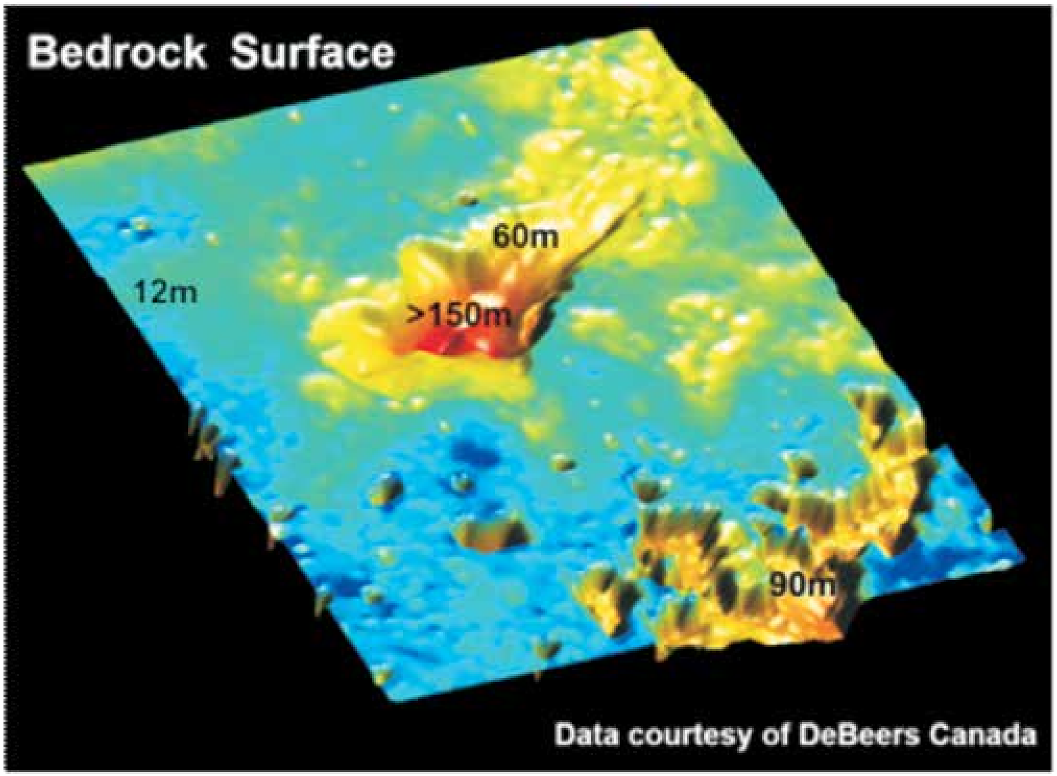

Figure 3: Thickness of the overburden estimated from RESOLVE® data.

Subsurface Foundation Evaluation – Mapping Levees

Flood control levees can be put at considerable risk of underseepage where sandy soil – usually abandoned river channels – exists under the levee, particularly if the channel is not protected from water pressure by a top clay blanket. High-resolution, frequency-domain RESOLVE® EM data was used in this example from Sacramento, California, to measure the extent of the channel in three dimensions, including areas where the channel did not extend to surface. Figure 4 shows the extent of the sandy zone (in orange-brown and red) with the overlying more conductive clay material stripped away.

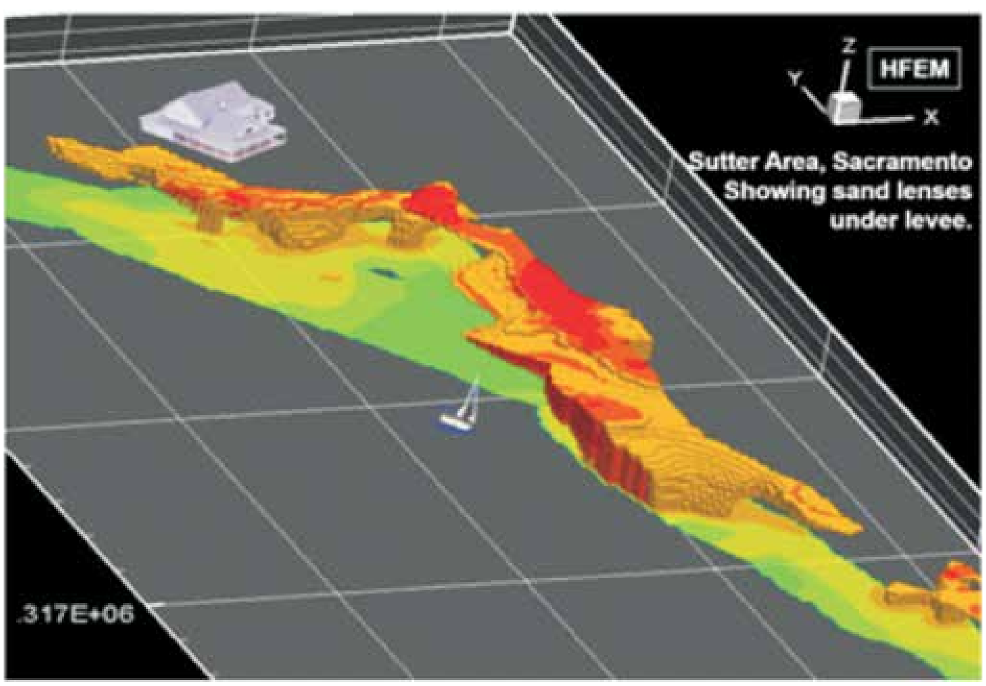

Figure 4: 3D view of the subsurface extent of a sandy channel in a flood-risk prone area in California.

Paleochannel and Aggregate Detection

Paleochannels are often the targets of airborne geophysical surveys, sometimes for the aquifers they create or as contaminated water pathways; sometimes for engineering planning purposes; sometimes for shallow natural gas deposits; and often as aggregate deposits. This RESOLVE® survey in Alberta, Canada, located both surface deposits of sandy soil, in blue in Figure 5, as well as a buried paleochannel. The data show that the channel is covered by a conductive clay cap (in red), indicating that it may be sealed well enough to contain the natural gas.

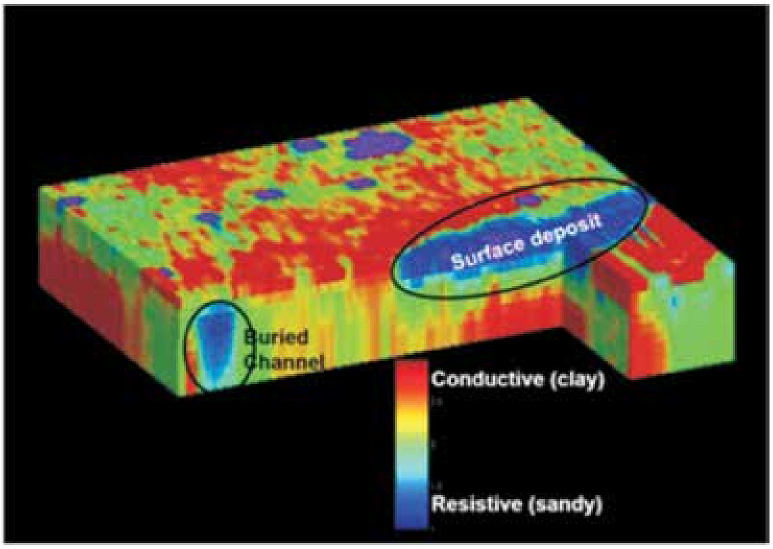

Figure 5: 3D resistivity model for buried paleochannel and aggregate deposits (blue).

Site Characterization – Mapping Contaminant Pathways

In August 2000, the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA) employed an airborne electromagnetic survey at the Sulphur Bank Mercury Mine in Lake County, California. There were indications that contaminants were leaking from the mine site into Clear Lake, putting at risk the quality of the water used by inhabitants around the lake. Preliminary drilling had failed to detect the contaminant flowpathway(s). The RESOLVE® airborne survey mapped the conductive contaminated water in the ground, and where it entered Clear Lake (Figure 6). The survey also mapped geological structure on land and below the lake (faults), which may have been conduits for the movement of contaminated ground water.

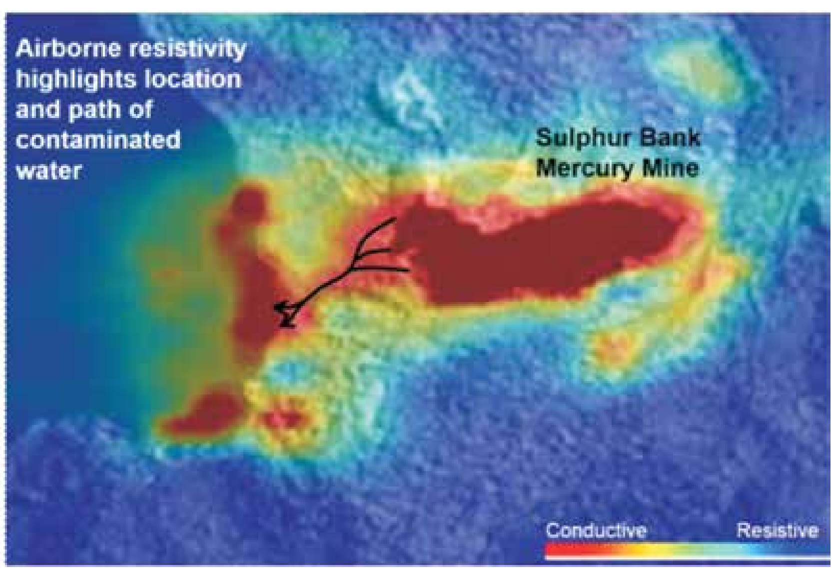

Figure 6: Contaminant mapping from RESOLVE® data.

Aquifer Mapping, United Arab Emirates

Potable water is, of course, vital to human development, and therefore often a target of airborne EM surveys. Fresh water is generally apparent as more resistive ground due to the lower salinity and more porous nature of the aquifers. In this TEMPEST® EM survey from the United Arab Emirates, the freshwater aquifer is apparent on top of a clay layer, in some places under a thin surficial layer (Figure 7).

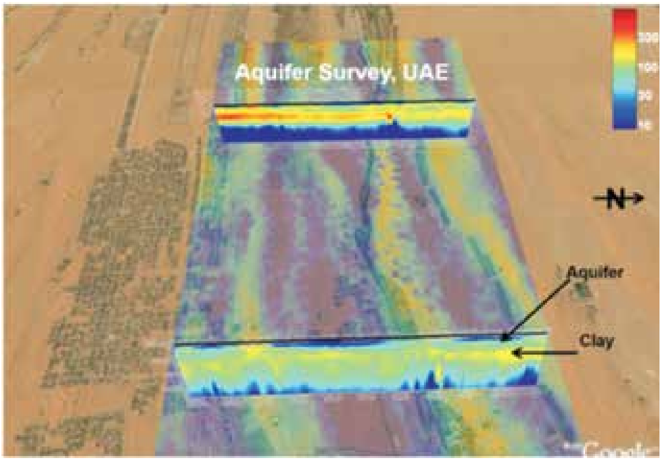

Figure 7: Resistivity sections from TEMPEST® data to map an aquifer in the United Arab Emirates

Permafrost mapping, Fort Yukon, Alaska

The presence and extent of permafrost is increasingly important as construction in the north proceeds, and as climate change becomes more of a concern. The high resistivity of frozen soil is easily mapped with a frequency-domain EM system such as RESOLVE®, as this example flown for the USGS in Ft Yukon, AK, shows (Figure 8). A representative section shows the type of surface melt that is apparent in the resistivity inversion section, including near-surface melt, zones with no permafrost (often under lakes) and taliks.

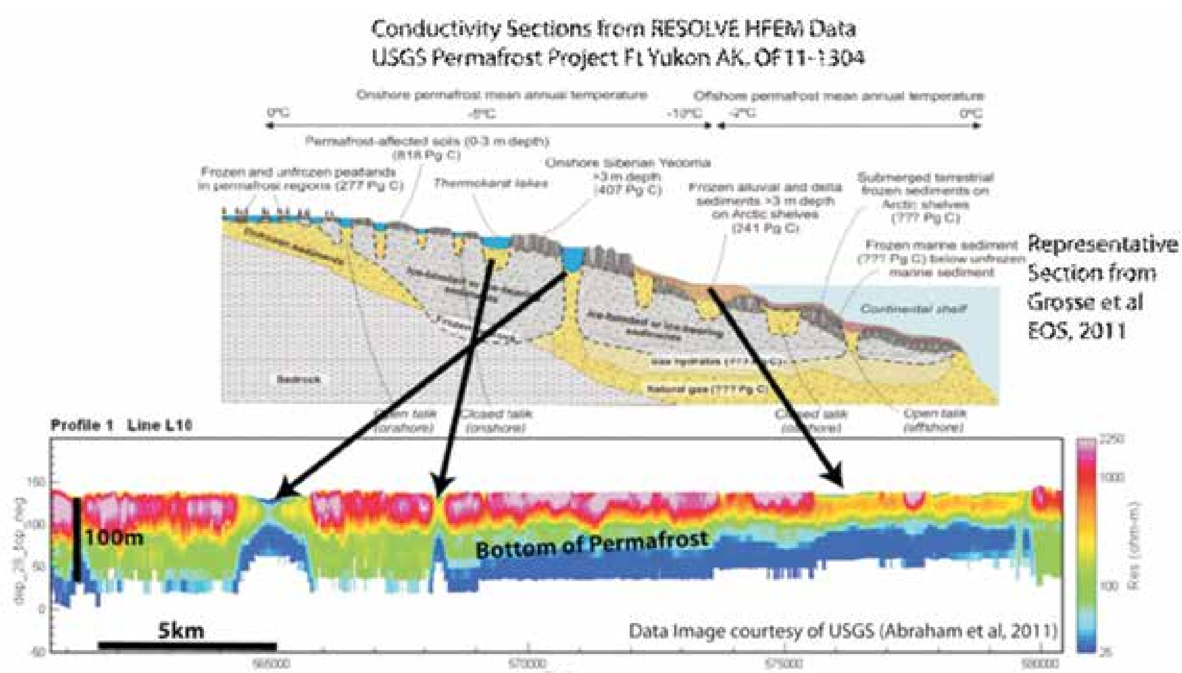

Figure 8: Resistivity section from RESOLVE® data to detect the presence of permafrost and to map its extents at Ft Yukon, Alaska.

Conclusions

Airborne geophysics, including electromagnetic, magnetic, radiometric, and gravity can be used for many applications for environmental and engineering projects. Although not as high resolution as ground geophysics, the fast coverage of large areas without the need for ground access makes airborne useful for regional coverage. Airborne geophysical surveys can provide an area overview before detailed ground geophysics and drilling are planned or conducted. Airborne surveys also have a role to play on preexisting projects to help fill in data gaps in the detailed work between the work sites. Applications have been many: soil mapping, water location, buried infrastructure location, and contaminant mapping for some examples – but many new applications are likely to become apparent as needs evolve and engineers gain experience and insight into the value of airborne geophysics.

AIRBORNE ELECTROMAGNETIC SURVEYS FOR U.S. GEOLOGICAL SURVEY PROGRAMS

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Introduction

The past two decades of development and application of airborne electromagnetic (AEM) methods for mineral exploration has been accompanied by increased applications to a wide range of geologic and hydrologic studies. Over this time, the U.S. Geological Survey (USGS) has played a leading role in developing new airborne geophysical calibration methods, refining standards for data acquisition, improving data processing and interpretation methods, and expanding the range of applications of airborne AEM methods. The USGS programs for which AEM studies have been conducted include geologic mapping, hydrology, minerals, energy, geothermal, human health, hazards, and climate programs. The success of these investigations is dependent upon the integrated interpretation of AEM data with a variety of geological, hydrological, engineering, and geochemical data (Smith and others, 2007). Though much of the research in airborne geophysics is motivated by the economy of mineral and energy exploration, alternative airborne geophysical applications are important in advancing the state-of-the-art and have significant societal relevance. In the coming decades increased needs for accurate subsurface characterization can be obtained in a cost-effective manner using airborne geophysics and AEM in particular.

We summarize some of the advances and applications for AEM studies that have taken place within the USGS since 1987. In particular, these studies (Figure 1) have focused on: (1) groundwater quality investigations of contamination from saline water co-produced from hydrocarbon extraction, (2) coastal studies mapping groundwater salinity, (3) a wide variety of hydrogeologic framework studies for groundwater quality and water resource management in sedimentary terrains, (4) characterization of the geologic framework of mineral resources and mining-related environmental impacts, (5) hazard mapping in active volcanic areas, (6) hydrogeologic framework and modeling studies of karstic terrains, and (7) permafrost mapping, climate studies, and related infrastructure assessment. Much of the data and interpretation from these AEM surveys has been released in journal publications and USGS reports available through the USGS Publication Warehouse (http://pubs.er.usgs.gov/). More information about USGS AEM projects and reports can be found at the Crustal Geophysics and Geochemistry Science Center web site: (http://crustal.usgs.gov/).

Keywords: Airborne Electromagnetic Methods, U.S. Geological Survey.

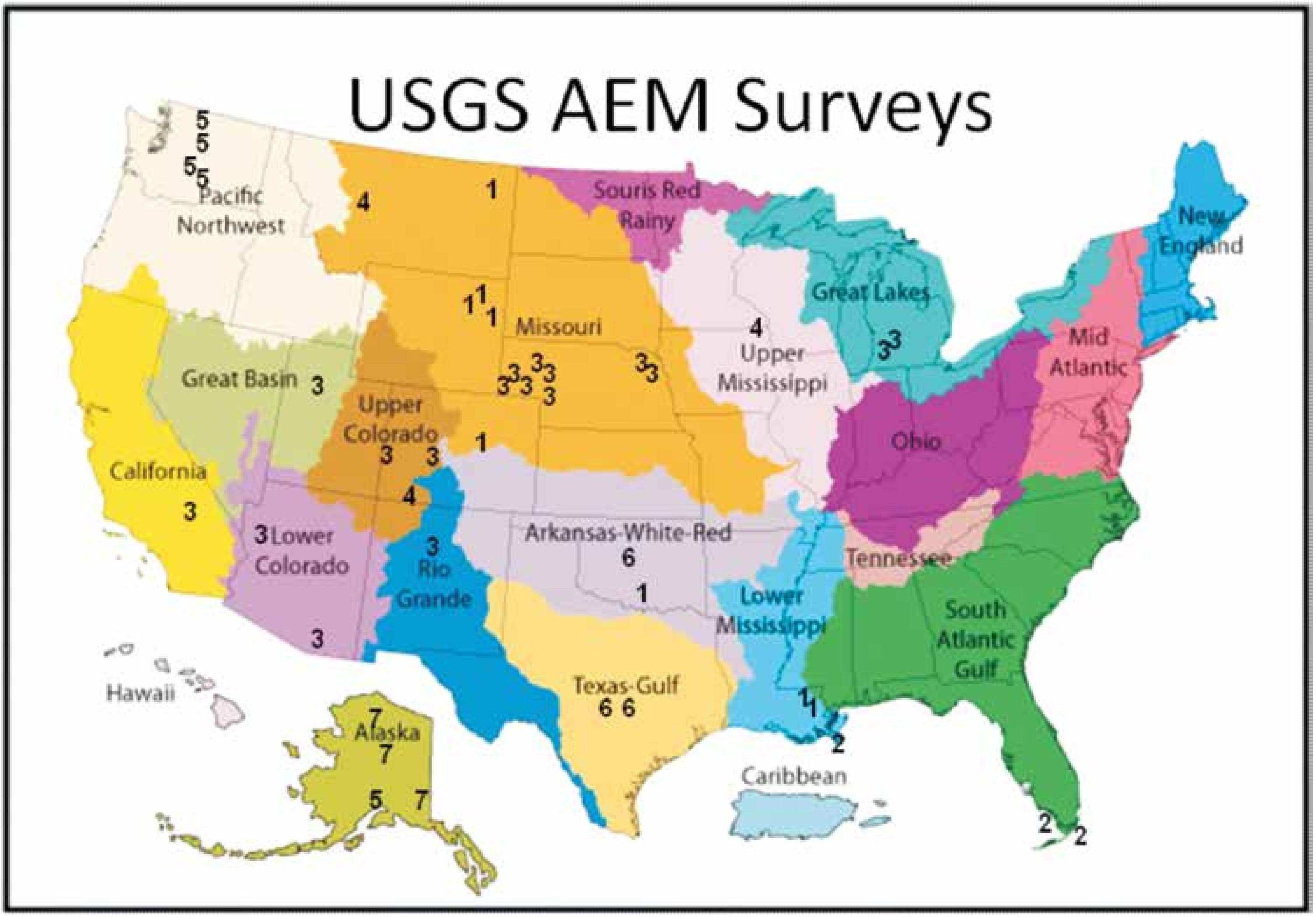

Figure 1: Generalized location of USGS airborne electromagnetic (AEM) surveys superimposed on watersheds (colored and labeled): (1) groundwater quality investigations of contamination from co-produced water from hydrocarbon energy production, (2) coastal studies mapping groundwater salinity, (3) hydrology and geologic framework mapping, (4) characterization of geologic framework of mineral resources and environmental impacts (acid mine drainage), (5) hazard mapping in active volcanic areas, (6) hydrogeologic framework and modeling studies of karstic terrains, and (7) permafrost mapping, climate studies, and infrastructure assessment.

Groundwater Contamination Related to Energy Production

Several AEM surveys have been conducted to map near-surface (less than 100 m) groundwater contamination from the disposal of saline produced water (in some cases >100,000 mg/L total dissolved solids; TDS). The first of these surveys was conducted in 1987 at an oil field in east-central Mississippi near Brookhaven (Figure 1; #1) (Smith and others, 1989). This survey was also one of the first groundwater-related applications of helicopter frequency-domain electromagnetic methods (HFEM). This survey successfully mapped pockets of shallow saline groundwater associated with produced-water disposal ponds, some of which had not been documented before the airborne surveys. One of the first conductivity-depth imaging algorithms developed by Pieter Sengpiel (1983) was applied to the electromagnetic (EM) data to produce conductivity depth sections along flight lines. This processing greatly enhanced the mapping of conductivity anomalies in depth slice maps that were not readily observed in the apparent resistivity maps plotted at individual frequencies. A repeat survey in 1997 showed changes in groundwater salinity caused by new point sources, some of which were confirmed by new monitoring wells drilled in the area (Smith and others, 1997). The success of the 1987 survey led to surveys in Texas funded by the Texas Railroad Commission and other state agencies to map saline waters in oil fields (Paine and Minty, 2005). These surveys successfully located point sources of shallow groundwater contamination. By 2004, when the USGS contracted an HFEM survey of part of the East Poplar Oil Field on the Ft. Peck Indian Reservation (northern Montana, Figure 1), the analog system used in the earlier surveys had been replaced by a broad-band digital system (Smith and others, 2006). Current research on this project is using newer methods for computation of conductivity-depth sections. These sections can be used to improve the hydrogeologic framework of numerical groundwater flow models being developed to predict the migration of a saline groundwater plume, several kilometers in areal extent.

Though produced waters associated with energy production are typically saline, water co-produced from coal bed methane (CBM) can have lower TDS concentrations than local groundwater. The rapid rise in production of natural gas from coal beds has raised environmental issues concerning proper disposal methods for the co-produced waters. Department of Energy (DOE) and USGS studies of co-produced waters from CBM development in the Powder River Basin of Wyoming have included HFEM surveys (Figure 1, northeastern Wyoming) of selected areas (Lipinski and others, 2008). In some areas, the HFEM surveys have helped to document how disposal of CBM-produced waters in ponds can lead to localized dissolution of salts, resulting in saline groundwater plumes in some areas. These studies led to the development of a geographic information system approach to assessing the risk of infiltration pond locations for disposal of CBM-produced water (Sams and others, 2007). An integrated study by the USGS and DOE was conducted to examine the beneficial use of CBM-produced waters in subsurface irrigation in the Powder River Basin. This study used HFEM to map shallow zones of high conductivity that could be due to high groundwater salinity, clay content, or both. Such areas are not favorable for installation of subsurface irrigation. Ground EM surveys were conducted over a five-year period to map conductivity variations due to changes in salinity and water content (Sams and others, 2014).

Coastal Processes Interpreted from Mapping Groundwater Salinity

Saltwater intrusion is an ideal mapping target for AEM techniques because of the high electrical conductivity of saline water and its contrast with lower conductivity freshwater. To rapidly cover large areas of the Florida Everglades where ground access is difficult, HFEM surveys were flown in 1994, 1996 and 1997 (Figure 1, #2, south Florida) covering more than a 1,000 square kilometers (Fitterman and Deszcz-Pan, 1998; 2001). The extent of saltwater intrusion was interpreted from conductivity-depth sections inverted from data along flight lines. Some of the first work in quantitative calibration of AEM survey data was done in this study to improve the accuracy of conductivity depth sections (Fitterman and Deszcz-Pan, 1998). The inversion technique works very well in the Everglades because of the sub-horizontal, relatively uniform geology and the absence of clay. Ground-based time-domain surveys combined with the HFEM inversion and borehole logging measurements were used to verify the calibration. The calibration methods developed in this project have been used in subsequent HFEM surveys. Application of AEM methods should be of use to study many coastal aquifers and processes, even where the geology is more complicated, because of the tendency of intruded saltwater to overprint geologic boundaries and to dominate the electromagnetic response.

In addition to airborne electromagnetic measurements, borehole geophysical measurements provide information on the aquifer formation resistivity and pore water specific conductance (SC). The relationship between these two properties offers a means of indirectly estimating pore-water SC from the airborne geophysical estimates of formation resistivity (Fitterman and Deszcz-Pan, 2001). Specific conductance can then be converted to chloride concentration using an established mixing model for the aquifer. The resulting product is a three-dimensional estimate of aquifer water quality. Maps constructed from the conductivity-depth profiles at specific depths show in detail the extent of saltwater intrusion and the influence of natural processes and human activities.

These data were used to develop variable density groundwater flow and transport models that incorporate salinity. The resulting models were used to develop a restoration plan for the South Florida ecosystem.

Characterization of Geologic Fremework for Mineral Resources and Environmental Impacts

Two projects on environmental impacts of mineral resource development have studied acid mine drainage in abandoned mine lands, located in the Animas River Basin, Colorado (Church and others, 2005) and the Boulder River Headwaters, Montana (Nimick and others, 2004), (Figure 1, #4). These projects gathered geological, geochemical, and geophysical data on the distribution of rock types, mines and prospects, mine dumps and active mine drainage sites necessary to characterize the watershed-scale subsurface and to prioritize remediation sites. Smith and others (2000) described the general aspects of the HFEM geophysical studies of these areas that began in early 1995.

The ore deposits of the Boulder River area (Boulder mining district) are situated in the volcanic Boulder Batholith of Cretaceous age. HFEM data were used in structural and lithologic mapping and in the evaluation of a closed open-pit mine as a mine waste repository (Smith and others 2000). The location of several groundwater monitoring sites near the pit was based on structures interpreted from the HFEM data (McCafferty and others, 2005).

The deposits of the Animas River Basin (Silverton mining district) are within a Tertiary age volcanic caldera. HFEM and magnetic surveys in the Animas River basin identified specific lithologic and structural features that are important in understanding the groundwater flow system. Geologic maps of the study area contain numerous structures and veins but only a few of these are associated with distinctive geophysical signatures. However the geophysical signatures indicated several structures that had not been previously mapped (McDougal and others, 2006). Geophysical maps identify areas of near-surface and subsurface conductivity and magnetic contrasts that suggest structural features that may influence groundwater flow. McCafferty and others (2006) used these data with geological information to construct geoenvironmental maps showing relative acid-neutralizing capacity and acid-generating potential of surface and near-surface rocks.

In late 2012 and early 2013, the USGS conducted airborne geophysical studies in Northeast Iowa (Figure 1, #4) to investigate structures and potential mineral resources associated with the 1.1 Ga Midcontinent Rift system. Full-tensor gravity gradiometry and helicopter time-domain EM (HTDEM) surveys were flown to investigate basement geometry and composition, as well as to map the thick package of Phanerozoic rocks blanketing the region. A three-dimensional stratigraphic model of the region, including the Precambrian basement surface, was assembled from HTDEM-derived resistivity models in concert with borehole lithology and stratigraphy (Bloss and others, 2014). The survey further revealed an impact structure, which is clearly visible in both the EM and gravity datasets. The HTDEM data identified and mapped a post-impact shale which is present only in the crater, having been eroded elsewhere within the survey area. The resulting 5.5-km diameter circular conductor aligns closely with the extent of the post-impact shale as identified in borehole data by the Iowa Geological and Water Survey. Airborne gravity gradient data reveal the signature of a low-density body co-located with the center of the impact structure, an observation borne out by subsequent modeling (Kass and others, 2013). The electrical conductivity and density of stratigraphic units both within as well as outside the impact structure were measured from core samples, and used to constrain the modeling and inversion of the airborne data.

Hydrologic and Geologic Framework Mapping

Over the past decade, there has been dramatic improvement in airborne magnetic and electromagnetic data acquisition through improved instrumentation and flight path recovery technology. These improvements have led to a revolution in airborne surveying applications in sedimentary terrains related to assessment and management of groundwater resources (Paine and Minty, 2005; Refsgaard and others, 2010). The locations of some of the hydrogeologic framework and groundwater studies carried out by the USGS that involve airborne electromagnetic and magnetic surveys are shown in Figure 1 (areas marked #3).

Fixed-wing time-domain electromagnetic surveys have been used in alluvial basins of New Mexico (Grauch and others 2001; Rodriguez and others, 2001, 2006) and Arizona (Bultmann and others, 1999; Pool and others, 2007, Dickinson and others 2010) to map the 3D distribution of alluvial aquifers and major grain-size facies within the alluvium. The primary aquifer materials of sand and gravel are more resistive than fine-grained deposits of silt and clay, which are poor aquifers. Results of the geophysical investigations have been used to help estimate aquifer properties in groundwater models critical to water management (Dickinson and others, 2010). In addition, the AEM data has been used to aid in interpretation of basin faults mapped by detailed aeromagnetic surveys (Grauch and others, 2001).

From 2004 through 2010, the USGS conducted several time and frequency domain helicopter EM surveys in Nebraska (Figure 1, #3) in cooperation with Nebraska Natural Resource Districts, the state of Nebraska, and USGS programs (Smith and others, 2011; Abraham and others, 2012a, 2012b). These projects incorporated interpretations based on AEM inverse models into hydrogeologic framework and modeling studies. These projects were designed to support water-resource management through the mapping of glacial and alluvial aquifers.

In western Nebraska, the integration of hydrogeologic data and numerical groundwater modeling with AEM surveys led to several innovations in survey design and interpretation. These study areas contain several hundred drill holes placed for aquifer characterization that were used to develop the hydrostratigraphy for a numerical groundwater model. The survey was designed with flight lines placed at intervals of tens of kilometers to not only collect data along drill hole transects but to also fill in between drill holes and along major drainages. This is in contrast to the more standard design of closely spaced parallel flight lines within a block area. The new interpretation methods included estimating a confidence metric on base-of-aquifer picks from AEM inverse resistivity models (Abraham and others, 2012a). The interpreted interface depths (points picked along resistivity depth sections) were used to refine the hydrostratigraphic geometry in the groundwater model, and resulted in improved model calibration and predictive capability.

As part of an effort to understand and manage groundwater resources in arid environments, the USGS is investigating a number of basins within the Fort Irwin National Training Center (Figure 1, #3, southern California) using a range of geophysical methods including gravity, aeromagnetic, and ground-based and airborne time-domain electromagnetic methods (Bedrosian and others, 2012). The HTDEM data show abrupt changes in measured response across faulted boundaries, reflecting the strong resistivity contrast between igneous rocks and basin sediments. The distribution of faults throughout the basin can be directly obtained from the airborne data. A resistivity stratigraphy has been developed by integrating borehole geophysical logs, lab resistivity measurements, and ground-based gravity and time-domain EM soundings. The results are applied to the airborne resistivity models and are used to trace aquifer hydrostratigraphy throughout the basin. Interpreted parameters include the depth to basement, the depth to water, and the thickness of the primary aquifer. Together with hydrologic investigations, these results are being used to estimate groundwater storage within the basin.

Two recent HTDEM surveys have been flown in Colorado for hydrogeologic framework and water-resource management studies. The survey in southwestern Colorado (Figure 1, #3) has been conducted to characterize a naturally occurring groundwater brine plume in the Paradox Valley, one of several collapsed salt anticlines in the region (Ball and others, 2014). Groundwater discharge to the Dolores River in Paradox Valley has historically been a substantial source of salt loading in the Colorado River Basin. The U.S. Bureau of Reclamation operates a salinity control project to reduce these loads, in which pumping wells reduce the volume of brine discharged to the river and produced brine is injected into deep aquifers below the salt formation. To support the development of predictive variable-density groundwater flow and transport models and improve the operation of the salinity control project, HTDEM data are being used to improve the constraints on the brine geometry and distribution. Using a stochastic inversion approach developed at the USGS (Minsley, 2011), the geometry of the brine-freshwater interface has been mapped in detail, including an analysis of uncertainty for this important interface. Resistivity variations within the plume can be related to variations in brine concentration and porosity.

A HDTEM survey in Central Colorado was carried out to map aquifers in an intermountain basin in the northern Rio Grande Rift system (Grauch and others, 2013). Resistivity inverse models from this survey map subsurface stratigraphy including disruptions along a series of range-front faults. Conductive lacustrine clay associated with Pleistocene Lake Alamosa can further be traced throughout the survey area and is an important component in understanding regional groundwater flow.

Karst Groundwater

The USGS has carried out two HFEM surveys for karst groundwater studies of the Edwards aquifer, Texas, and the Arbuckle-Simpson aquifer, Oklahoma (Figure 1, #6) (Smith and others, 2008). Flown in the Seco Creek area (west) in 2002 and the other in northern Bexar County in 2004 (Smith and others, 2003, 2005). The Seco Creek survey demonstrated that the structure of the Edwards Aquifer recharge zone is much more complicated than mapped by traditional geologic methods. In addition, the HEM data established that the Edwards Group could be divided into upper and lower Devils River units based on their different electrical resistivity signatures. The detailed airborne magnetic data from the Seco Creek HFDEM survey provided the first evidence that some of the major structures in the Edwards Limestone might be associated with magnetic lows (Smith and Pratt, 2003). More detailed leveling of a larger fixed-wing aeromagnetic dataset acquired in 2001 suggests that major faults, many of which are covered by thick surficial deposits, have a magnetic expression. The HFDEM survey in northern Bexar County covered some of the older Glen Rose Formation which composes the Trinity aquifer north of the exposed Edwards recharge zone. This survey demonstrates that different hydrostratigraphic units of the Glen Rose Formation can be differentiated based on their electrical signatures. These units are important in understanding recharge within the Trinity aquifer and its hydrologic relationship to the Edwards aquifer. The HFDEM survey also helped to improve structural maps where traditional mapping is hampered by poor exposures or lack of land access.

An HFEM survey of the Arbuckle karstic limestone done in 2007 (Smith and others, 2009) produced higher resolution mapping of known structures and defined many new structures. In addition, the resistivity depth sections mapped the extent of the shallow epikarst which had not been well mapped prior to this survey. The epikarst plays an important role in the shallow hydrology of the area.

Surveys Flown for Volcano Hazards

Flank collapses of volcanoes pose significant hazards, potentially triggering lahars, eruptions, and tsunamis. Significant controls on the stability of volcanoes are the distribution of hydrothermal alteration and the location of groundwater within the edifice. Interaction of groundwater with acidic magmatic gases can further lead to hydrothermal alteration that mechanically weakens rocks and makes them prone to failure and flank collapse. Detecting the presence and volume of hydrothermally altered rocks and shallow groundwater is thus critical for evaluating landslide hazards. Airborne EM studies on volcanoes are challenging, however, due to the extreme topography and highly resistive environment. The first airborne EM survey for volcanic hazards was flown in 1996 over Mount Rainer in in the Cascades volcanic arc (Figure 1; #5) (Finn and others, 2001). Subsequent helicopter magnetic and electromagnetic surveys were flown over the rugged, ice-covered Mount Adams, Mount Baker, and Mount Iliamna (Alaska) volcanoes, as well as the relatively ice-free Mount St. Helens. The resistivity models resulting from these surveys reveal the distribution of alteration, water and ice thickness essential to evaluating volcanic landslide hazards. The models, combined with geological mapping and rock property measurements, indicate, for example, the presence of appreciable thicknesses (>500 m) of water-saturated hydrothermally altered rock west of the modern summit of Mount Rainier and in the central core of Mount Adams north of the summit. Water-saturated alteration at Mount Baker is restricted to thinner (<300 m) zones beneath Sherman Crater and the Dorr Fumarole Fields and at the summit of Mount Iliamna. The AEM data identified water-saturated fresh volcanic rocks from the surface to the detection limit (100–200 m) in discreet zones on the summits of Mount Rainier and Mount Adams, in shattered fresh dome rocks within the crater of Mount St. Helens and in the entire summit region at Mount Baker. A 50-100 m thick water-saturated layer is further imaged within or beneath the glaciers flanking Mount Iliamna. Removal of ice and snow during eruptions and landslide can result in lahars and floods, however, ice thickness measurements critical for evaluating flood and mudflow hazards are very sparse on most volcanoes. The AEM data have further been utilized to determine ice thickness over portions of Mount Baker and Mount Adams volcanoes (Finn and others, 2012). The best estimates for ice thickness are obtained over relatively low resistivity (<800 ohm-m) ground for the main ice cap on Mount Adams and over most of the summit of Mount Baker. The modeled distribution of alteration, pore fluids, and partial ice volumes on these volcanoes are being used to identify likely sources for future alteration-related debris flows and to refine hazard assessments.

Surveys Flown for Permafrost, Climate and Infrastructure

Permafrost mapping has been done with HFEM surveys along the Alaska highway corridor for the state of Alaska Division of Geophysical and Geologic Surveys (DGGS) in 2005 and 2006 (Burns, 2006) and in 2010 in the area of Fairbanks and Ft. Yukon (northern Alaska, Figure 1, #7; Ball and others, 2011). In the case of the highway survey, the USGS is collaborating with the state of Alaska DGGS in using inversion of the HFEM data for permafrost mapping and geologic framework studies (Kass and others 2012). The main motivation for this survey was to collect subsurface information about lithology and permafrost for possible infrastructure development along the corridor. Interpretation of the survey data lead to improvement of permafrost distribution maps and refinement of subsurface mapping of Quaternary features such as alluvial fans and dune fields (Kass and others, 2012).

The HFEM survey at Ft. Yukon was conducted primarily to map the spatial extent of permafrost in three-dimensions (http://www.whitehouse.gov/blog/2012/02/03/alaskan-permafrost-mapped-skies). The 1,800 line-km survey shows sediments deposited over the past 4 million years and the configuration of permafrost to depths of 100 m in the Yukon Flats area near Fort Yukon, Alaska. The Yukon Flats is near a boundary between continuous and discontinuous permafrost, making it an important location for researching permafrost dynamics. The results not only provide a detailed snapshot of the present-day configuration of permafrost, but they also expose previously unseen details about potential surface – groundwater connections and the thermal legacy of surface water features recorded in the permafrost over the past approximately 1,000 years (Minsley and others, 2011). This work will be a critical baseline for future permafrost studies aimed at exploring the connections between hydrogeologic, climatic and ecological processes, and have significant implications for the stewardship of Arctic environments. Several subsequent studies have used the AEM data to further investigate surface water and groundwater dynamics (Jepsen and others, 2013), and to extrapolate interpretations of shallow permafrost features across the entire Yukon Flats region by integrating AEM and satellite remote sensing datasets (Pastick and others, 2013). Numerical simulations of permafrost evolution beneath lakes (Wellman and others, 2013) are being coupled with airborne geophysical predictions (Minsley and others, 2013) to further improve our understanding of geophysical signatures associated with permafrost-impacted hydrologic systems.

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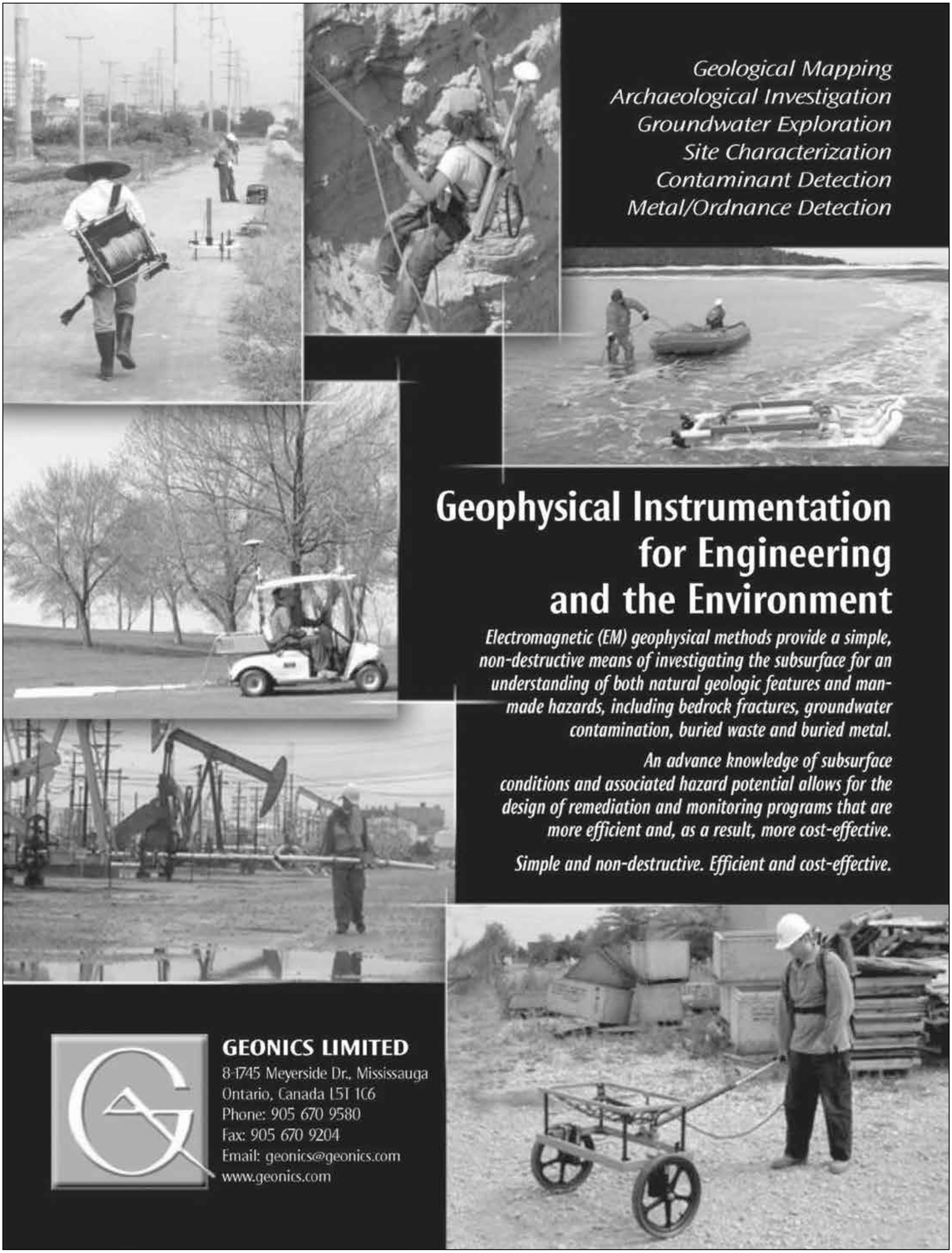
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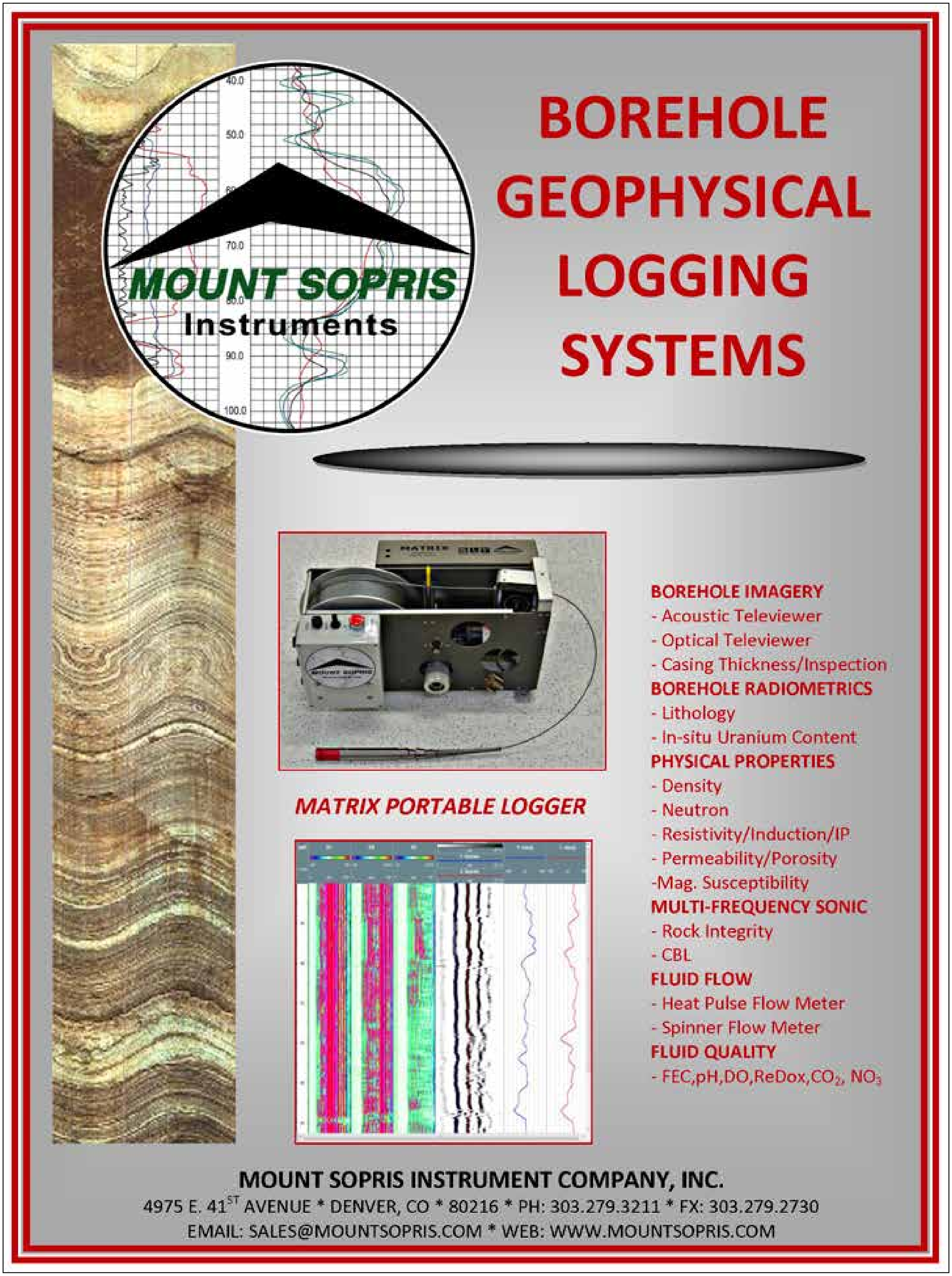
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German Guideline for Seismic Site Characterization

Dr. Ernst Niederleithinger, BAM, Berlin, Germany.

Seismic methods, which are acquiring information about the subsurface using elastic waves, are more and more used in site characterization. These techniques and their fields of application are mentioned in European standards and regulations but not described or explained in detail. The ASTM standards existing for some methods have limitations as well.

The new guideline B08 “Site Investigation by Seismic methods” has recently been published by DGZFP (German Society for Non-Destructive Testing) and is available online at www.dgzfp.de . Basic concepts of seismic exploration are described shortly as well as the numerous techniques including applications and limitations. Surface, borehole and offshore methods are included. An application matrix helps in choosing the right method. Comments on tendering and bidding are included as well as measures for quality assurance. This guideline should help those, who need or offer geophysical services.

The guideline has been written by a team of authors from industry, academia and authorities, coordinated by Dr. Ernst Niederleithinger (BAM) und Prof. Dr. Frank Wuttke (Bauhaus-University Weimar, meanwhile Christian-Albrechts-University Kiel) under the auspices of the DGZfP committee “Nondestructive testing in Civil Engineering/ sub-committee “Site investigations”. The guideline is available in German and English. The authors intend to provide a continuous update as well as another guideline on non-seismic methods for site investigation.

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ADSC's Michael W. O'Neill Lecture Award Announced

The International Association of Foundation Drilling, ADSC, has announced the "ADSC Michael W. O'Neill Lecture Award". This Lecture Award honors Dr. O'Neill, one of the world's leading experts in deep foundations, who passed away in 2003 leaving a legacy of exceptional contributions to the deep foundation industry both in academia and in practice. The inaugural Lecture Award will be presented in San Antonio, Texas at the 2015 International Foundation Congress and Equipment Exposition (IFCEE, which is sponsored by ADSC, the Deep Foundations Institute, the Geo-Institute of ASCE and the Pile Driving Contractor's Association) to Jerry A. DiMaggio, P.E., retired Principal Bridge Engineer and Geotechnical and National Program Manager with the Federal Highway Administration of the United States Department of Transportation. The ADSC Michael W. O'Neill Lecture Award will then be presented triennially at each future IFCEE "*for outstanding contributions to the advancement of the state-of-the-practice in the design and construction of deep foundations through practical, applied research and/or through recommended improvements to design and/or construction methodologies."* The establishment of an international lecture and award to honor Dr. O'Neill is the brainchild of Dr. Anna Sellountou, who studied under Dr. O'Neill and is now with Pile Dynamics, Inc. The idea was fully supported by ADSC, the sole underwriter of the lecture award.

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☐ Research/Academia	☐ Hazardous Waste	☐ Seismic	☐ EER1	
☐ Government Agency	☐ Humanitarian Geo.	☐ Other	☐ GeoInstitute	
☐ Other	☐ Mining		☐ GSA	
	☐ Shallow Oil & Gas		☐ MGLS	
	☐ UXO		☐ NGWA	
	☐ Other		☐ NSG	
			☐ SEG	
			☐ SSA	
			☐ SPWLA	

1720 South Bellaire Street | Suite 110 | Denver, CO 80222-4303
(p) 001.1.303.531.7517 | (f) 000.1.303.820.3844 | staff@eegs.org | www.eegs.org

Environmental and Engineering Geophysical Society

2014 Membership Application

Renew or Join Online at www.EEGS.org

FOUNDATION CONTRIBUTIONS

FOUNDERS FUND

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

Foundation Fund Total: $ ____________

STUDENT SUPPORT ENDOWMENT

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

Student Support Endowment Total: $ ____________

CORPORATE CONTRIBUTIONS

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

Corporate Contribution Total: $ ____________

Foundation Total: $ ____________

PAYMENT INFORMATION

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

☐ **AmEx** ☐ **Discover**

Subtotals

Membership: $ ____________

Foundation Contributions: $ ____________

Grand Total: $ ____________

Card Number **Exp. Date**

Name on Card

Signature

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

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

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

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

QUESTIONS? CALL 001.1.303.531.7517

EEGS CORPORATE MEMBERS

Corporate Benefactor

Your Company Here!

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Geophysical Survey Systems, Inc.
www.geophysical.com

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Corporate Donor

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EEGS STORE

Environmental and Engineering Geophysical Society

2014 Publications Order Form

ALL ORDERS ARE PREPAY

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

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

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

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

SAGEEP PROCEEDINGS

			Member	Non-Member
	0034	2013 (CD-ROM)**NEW**	$75	$100
	0033	2012 (CD-ROM)	$75	$100
	0030	2011 (CD-ROM)	$75	$100
	0029	2010 (CD-ROM)	$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

	0032	2010 Application of Time Domain Electromagnetics to Ground-water Studies – David V. Fitterman	$20	$30
	0027	2010 Principles and Applications of Seismic Refraction Tomography (Printed Course Notes & CD-ROM) - William Doll	$70	$90
	0028	2009 Principles and Applications of Seismic Refraction Tomography (CD-ROM w/ 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

	0031	Advances in Near-surface Seismology and Ground Penetrating Radar—R. Miller, J.Bradford, K.Holliger Special student rate - $95.00	$109	$149
	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
	0035	Einstein Redux: A Humorous & Refreshing New Chapter in the Einstein Saga—D.Butler	$20	$25
		EEGS T-shirt (X-Large) Please circle: white/gray	$10	$10
		EEGS Lapel Pin	$3	$3
		SUBTOTAL—SHORT COURSE/MISC. ORDERED ITEMS:		

Publications Order Form (Page Two)

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

Member Rate: $15

Non-Member Rate: $25

Qt.	Year	Issue
	1995	JEEG 0/1 - July
		JEEG 0/2 - January
	1996	JEEG 1/1 - April
		JEEG 1/2 - August
		JEEG 1/3 - December
	1998	JEEG 3/2 - June
		JEEG 3/3 - September
		JEEG 3/4 - December
	1999	JEEG 4/1 – March
		JEEG 4/2 - June
		JEEG 4/3 - September
		JEEG 4/4 - December
	2000	JEEG 5/3 - September
		JEEG 5/4 - December
	2001	JEEG 6/1 - March
		JEEG 6/3 - September
		JEEG 6/4 - December
	2003	JEEG 8/1- March
		JEEG 8/2 - June
		JEEG 8/3 - September
		JEEG 8/4 - December

Qt.	Year	Issue
	2004	JEEG 9/1- March
		JEEG 9/2 - June
		JEEG 9/3 - September
		JEEG 9/4 - December
	2005	JEEG 10/1 - March
		JEEG 10/2 - June
		JEEG 10/3 - September
		JEEG 10/4 - December
	2006	JEEG 11/1 - March
		JEEG 11/2 - June
		JEEG 11/3 - September
		JEEG 11/4 - December
	2007	JEEG 12/1 - March
		JEEG 12/2 - June
		JEEG 12/3 - September
		JEEG 12/4 - December
	2008	JEEG 13/1 - March
		JEEG 13/2 - June
		JEEG 13/3 - September
		JEEG 13/4 - December

Qt.	Year	Issue
	2009	JEEG 14/1 - March
		JEEG 14/2 - June
		JEEG 14/3 - September
		JEEG 14/4 - December
	2010	JEEG 15/1 - March
		JEEG 15/2 - June
		JEEG 15/3 - September
		JEEG 15/4 - December
	2011	JEEG 16/1 - March
		JEEG 16/2 - June
		JEEG 16/3 - September
		JEEG 16/4 - December
	2012	JEEG 17/1 - March
		JEEG 17/2 - June
		JEEG 17/3 - September
		JEEG 17/4 - December
	2013	JEEG 18/1 - March
		JEEG 18/2 - June
		JEEG 18/3 - September
		JEEG 18/4 - December

SUBTOTAL—JEEG ISSUES ORDERED	

SUBTOTAL - SAGEEP PROCEEDINGS ORDERED	
SUBTOTAL - SHORT COURSE / MISCELLANEOUS ITEMS ORDERED	
SUBTOTAL - JEEG ISSUES ORDERED	
CITY & STATE SALES TAX (If order will be delivered in the Denver, Colorado—add an additional 7.62%)	
SHIPPING & HANDLING (US—$10; Canada/Mexico—$20; All other countries: $45)	
GRAND TOTAL:	

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Environmental and Engineering Geophysical Society

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Web Site: www.eegs.org

2014 Merchandise Order Form

ALL ORDERS ARE PREPAY

Sold To:

Name: ______________________________
Company: ______________________________
Address: ______________________________
City/State/Zip: ______________________________
Country: ______________ Phone: ______________
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Name: ______________________________
Company: ______________________________
Address: ______________________________
City/State/Zip: ______________________________
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ITEM DESCRIPTION	QTY	T-SHIRT COLOR WHITE/GRAY	MEMBER RATE	NON-MEMBER RATE	TOTAL
EEGS Mug			$10	$10	
T-shirt (Medium)			$10	$10	Sold Out
T-shirt (Large)			$10	$10	Sold Out
T-shirt (X-Large)			$10	$10	
T-shirt (XX-Large)			$10	$10	Sold Out
EEGS Lapel Pin			$3	$3	

SUBTOTAL – MERCHANDISE ORDERED:

TOTAL ORDER:

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

GRAND TOTAL:

Payment Information:

☐ Check #: ______________ (Payable to EEGS)

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

☐ Visa ☐ MasterCard ☐ AMEX ☐ Discover

Card Number: ______________ Cardholder Name (Print): ______________

Exp. Date: ______________ Signature: ______________

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

THANK YOU FOR YOUR ORDER!

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