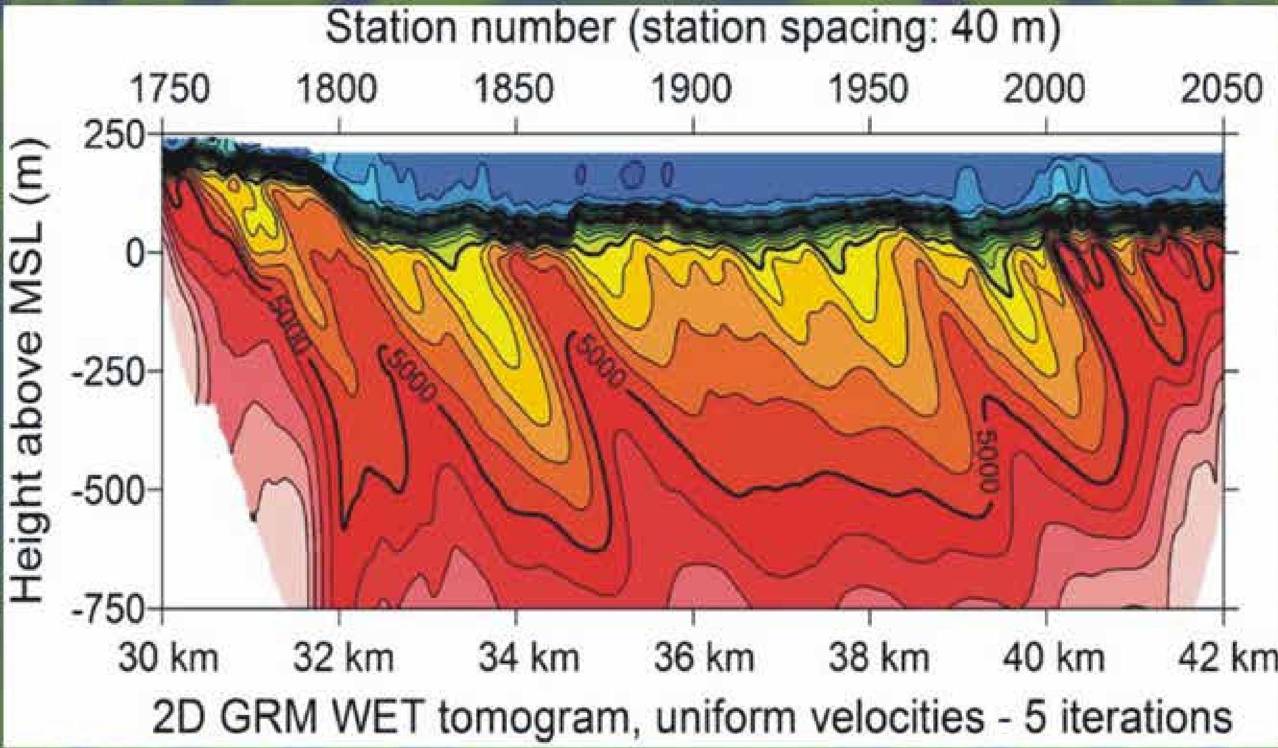
*Fast*TIMES

Does Diving Wave Tomography Improve Discovery in Near Surface Refraction Seismology?

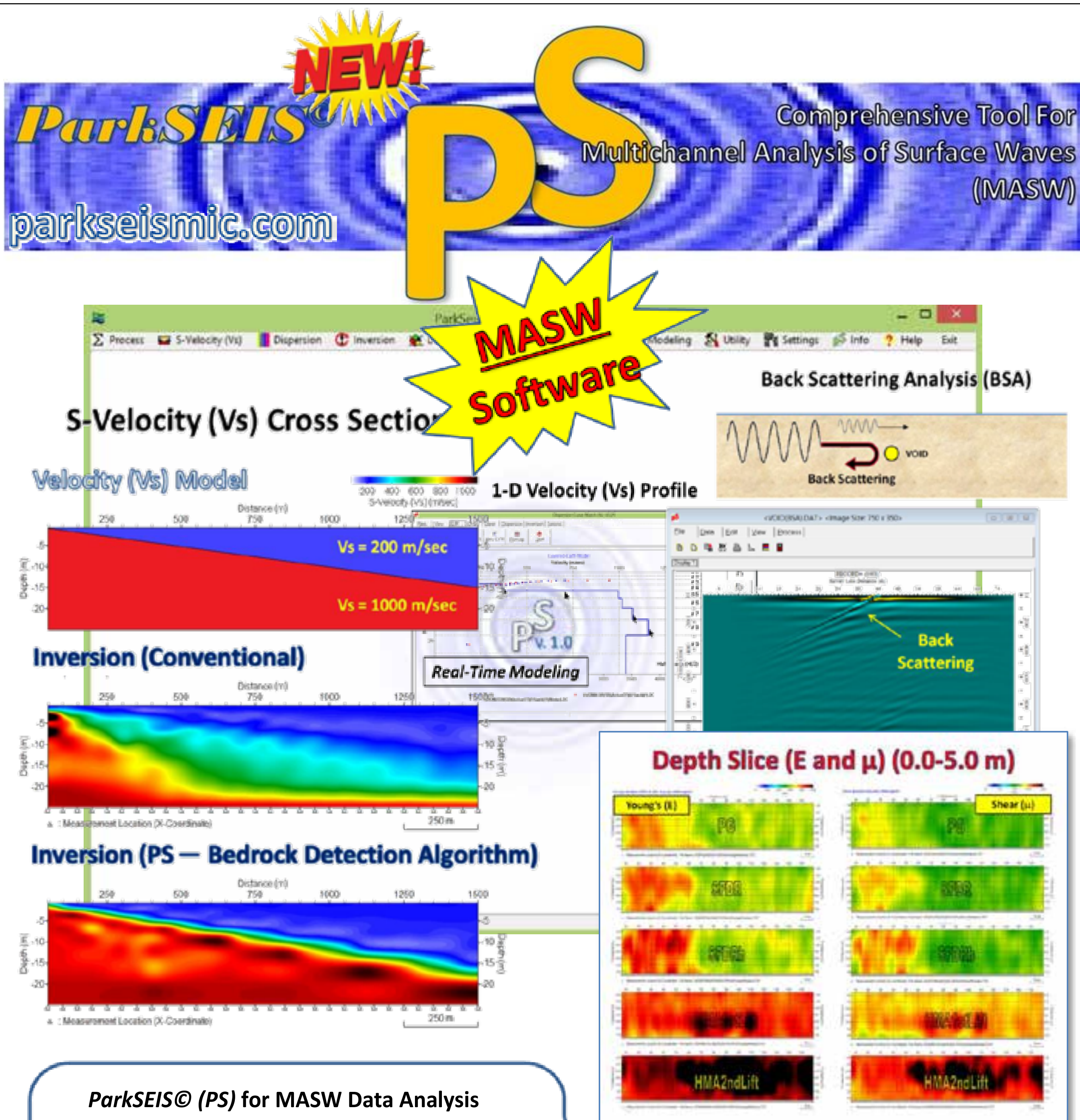


Supplement to the June Issue on Archaeological Geophysics:

Comparison of Two GPR Surveys with Different Grid Spacings to Identify Unmarked Graves in the 19th Century Cemetery at Snyder County, PA

September 2015

Volume 20, Number 3



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In this issue of *Fast*TIMES, there is a discussion paper on seismic refraction tomography and a supplement article to the June 2015 special issue on archeological geophysics.

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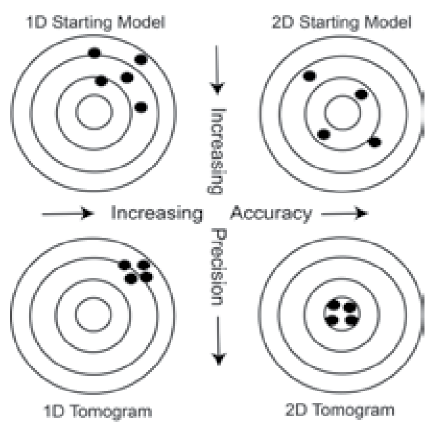

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*Fast*TIMES

*Fast*TIMES (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 *Fast*TIMES, a magazine for the near-surface community, and (4) maintaining relationships with other professional societies relevant to near-surface geophysics.

JOINING EEGS

EEGS welcomes membership applications from individuals (including students) and businesses. Annual dues are $90 for an individual membership, $50 for introductory membership, $50 for a retired member, $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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To advertise in FastTIMES, contact:

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*Fast*TIMES is published electronically four times a year. Please send articles to any member of the editorial team by Dec. 1, 2015. Advertisements are due to Jackie Jacoby by Dec. 1, 2015.

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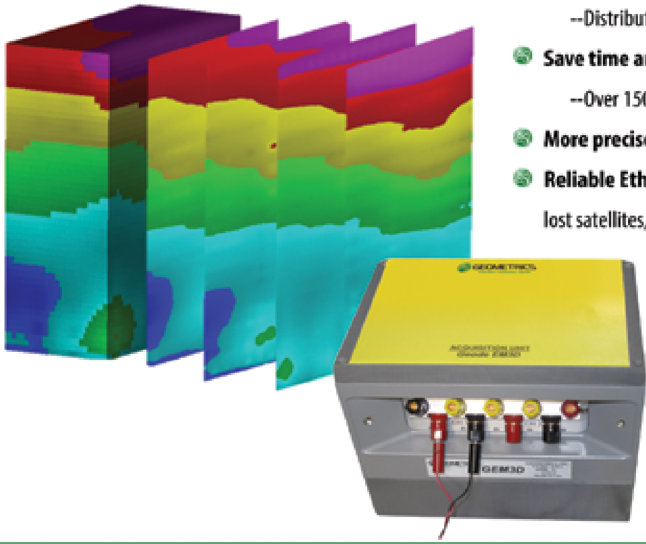

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CALENDAR

2015

October 26 - 31	Society of Exploration Geophysicists International Exposition and 85th Annual Meeting New Orleans, Louisiana USA http://www.seg.org
November 15 - 18	3rd International Conference on Engineering Geophysics Al Ain, United Arab Emirates http://www.seg.org/events/upcoming-seg-meetings/2015/iceg-uae-15
November 24 - 26	3rd International Conference on Geoelectric Monitoring (GELMON 2015) Vienna, Austria http://www.geophysik.at/index.php/workshop-gelmon-2015
December 3 - 4	SurfSeis - Multichannel Analysis of Surface Waves (MASW) Workshop Lawrence, Kansas, USA http://www.kgs.ku.edu/software/surfseis/workshops.html

2016

March 6 - 7	2nd Society of Exploration Geophysicists and Dahran Geoscience Society Workshop on Near Surface Modeling and Imaging Manama, Bahrain http://www.seg.org/events/upcoming-seg-meetings/2016/ns-modelling-imaging-2016
March 20 - 24	Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP) Denver, Colorado, USA http://www.eegs.org/sageep-2016 (Note: See page 52 for additional information.)
May 9 - 13	Geophysics and Remote Sensing for Archaeology Pompeii, Italy http://old.ibam.cnr.it/ARCHEO_School_finale.pdf

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

NOTES FROM EEGS

PRESIDENT'S MESSAGE

Lee Slater, President

(lslater@rutgers.edu)

Time to Commit

The last few months of my presidency have involved steering EEGS through the tortuous negotiations with AGU, EAGE, and SEG regarding the possibility of a true joint society near surface geophysics meeting that would occur in the spring and replace our established SAGEEP meeting. This represents a bold move for EEGS, requiring the organization to step outside of its comfort zone regarding the composition and administration of a spring meeting. The very successful 2015 SAGEEP meeting in Austin demonstrated that EEGS can organize a high quality and profitable meeting. A joint meeting among the four organizations represents a leap into the unknown, requiring work by the board and our management staff. Despite the uncertainty, the EEGS board recently composed a proposal and cost model that would serve as the foundation of a joint meeting with equal participation by the four organizations in the structure of the meeting and the scientific content. In doing so, EEGS demonstrated that it is ready to commit to such a venture, despite the uncertainty associated with giving up its regular SAGEEP meeting, based on the premise that such a joint collaboration would ultimately benefit the broad near surface geophysical community.

EEGS has received a strong commitment to participate in this venture from EAGE, but is currently waiting on a formal response from AGU and SEG. Although the joint meeting involves a small leap of faith into the unknown, I urge the elected officials at AGU and SEG to join in this venture with EEGS and EAGE to commit to a meeting that could be convened as early as spring 2017. The status quo is far from ideal, with the near surface geophysical community fragmented across multiple societies and meetings. SEG and AGU currently have an opportunity to commit to this venture and collaborate to produce a new spring meeting that could replace our established SAGEEP meeting. My hope is that the current officials will have the vision and initiative to overcome the organizational obstacles that have stalled previous large scale collaborations. If they chose not to, I urge every member to contribute to the long term prosperity of EEGS by contributing to future SAGEEP meetings to help ensure that they are as successful as the excellent 2015 meeting in Austin.

Lee Slater, EEGS President

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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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. Make this the year your company gets involved! Contact Lee Slater (lslater@rutgers.edu) for more information.

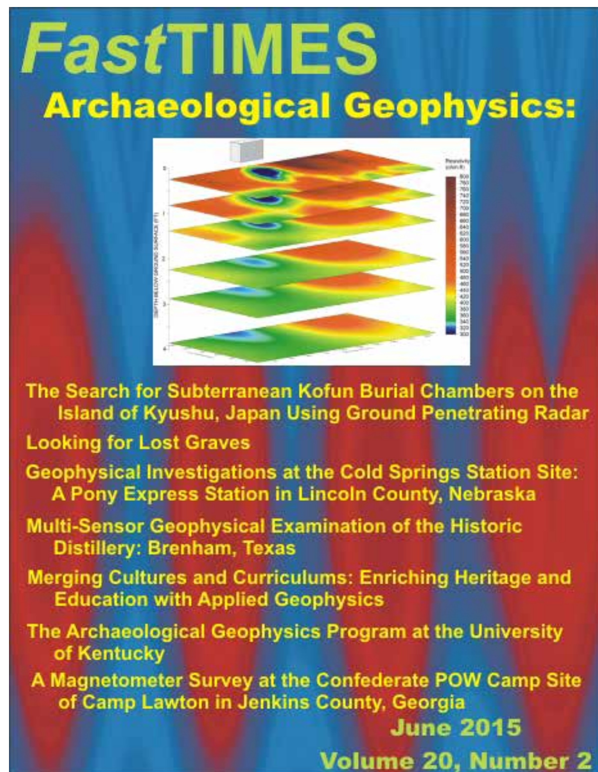
From the *Fast*TIMES Editorial Team

*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/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/fasttimes you'll now find calls for articles, author guidelines, current and past issues, and advertising information.

Special thanks are extended to Daniel Bigman, for his review of the archeological geophysics article included in this issue, "Comparison of Two GPR Surveys with Different Grid Spacings to Identify Unmarked Graves in a 19th Century Cemetery at Snyder County, PA".



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 Dec. 1, 2015 to ensure inclusion in the next issue. We look forward to seeing your work in our pages. Note: *Fast*TIMES continues to look for Guest Editors who are interested in organizing a *Fast*TIMES issue around a special topic within the Guest Editor's area of expertise. For more information, please contact Barry Allred (Barry.Allred@ars.usda.gov), if you would like to serve as a *Fast*TIMES Guest Editor.

Message from the *Fast*TIMES Editor-in-Chief

The *Fast*TIMES editorial team has been expanded substantially over the last few months. Besides myself and Moe Momayez (University of Arizona, moe.momayez@arizona.edu), the *Fast*TIMES editorial team now includes five new members:

Dan Bigman, Bigman Geophysical, LLC, dbigman@bigmangeophysical.com,
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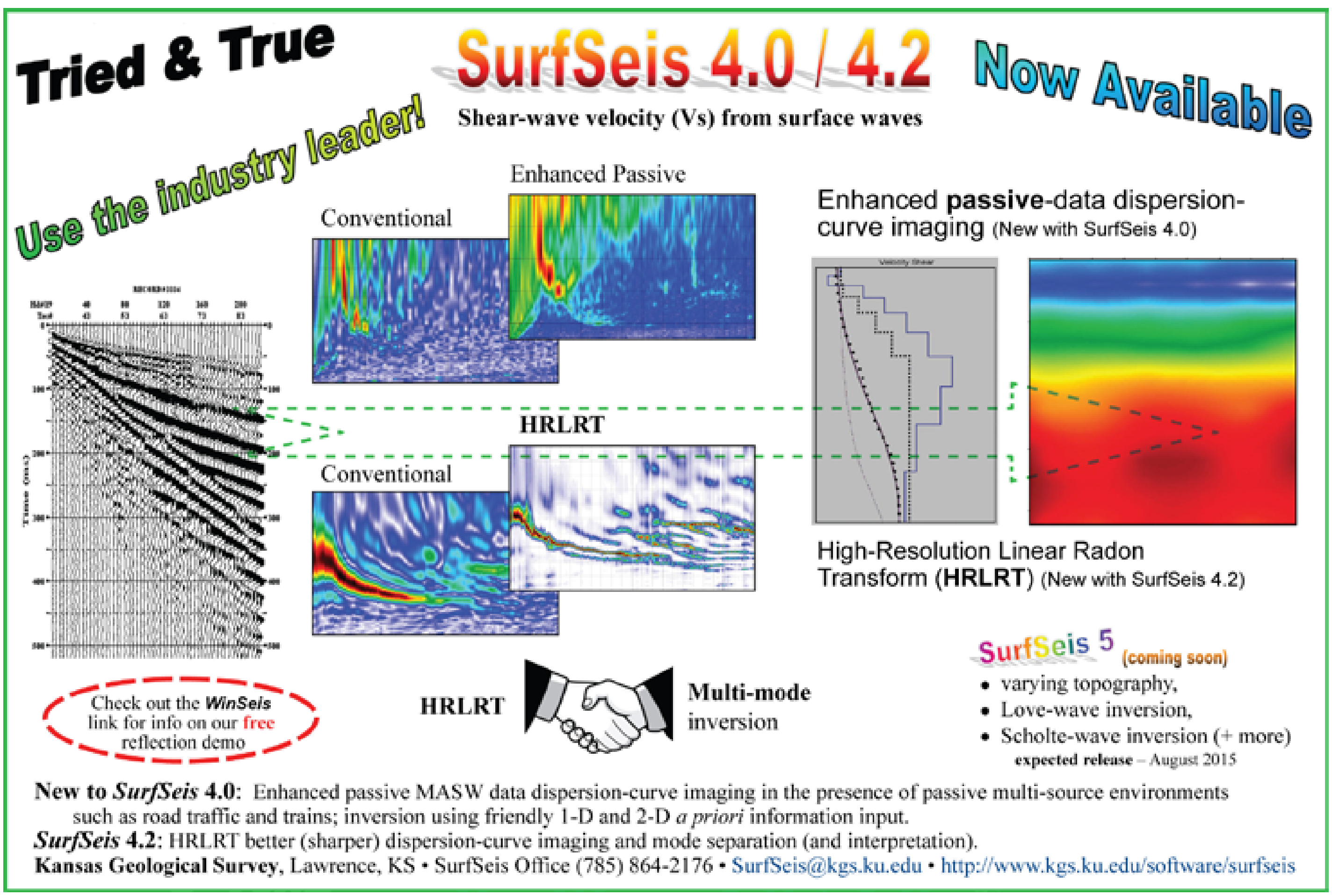
Ron Kaufmann, Spotlight Geophysical Services, ron@spotlightgeo.com.

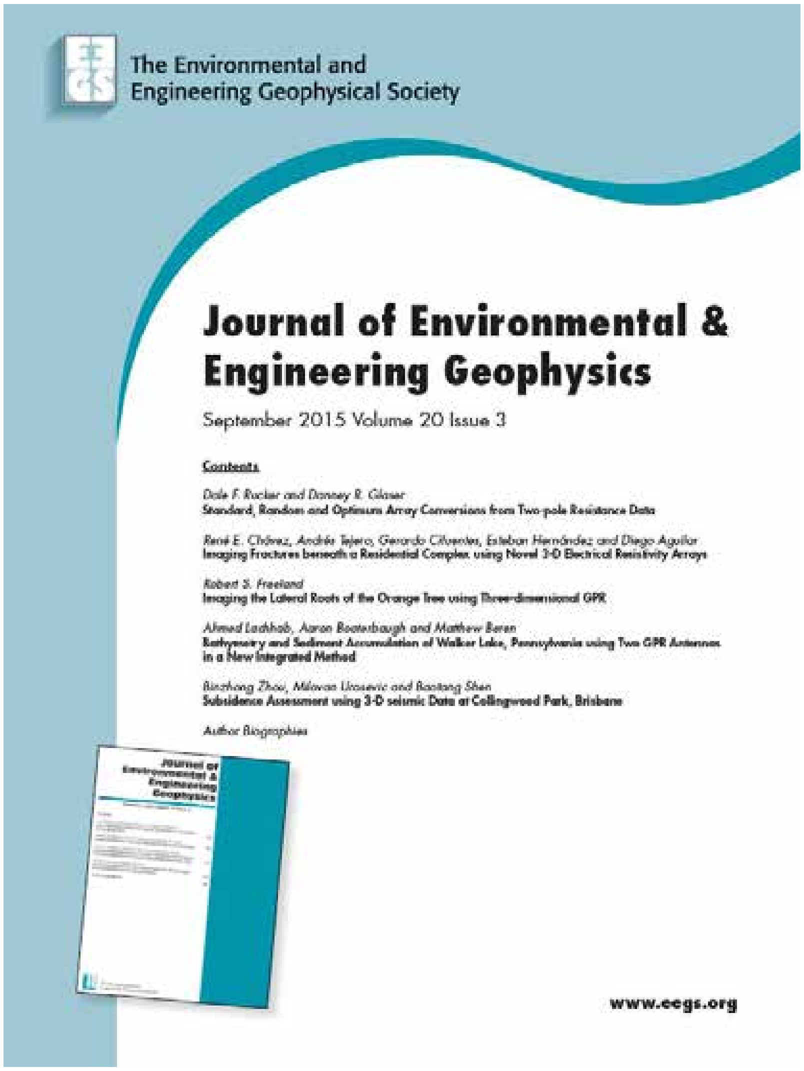
With our larger editorial team, we will better serve EEGS members by organizing *Fast*TIMES issues focused on special topics of great interest to our readers. The December 2015 *Fast*TIMES will focus on radio magnetotelluric methods. The the topic for the the March 2016 *Fast*TIMES will be the use of unmanned aerial vehicles (UAVs) in geology. Those interested in contributing a radio magnetotelluric article to the December 2015 *Fast*TIMES should contact Moe Momayez (moe.momayez@arizona.edu), while those interested in the contributing a UAV article to the March 2016 *Fast*TIMES should contact Ron Bell (International Geophysical Services, LLC, rbell@igsdenver.com). Furthermore, we now encourage our readers to submit letters to the editor for comments on articles published in *Fast*TIMES. In particular, some of our readers may have different points of view than those expressed in this issue by Derecke Palmer (University of New South Wales) in his article, "Does Diving Wave Tomography Improve Discovery in Near Surface Refraction Seismology? ". Letters to the editor regarding Dr. Palmer's article should be sent to Barry Allred (Barry.Allred@ars.usda.gov) by December 31, 2015 in order to be included in the March 2016 *Fast*TIMES.

Barry Allred, *Fast*TIMES Editor-in-Chief, Barry.Allred@ars.usda.gov



JEEG NEWS AND INFO

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



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Standard, Random and Optimum Array Conversions from Two-pole Resistance Data
Dale F. Rucker and Danney R. Glaser

Imaging Fractures beneath a Residential Complex using Novel 3-D Electrical Resistivity Arrays
René E. Chávez, Andrés Tejero, Gerardo Cifuentes, Esteban Hernández, and Diego Aguilar

Imaging the Lateral Roots of the Orange Tree using Three-dimensional GPR
Robert S. Freeland

Bathymetry and Sediment Accumulation of Walker Lake, Pennsylvania using Two GPR Antennas in a New Integrated Method
Ahmed Lachhab, Aaron Booterbaugh, and Matthew Beren

Subsidence Assessment using 3-D seismic Data at Collingwood Park, Brisbane
Binzhong Zhou, Milovan Urosevic, and Baotang Shen

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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 http://www.eegs.org/jeeg.

CALL FOR PAPERS

Airborne Geophysics

Special Issue
of the
Journal of Environmental and Engineering Geophysics

The *Journal of Environmental and Engineering Geophysics* (JEEG) announces a Call for Papers for a special issue on Airborne Geophysics. This issue is scheduled for publication in March 2017.

The special issue co-editors are Antonio Menghini, Aarhus Geophysics, Denmark and Les Beard, Zonge International, Arizona, USA. Sponsorship of this issue is still open.

Suggested themes are:

- New developments in equipment
- Novel airborne geophysical systems, including unmanned systems
- Data acquisition, modeling, and inversion
- Case histories, including:
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    - engineering
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    - environment
    - mining
    - exploration

International contributions are encouraged. The special issue will accommodate six to eight papers, but all accepted papers will be considered for publication in other JEEG issues.

Papers may be submitted through the JEEG submission site, http://jeeg.allentrack.net. Indicate in the cover letter that the paper is for consideration in the Airborne Geophysics special issue. The deadline for submissions is February 28th, 2016.

Questions may be directed to:

Special Issue Co-Editors—Antonio Menghini, am@aarhusgeo.com
Les Beard, LPBeard@comcast.net
JEEG Editor—Janet Simms, Janet.E.Simms@usace.army.mil

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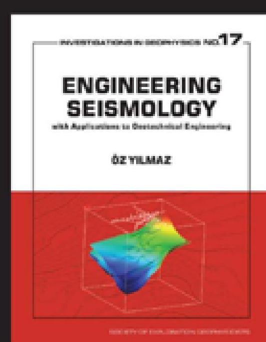

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SUCCESS WITH GEOPHYSICS

*Fast*TIMES welcomes short articles on applications of geophysics to the near surface in many disciplines, including engineering and environmental problems, geology, hydrology, agriculture, archaeology, and astronomy. In this issue of *Fast*TIMES, there is a discussion paper on seismic refraction tomography and a supplement article to the June 2015 special issue on archeological geophysics. Readers are very much encouraged to submit letters to the editor for comments on articles published in *Fast*TIMES.

DOES DIVING WAVE TOMOGRAPHY IMPROVE DISCOVERY IN NEAR SURFACE REFRACTION SEISMOLOGY?

Derecke Palmer, Senior Visiting Fellow in Geophysics
School of Biological, Earth and Environmental Sciences
The University of New South Wales
Sydney NSW 2052 Australia
email: d.palmer@unsw.edu.au

Summary

This commentary poses the fundamental question of whether the widespread implementation of diving wave refraction tomography in the near surface is addressing the right problems. It presents a thought provoking critique from an *accuracy* versus *precision* perspective. It represents an alternate description of the ongoing so-called model-driven versus data-driven conversation. The central proposition of this critique is that the current focus on misfit errors, which are a measure of the *precision* of the model parameters, are commonly, but erroneously, employed as a measure of the validity or the *accuracy* of the model. This fundamental error of science ignores the reality of non-uniqueness, which is the geophysicist's "elephant in the room." The anecdotal evidence suggests that the widespread perception that diving wave refraction tomography is the panacea, the so-called "silver bullet," has contributed to an alarming de-skilling of many practitioners of near surface refraction seismology. It has resulted in a plethora of low resolution tomograms which have done little to advance exploration or investigation and in turn, discovery in the near surface. In fact, it can be argued that this perception has impeded a long overdue modernization of routine near surface refraction seismology with either qualitative or quantitative full waveform methods.

Is Discovery More Important Than Cosmetics?

For much of the early history of near-surface refraction seismology, an important focus was the development of graphical and analytical methods for the inversion of traveltime data. It came to a close with the publication of a major volume (Musgrave, 1967), which summarized a great deal of the existing knowledge, and a monograph (Palmer, 1980), which synthesized much of that knowledge into a concise methodology.

Keywords: Seismic Refraction, Tomography, Inversion Methods, Accuracy Versus Precision.

That period can be characterized as having a focus on *vertical and spatial resolution*, that is, on how closely the model corresponded with the true seismic velocities. It represented an emphasis on *accuracy* and *model generation*. In turn, model generation is an essential prerequisite for *discovery* (Reading et al, 2011).

In the last three decades however, there has been a shift in focus with the widespread adoption of model-based inversion, as has occurred with virtually all aspects of exploration geophysics. With these methods, which are generally known as refraction tomography or tomographic inversion, *a starting model is systematically updated until the computed response is similar to the data*.

The first implementations of refraction tomography were simple manual ray tracing methods through two-dimensional models with constant velocity compartments (Ackermann et al., 1982; Whiteley, 2004). These manual ray tracing methods were soon superseded by automatic methods, in which the forward modelling and the subsequent model updates are carried out automatically by the computer program rather than by the practitioner (Lanz et al., 1998; Stefani, 1995; Zhang and Toksoz, 1998; Zhu et al., 1992).

The implementations of automatic refraction tomography have not been constrained by the practicalities of modelling large numbers of traveltimes. As a result, many have adopted so-called *diving wave tomography*, in which low resolution 1D starting models such as smooth vertical velocity gradients are employed, with the expectation that tomography will significantly improve the resolution of the model.

The major focus of refraction tomography has been on *model improvement* or *cosmetics* through minimizing misfit errors, that is, on *precision*. Figure 1 is a common target analogy which illustrates the difference between accuracy and precision.

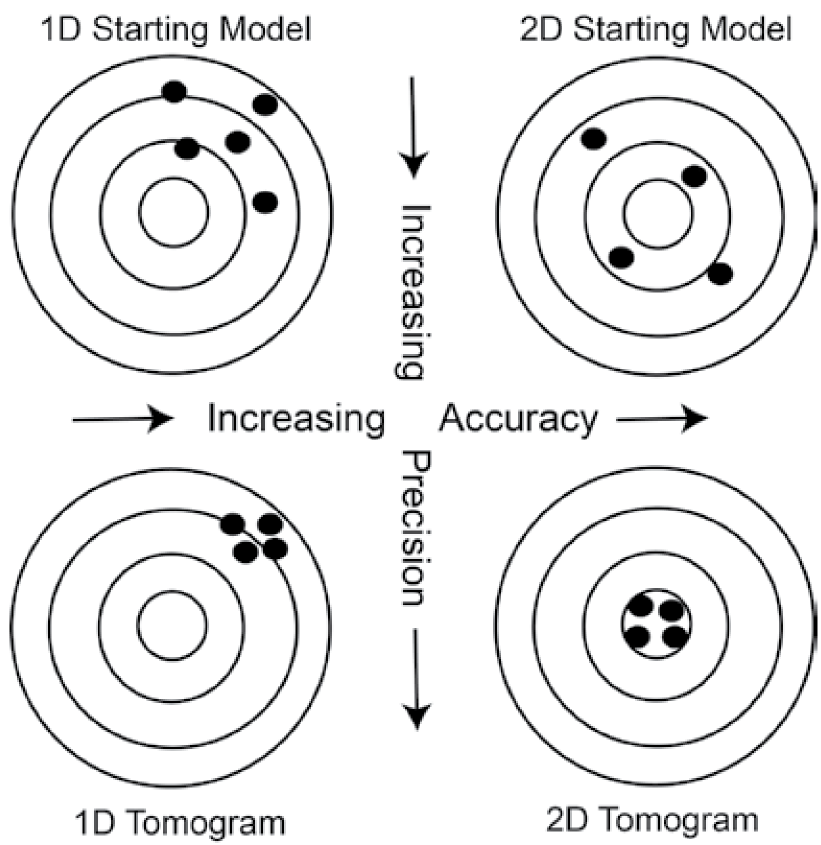

Figure 1: A common target analogy illustrating the difference between accuracy and precision.

The widespread adoption of automatic refraction tomography has resulted in a systematic reduction in the awareness of fundamental refraction and model-based inversion concepts throughout much of the near surface geophysics profession. It has resulted in the alarming de-skilling of many practitioners of near surface refraction seismology, which in turn, has had two regrettable consequences.

The Critical Importance of the Starting Model

The first is a common but erroneous perception that refraction tomography has superseded traditional graphical and analytical inversion methods, such as wavefront reconstruction (Rockwell, 1967), and the generalized reciprocal method (GRM) (Palmer, 1980, 1981). It represents a failure to draw a clear distinction between model generation with inversion algorithms and model improvement with tomography, that is, between accuracy and precision (Palmer, 2015).

The following quotation from Menke (1989, p.2) emphasizes the importance of the starting model with model-based inversion, such as, refraction tomography. *"The role of model-based inversion is to provide information about the unknown numerical parameters which go into the model, not to provide the model itself."*

For example, the so-called blind test of inversion and tomographic refraction analysis methods using a synthetic first-arrival-time dataset (Zelt et al, 2013), only provides general descriptions of the starting models and only presents the final tomograms. There are no figures which clearly demonstrate the systematic progression of the various model-based inversion processes from the starting models to the final tomograms. The blind test does not effectively differentiate the relative contributions of model generation with inversion algorithms from model improvement with refraction tomography (see for example Palmer 2015, Figs 3 & 8-9). It can be concluded that the blind test has not facilitated a useful assessment of the relative importance of accuracy and precision.

By contrast, Figure 2 demonstrates the importance of the starting model. The three tomograms were generated from the same traveltime data which were acquired as part of regional seismic reflection investigations (Drummond et al, 2000), over part of the Palaeozoic Lachlan Fold Belt in south-eastern Australia (Jones and Drummond, 2001; Barton and Jones, 2003). The tomograms are for a 12 km section which crosses the Marsden thrust, which is a major regional geological feature, and the adjacent flood plain of the Lachlan River, for which the weathered layer consists of up to 150 m of unconsolidated Tertiary alluvium.

The three tomograms were generated with the same commercially available refraction tomography software, which employs a wavepath eikonal traveltime (WET) tomography approach (Schuster and Quintus-Bosz, 1993). The tomograms, which are taken from Palmer (2013a), employ a 2D detailed GRM (Palmer, 2010d), a 1.5D medium resolution COG GRM (Palmer, 2012) and a 1D low resolution smooth vertical velocity gradient starting models. All three tomograms generate comparable misfit errors, that is, they all exhibit acceptable precision. Two conclusions can be drawn from this and similar studies (Palmer, 2013b, 2015).

The first is the reality of non-uniqueness. In the near surface, the fundamental causes of non-uniqueness are extrapolation with the seismic velocities in the weathered layers, (undetected layers, vertical velocity gradients, velocity reversals, seismic anisotropy) and ill-posedness with the seismic velocities in the sub-weathered layers. In fact, ill-posedness is synonymous with non-uniqueness (Oldenburg and Li, 2005).

Second, these studies demonstrate that common implementations of refraction tomography neither improve significantly the spatial resolution of the starting model, nor do they automatically converge to a single "accurate" high resolution tomogram. In Figure 2, the average approximate spatial wavelengths of the seismic velocities in the sub-weathering range from ~250 m for the GRM, to ~500 m for the COG GRM to >2500 m for the 1D vertical velocity gradients. It demonstrates that if a low resolution starting model is used, then the final result will usually be a low resolution tomogram.

Furthermore, repeated applications of WET refraction tomography usually result in a systematic reduction in resolution, because the inherent ill-posedness is addressed through extensive smoothing and regularization. Palmer (2013b, Fig. 10), demonstrates that all starting models converge to essentially identical low resolution tomograms, given a sufficient number of iterations. Similarly, Palmer (2015, Figs 3 & 8-9) demonstrates that a systematic reduction in misfit errors can come at the cost of a systematic reduction in resolution, even with a medium resolution 1.5D COG GRM starting model. These studies question whether a focus on simplistic comparisons of misfit errors constitutes a useful measure of either accuracy or resolution.

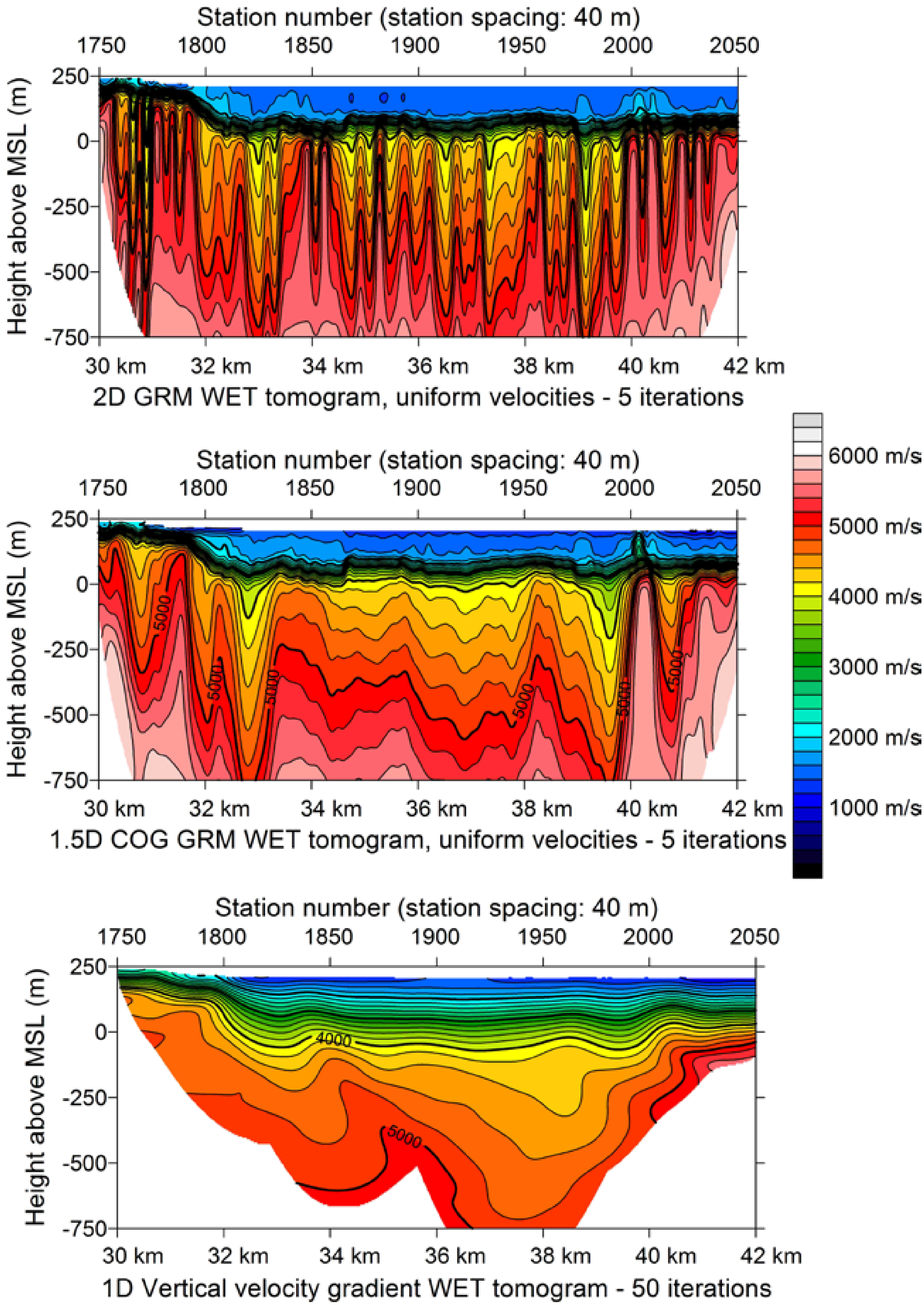

Figure 2: WET tomograms derived from the same traveltime data with 2D detailed GRM, 1.5D medium resolution COG GRM, and 1D low resolution smooth vertical velocity gradient starting models.

Similar results were obtained with the blind test of Zelt et al (2013). The combination of generally low resolution starting models, together with numerous iterations of tomography, resulted in all tomograms exhibiting much the same low spatial resolution. Non-uniqueness and resolution can be viewed as different sides of the same coin. Whereas Figure 2 demonstrates non-uniqueness in terms of the spatial resolution of the starting model, Palmer (2015) demonstrates that non-uniqueness and the generation of artefacts become even more significant within the global model space of high resolution 2D starting models. It can be concluded that optimizing the model parameters with model-based inversion is separate from the validation of the accuracy of the starting model.

Ineffective Methods of Quality Assurance

The second, and possibly the most concerning, is that default implementations of refraction tomography using 1D starting models are not amenable to effective quality assurance or critical evaluation. How do we know if the model is "correct," that is, if it is accurate. *Traveltime misfit errors, which are a measure of precision, are commonly, but erroneously, employed as a measure of accuracy.* It is not unusual for the number of iterations to run into the many hundreds, in order to achieve infinitesimal improvements in misfit errors but with the inevitable loss of resolution (Palmer, 2013b, 2015), in the belief that the final result is more "accurate." Furthermore, ray path coverage images are essentially *circulus in probando*, that is, they assume that which they seek to demonstrate.

Figure 3 is taken from Lamb et al (2012). The electrical resistivity tomography image at the top clearly supports two faults. By contrast, the default WET refraction tomogram in the centre is relatively featureless, and it appears to be inconsistent with the shot record. In fact, all 4 WET tomograms in Lamb et al (2012) exhibit the same featureless quasi-horizontal layering.

No doubt the WET tomogram exhibits acceptable standards of precision, that is, it is likely to have been iterated until the misfit errors were an acceptable minimum. Nevertheless, the accuracy of the WET tomogram is still questionable, in view of the resistivity tomogram, irrespective of precision of the traveltime misfit errors.

Furthermore, the generally poor resolution of most default 1D tomograms facilitates confirmation bias (in the vernacular, "what answer do you want?") and any differences with bore holes are rarely addressed critically. For example, in Brojerdi et al (2014), the shot records indicate that the base of the weathering has a seismic velocity of 5000 m/s. Nevertheless, the 1D tomograms have been interpreted so that the base of weathering corresponds with a seismic velocity of 3000 m/s, in order to agree with the borehole data!

One of the more extraordinary examples of the lack of basic measures of quality assurance, such as the presentation of the starting model, is demonstrated in Whiteley and Leung (undated). The refraction tomogram generated by interactive ray tracing, exhibits extensive under-fitting and over-fitting, as well as a remarkable similarity with the tomogram generated with 1D WET tomography using vertical velocity gradients (Palmer, 2010a, 2010b). Nevertheless, the authors claim the application of an as yet unpublished inversion strategy, and even conclude that the GRM is "fundamentally technically flawed" (Whiteley, 2011).

Effective quality assurance and critical evaluation are essential for any ongoing innovation and advancement. This study advocates the presentation of the starting model as a minimum. Furthermore, this study advocates greater presentation of various parameters derived from the field data, which constitute processing stages intermediate to the final depth domain oriented tomogram, and which can constitute considerably more useful alternatives to the shot records, such as that shown in Lamb et al (2012).

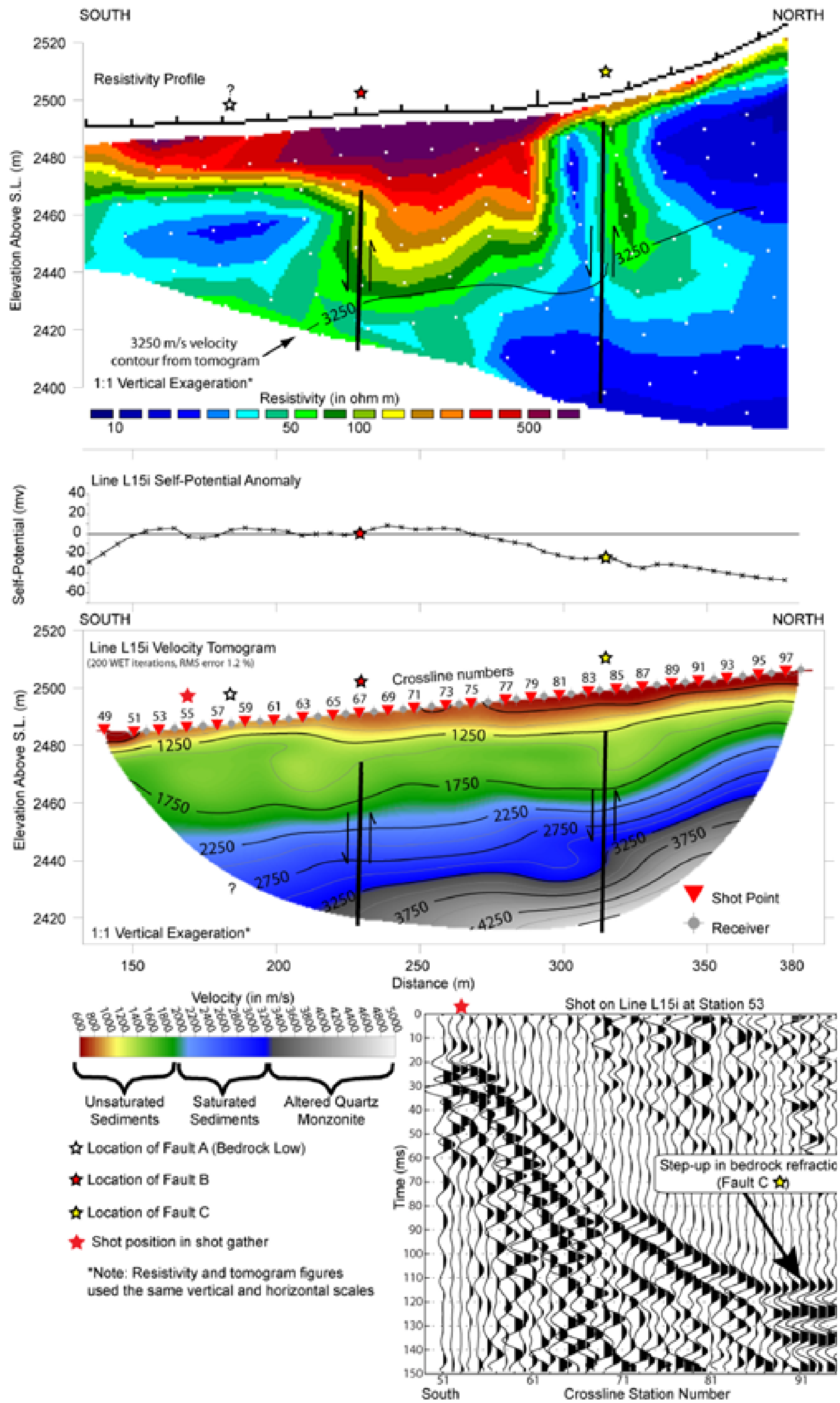

Figure 3: The resistivity tomogram suggests a more complex geology than the WET refraction tomogram. This figure was taken from Lamb, A. P., Liberty, L. M., and van Wijk, K, 2012, Near-surface imaging of a hydrogeothermal system at Mount Princeton, Colorado using 3D seismic, self-potential, and dc resistivity data. The Leading Edge, 31(1), 70-74.

Accuracy and Precision from a Backus-Gilbert Perspective

Much of the current theory for the inversion of geophysical data had its genesis with the three landmark publications of Backus and Gilbert (1967, 1968, 1970). They showed that linear inverse problems can have either a single unique solution or infinitely many solutions. In the latter case, it is possible to generate linear combinations of the data, which represent unique averages of the model. Any model which reproduces the observations must have the same averages. Backus and Gilbert called this process *appraisal*, whereas they called model-based inversion, such as refraction tomography, *construction* (Oldenburg, 1984).

The inversion algorithms of the GRM consist of simple linear combinations of the traveltime data, and therefore, they constitute a version of Backus-Gilbert appraisal. Accordingly, it can be concluded that accuracy, model generation, and the GRM inversion algorithms correspond with appraisal, whereas precision, misfit errors and refraction tomography correspond with construction.

Paradoxically, any unique average will not necessarily reproduce the observations, even though any model which reproduces the data must have the same averages (Oldenburg, 1984). It suggests that accuracy is possibly more important than precision, and that misfit errors should not be given *undue* emphasis (Lines and Treitel, 1985).

Furthermore, it can be concluded that the 1D starting models, consisting of smooth vertical velocity gradients do not represent valid starting models, because they do not satisfy the Backus-Gilbert appraisal criterion. In fact, many traditional refraction inversion methods, such as the delay time method (DTM) (Taner et al, 1998) and even many optimization methods, such as generalized linear inversion (GLI), do not satisfy the Backus-Gilbert appraisal criterion.

An important feature of many analytical methods, such as the GRM, is that they are applied in the time domain, that is, before the transformation to the depth domain with the seismic velocities, which constitute the principal sources of non-uniqueness. As is shown below, the application of the COG GRM and RCS algorithms in the data domain, that is, the implementation of Backus-Gilbert appraisal, constitute useful intermediate processing operations, which can facilitate the generation of high resolution conceptual models, that is, they can be employed to validate accuracy. It parallels the application of many standard processing operations with routine seismic reflection investigations, such as normal moveout corrections, CMP stacking and deconvolution, which are implemented in the time domain, that is, the data domain.

COG GRM as a Measure of Accuracy

The inversion algorithms of the common offset gather (COG) adaptation of the GRM (2012, 2013a), consist of simple linear combinations of the traveltime data. They constitute a version of Backus-Gilbert appraisal, and accordingly, they can be employed for quality assurance, that is, as a measure of accuracy.

Figure 4 presents the 1.5 D COG GRM time model and refractor velocity histograms for the traveltime data which are inverted in Figure 2. These histograms confirm that the time model of the base of the weathering, and the seismic velocities within the sub-weathering are considerably more complex than the 1D WET tomogram in Figure 2 might suggest. In particular, Figure 4 shows a major thrust feature between stations 1860 and 1900. At the other extreme of resolution, there is a small offset in the histogram of the time model at station ~1815. These features correspond with decreases in the seismic velocities in the sub-weathering in the 1.5D COG GRM and the 2D GRM WET tomograms in Figure 2. Furthermore, both are supported in the stacked and deconvolved RCS in Figure 5.

Neither of these large or small scale structures is readily apparent in the 1D WET tomogram in Figure 2. Figure 4 is a compelling demonstration of the usefulness of a high resolution but relatively low precision conceptual model.

Figure 4 also demonstrates that the traveltime data represent minimal penetration within the sub-weathering, consistent with uniform seismic velocities, and that the spatial changes in the time model and the seismic velocities are considerably more significant than any vertical changes caused by vertical velocity gradients in the sub-weathered zone. However, Figure 4 does not preclude the possibility of vertical velocity gradients in the sub-weathering, because minimal penetration of the first arrivals within each layer is also consistent with even extremely large vertical velocity gradients, such as the hyperbolic cosine function (Palmer, 2010c, Figure 1).

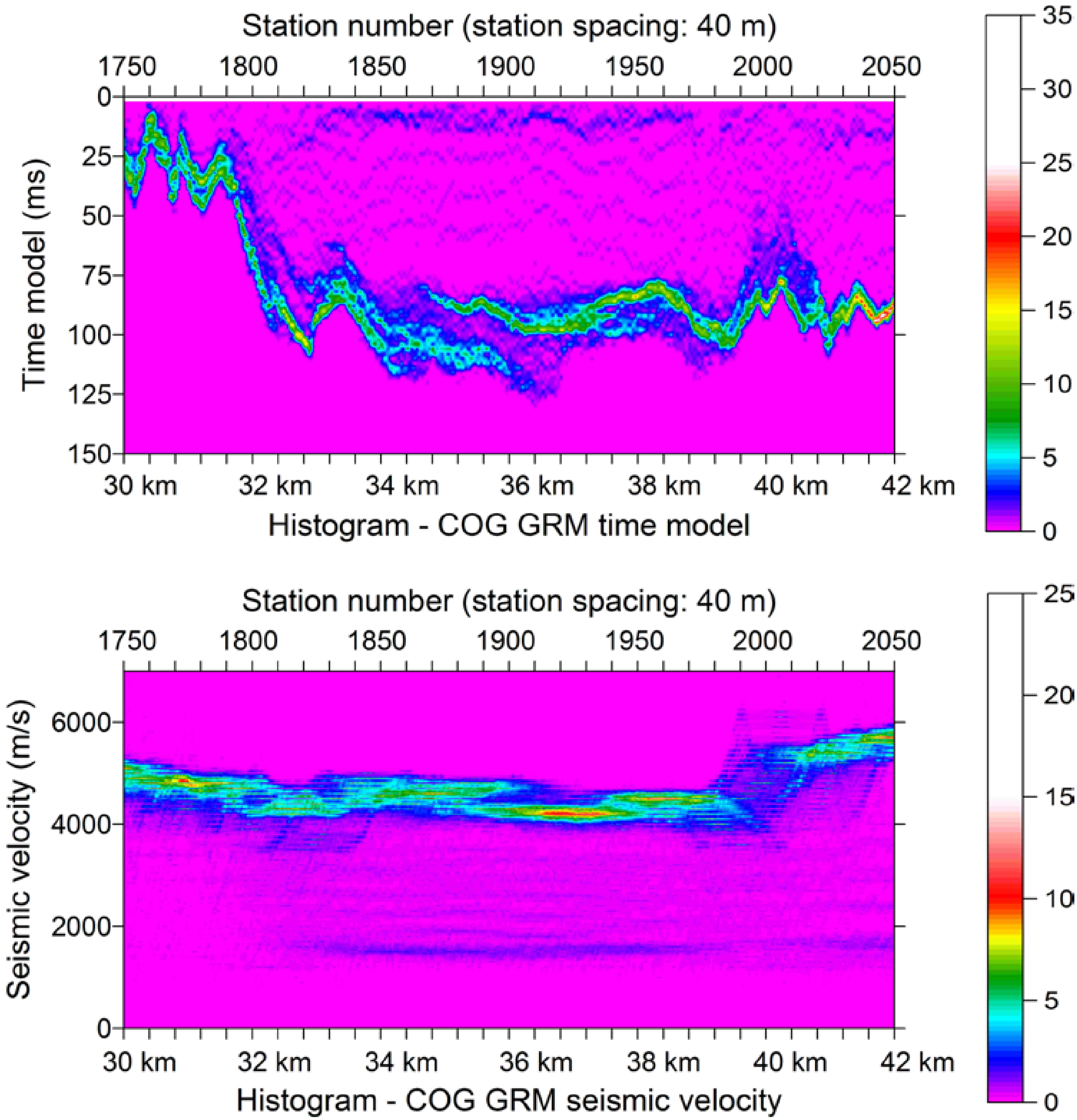

Figure 4: COG GRM time model and seismic velocity histograms.

Full Waveform Methods as a Measure of Accuracy

The Backus-Gilbert concept of appraisal of generating unique averages of the model with linear combinations of the data can be readily extended to full waveform methods with the refraction convolution section (RCS) (Palmer, 2001). The essential process for the generation of the time model with the GRM is the addition of the forward and reverse scalar traveltimes. The RCS achieves the equivalent process through the convolution of the corresponding seismic traces, since convolution adds phase, that is, traveltimes, and multiplies amplitudes.

In the strict sense, a full waveform COG section is generated simply by displaying all traces with the same source-to-receiver offset. This study employs COG sections in which the first breaks have been adjusted to correspond with the one-way time model of the weathered layer. The time model has been obtained with a multi-fold GRM-based inversion of the traveltime data.

Figure 5 presents the stacked and deconvolved RCS, the stacked and deconvolved full waveform COG for the forward and reverse traces for 80-85 station offsets and the stacked CMP reflection section. Figure 5 supports a more complex model of the near surface region than the 1D WET tomogram in Figure 2. It is proposed that the RCS, together with full waveform common offset gathers (COG), can provide a more useful and more convenient alternative measure of accuracy to the presentation of individual shot records (Lamb et al, 2012, Figure 4).

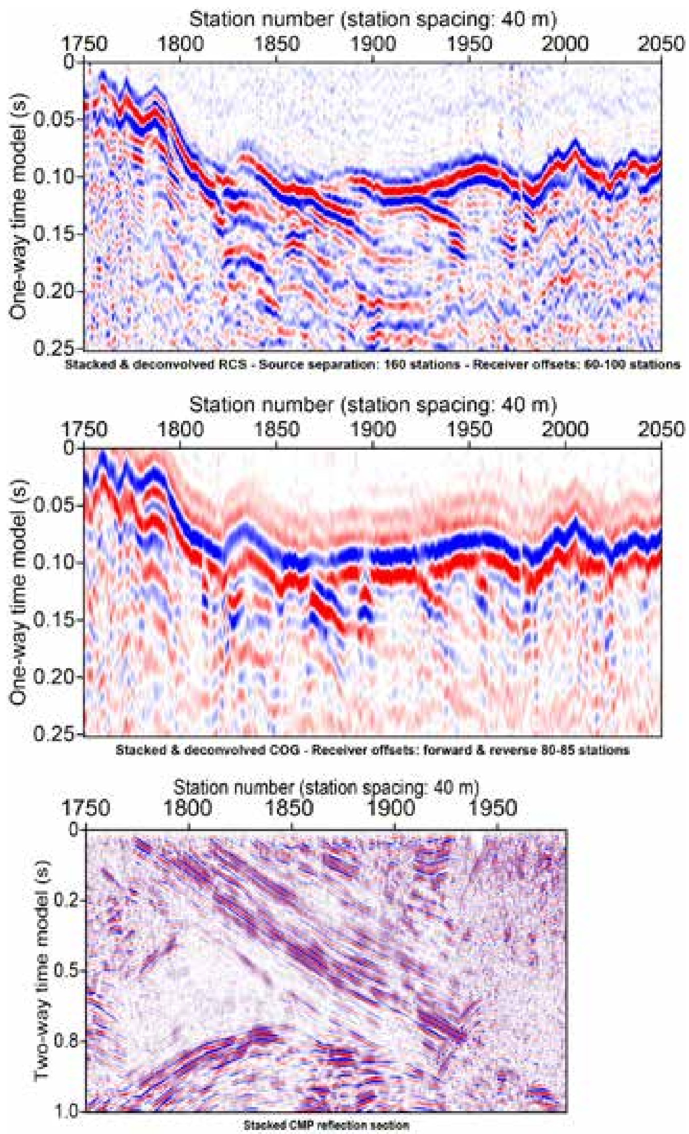

Figure 5: The stacked and deconvolved RCS, the full waveform COG for the forward and reverse traces for 80-85 station offsets and the stacked CMP reflection section.

Are Smooth Vertical Velocity Gradients Self-Evident Facts?

Many implementations of automatic refraction tomography assume a 1D starting model consisting of smooth vertical velocity gradients. They are usually considered to be self-evident because it can be reasoned that (i) in most geological environments, the seismic velocities generally increase monotonically with depth, and that (ii) the transitions between major geological entities, such as that between the weathered and sub-weathered regions, are more likely to be gradational, rather than abrupt discontinuities.

The issue is not whether vertical velocity gradients exist in the weathered layer, but rather the magnitude of any such gradients. Extensive theoretical, experimental and field investigations more than fifty years ago suggest that (i) the vertical velocity gradients due to the normal compaction of unconsolidated clastic sediments are quite modest and vary as the one sixth power of depth ($Z^{1/6}$) (Palmer, 2001, p.660), and that (ii) they are commonly of the order of 1 m/s per metre (Dobrin, 1976).

By contrast, the average vertical velocity gradient in the 1D tomogram in Figure 2 is ~10 m/s per metre, which is an order of magnitude greater than values representative of unconsolidated clastic sediments. In Figure 2, the vertical velocity gradient results in depths to the base of the weathering which are twice those recorded in numerous water bores.

Equation 1 is an expression for the average vertical gradient derived from Palmer (2010c, equation 1), where the seismic velocity in the weathered layer is approximated with the hyperbolic cosine function. This gradient, which is the maximum vertical gradient consistent with linear traveltime graphs (Palmer, 2010c, Figure 1), is presented in Figure 6, for a range of time models of the weathered layer. An approximate time model of 100 ms and seismic velocities of 1600 m/s and ~5000 m/s, can be derived from Figure 4. Figure 6 shows that the average vertical gradient is approximately 10 m/s per metre:

$$average\ gradient = \frac{2\left(1-\left(V_1/V_n\right)^2\right)}{\pi\, t_G \left(V_1/V_n\right) acosh\left(V_n/V_1\right)} \quad , \qquad (1)$$

where t_G is the time model to the base of the weathering, V_1 is the seismic velocity at the surface of the weathering, and V_n is the seismic velocity in the sub-weathering.

Figure 6 demonstrates that unrealistically high vertical velocity gradients are usually the results of interpolation between the measured seismic velocities over the shallow depths to the base of the weathering, which are characteristic of most near surface investigations. (Generally, realistic gradients are achieved with depths greater than approximately 750 m.) The fact that the weathered layer can be modelled precisely with both uniform or constant seismic velocities and the hyperbolic cosine function emphasizes the reality of non-uniqueness in the seismic velocity model in the weathered layer(s) due to extrapolation, and the inappropriateness of misfit errors as a measure of the accuracy of any vertical velocity gradients.

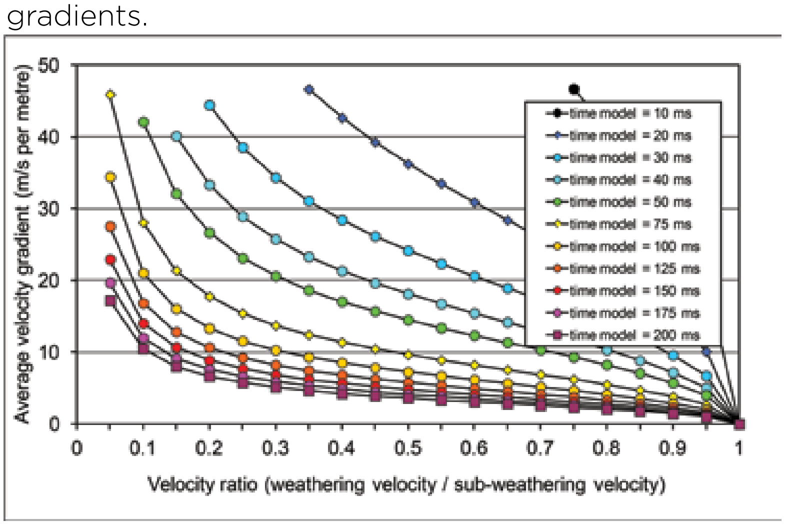

Figure 6: Average vertical velocity gradient as a function of the time model to the base of the weathering, and the seismic velocities.

Are Model Generation and Risk Taking Essential for Discovery?

The widespread focus on precision and minimizing misfit errors represents a culture of risk minimization. It contrasts with an earlier focus on model generation which is essential for exploration and/or investigation and in turn, discovery, and which often can be an inherently risk taking activity.

In many ways, the professional culture of engineering can be characterized as one of risk minimization, that is, engineers live in fear of disasters, such as the collapse of a bridge or the blow out of a well. By contrast, the professional culture of the geosciences can be characterized as one of risk taking, that is, geoscientists live in hope that one day they may actually discover something of significance.

The adoption of a risk minimization culture is understandable with many geophysicists involved with geotechnical investigations. Whereas the drilling of a dry well can be more of an embarrassment for the explorationist, any ambiguity in site characterization with major civil engineering construction projects can often result in expensive litigation.

Nevertheless, it can be argued that it is past time to re-establish a culture of discovery, that is, to place greater emphasis on model generation and accuracy. Reading et al (2011) propose the use of a wider range of strategies for data inference in geophysics.

Recognizing, Generating and Resolving Non-Uniqueness

Given the importance of the starting models, the task becomes one of generating models which are fit for purpose. In many groundwater investigations where the accurate mapping of the weathered layers is the prime objective, then a combination of electrical resistivity and surface wave seismic methods might be the most efficacious. However, in geotechnical investigations, where the depth to, and the seismic velocities within the sub-weathering are the prime objective, then seismic refraction methods can offer significant advantages.

In many geotechnical site investigations, such as for highway, railway or utilities construction, the principal objective is usually the determination of the thickness of weathered rock which can be excavated with low cost methods. The use of low resolution methods, such as 1D vertical velocity gradient tomograms, and even the 2D common reciprocal method (CRM) (also known as the ABC, plus/minus and Hagiwara's methods) is widespread. Given the sensitivity of these projects to the variation in costing between low cost mechanical excavation and high cost drilling and blasting, it is common to include extensive drilling programs to help minimise any uncertainty. These approaches usually address any inconsistencies through the use of "pragmatic" correlations between the seismic and the drilling results (Brojerdi et al, 2014). The fact that this somewhat expedient approach has been employed successfully for many decades is testament to its efficacy. Furthermore, the values of the seismic velocities, which can be useful measures of rock strength, are usually superseded with UCS tests on rock samples obtained from drilling or excavation, where that information is critical to engineering design.

In other investigations however, such as for damsite or tunnel construction, a major concern is the occurrence of narrow zones of weathered or fractured rock, which may enhance the flow of groundwater. Such narrow zones usually exhibit abnormally low seismic velocities. In these investigations, the spatial resolution of the seismic velocities can be an important issue.

It has been the author's limited observation that the average spatial resolution of the seismic velocities in the sub-weathering is approximately 5-10 stations with the 2D GRM, approximately 20 stations with the 1.5D COG GRM and more than 100 stations with 1D vertical velocity gradients. These very approximate values appear to apply with small station spacings, such as 2.5 – 5 m (Palmer, 2006, 2010d), medium station spacings, such as 10 m, (Palmer, 2015), and large station spacings, such as 40 m in Figure 2.

However, there are additional challenges in generating detailed starting models with the application of detailed 2D inversion algorithms, such as those of the GRM. Palmer (2015) observes that the seismic velocities in the weathering and the sub-weathering are inter-related: as the seismic velocities in the weathering are varied, so too are the seismic velocities in the sub-weathering. Other studies (Palmer, 2010c), demonstrate that artefacts with both low and high seismic velocities in the seismic velocities in the sub-weathered layer can be readily generated using the XY parameter of the GRM as a measure of the average vertical seismic velocity in the weathered layer (Palmer 2010d, equation A7).

Furthermore, the range of average vertical velocities in the weathering, which are consistent with traveltime graphs consisting of linear segments, can often double from constant or uniform velocities to the hyperbolic cosine function (Palmer, 2015). Therefore, traditional methods for addressing the so-called undetected layer problem by essentially inserting an additional layer (eg. Ivanov et al, 2013), may be only partially effective, because they do not address any changes in the velocity model in the sub-weathering.

As stated previously, non-uniqueness and resolution are different sides of the same coin. As greater spatial resolution is sought with 2D inversion algorithms, then the global model space of geologically reasonable models which fit the data becomes considerably larger (Palmer, 2015). Therefore, the challenge is to not only to generate detailed 2D starting models which properly investigate the model space, but to demonstrate which model is the most probable. The so-called blind test of inversion and tomographic refraction analysis methods using a synthetic first-arrival-time dataset (Zelt et al, 2013) does not usefully address this fundamental issue of non-uniqueness.

It is proposed that all strategies for validating the accuracy of any model must include embracing, demonstrating and resolving non-uniqueness. Such a strategy is essential to verify that a global model space, which represents all geologically reasonable seismic velocities, and which is specific to each investigation, is properly investigated.

Do Ongoing Model Studies Reduce Risk?

While tests of various geophysical inversion methods using synthetic sets of data can often be useful, it is essential that the synthetic data be based on field data and therefore, be representative of genuine geological models. It has been the author's experience that field data usually generate more realistic and more interesting challenges. In the words of the polymath J B S Haldane, "My own suspicion is that the Universe is not only queerer than we suppose, but queerer than we can suppose."

The geological verisimilitude of the Zelt model is questionable. If the low angle low velocity zone in the sub-weathering is representative of a thrust, then it would be reasonable to anticipate that the hanging wall might show some evidence of a fault-bend fold or "ramp anticline". Such features can be clearly seen in Figures 4 and 5. Also, other structures such as changes in depth might exhibit consistent structural styles, such as consistent dip directions and depth changes. However, the change in depth in the synthetic model suggests a normal fault, which is inconsistent with the existence and orientation of the adjacent low angle thrust.

Can Refraction Attributes Reduce Risk?

Whereas Palmer (2015) might advocate a more proactive approach to accuracy, non-uniqueness, and resolution with the greater use of traditional detailed 2D traveltime inversion algorithms, such as those of the GRM, that strategy is unlikely to be a widely adopted in the foreseeable future. Not only has automatic refraction tomography de-skilled many practitioners in traditional refraction inversion methods, but currently there is no commercially available software which is suitable for routine production applications. Furthermore, even the application of medium resolution 1.5D COG GRM methods is unlikely, because it is most useful with data recorded with CMP methods. By contrast, most near surface refraction data is recorded with a static spread approach, such as that in Zelt et al (2013). Are there other alternatives?

Up to approximately 50 years ago, seismic refraction methods were often employed in areas of poor reflection data quality as a viable alternative for petroleum exploration. However, there has been an ongoing spectacular evolution of exploration reflection seismology, with for example, common midpoint (CMP) stacking, digital processing, 3D methods and attribute analysis. As a result, there are very few areas where current seismic reflection technology fails to generate useful results.

By contrast, refraction seismology has yet to undertake a comparable modernization. The vast majority of seismic refraction investigations, whether they be for statics corrections, geotechnical or crustal investigations, still only employ scalar traveltimes. There are no widely accepted methods for either qualitative or quantitative full waveform analysis of seismic refraction data in a manner comparable to the full waveform methods routinely employed with seismic reflection data. Accordingly, most implementations of refraction seismology can be viewed as representative of a 50 year old technology, refraction tomography notwithstanding (Palmer, 2008, 2010b).

For example, there are virtually no studies of the head coefficient, which is the refraction analogue of the reflection coefficient. In view of the long standing focus on traveltime inversion since the introduction of exploration refraction seismology approximately a century ago, almost to the exclusion of all other aspects, it is not surprising that quantitative full waveform refraction methods offer considerable scope for advancement (Palmer, 2010b, 2010e, 2011).

Figure 7 is a comprehensive summary of the head coefficient and the various refraction attributes derived from the first arrival head wave amplitude and traveltime data. In general, there is a reasonable correlation between the occurrences of the dipping events in the RCS in Figure 5 with changes, which are usually increases, in the head coefficient in Figure 7. For example, the dipping event which originates at approximately station 1860 corresponds with the maximum head coefficient. Also, the dipping event at station 1925 corresponds with a large change in the head coefficient. There is also a reasonable correlation with the P-wave modulus. However, the correlation is not exact, no doubt due in part to the fact that the amplitudes have been measured on the first breaks and their significance is then extended to the later arrivals.

There is an unexpected but nevertheless a reasonable correlation between the time model and the P-wave modulus between stations 1800 and 2050. These results suggest that the P-wave modulus might be a useful indicator of the resistance of the rock to weathering, and in turn, it might be a useful measure of rock strength, in addition to the P-wave velocity, for many geotechnical investigations. Furthermore, it is likely that full waveform methods offer substantial advances for relatively little effort. In the vernacular, they constitute "low hanging fruit."

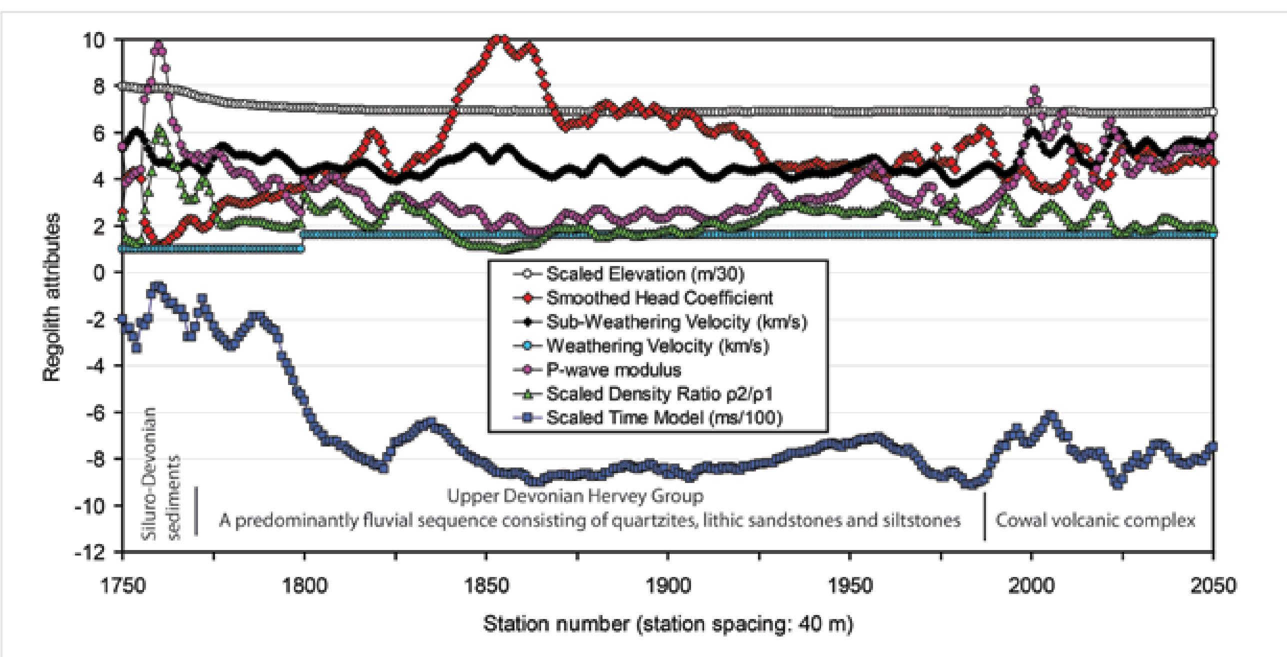

Figure 7: Summary of refraction attributes derived from traveltime and amplitude data.

In particular, the stacked RCS constitutes an extremely convenient approach for routine full waveform refraction methods. It is efficacious with moderate CMP fold, it preserves detailed structure (compare the small offset at station 1815 in the RCS with the stacked COG in Fig 5), and it is amenable to further processing, such as flattening and spectral analysis, both of which can facilitate the detection of faulting and fracturing.

Figure 8 demonstrates that the spatial resolution of a simple spectral analysis of the first few cycles of the stacked RCS is comparable to that of the 2D GRM WET tomogram, which accommodates dipping interfaces. Furthermore, the regions of pronounced low and high frequency attenuation, such as stations 1830 and 1980, correlate with regions of lower seismic velocities in the RCS (Palmer, 2010b, 2010e). *It is anticipated that narrow zones exhibiting pronounced attenuation of the higher frequency components may eventually prove to be a more reliable indicator of fractured rock for which there may be only relatively subtle variations in seismic velocities.*

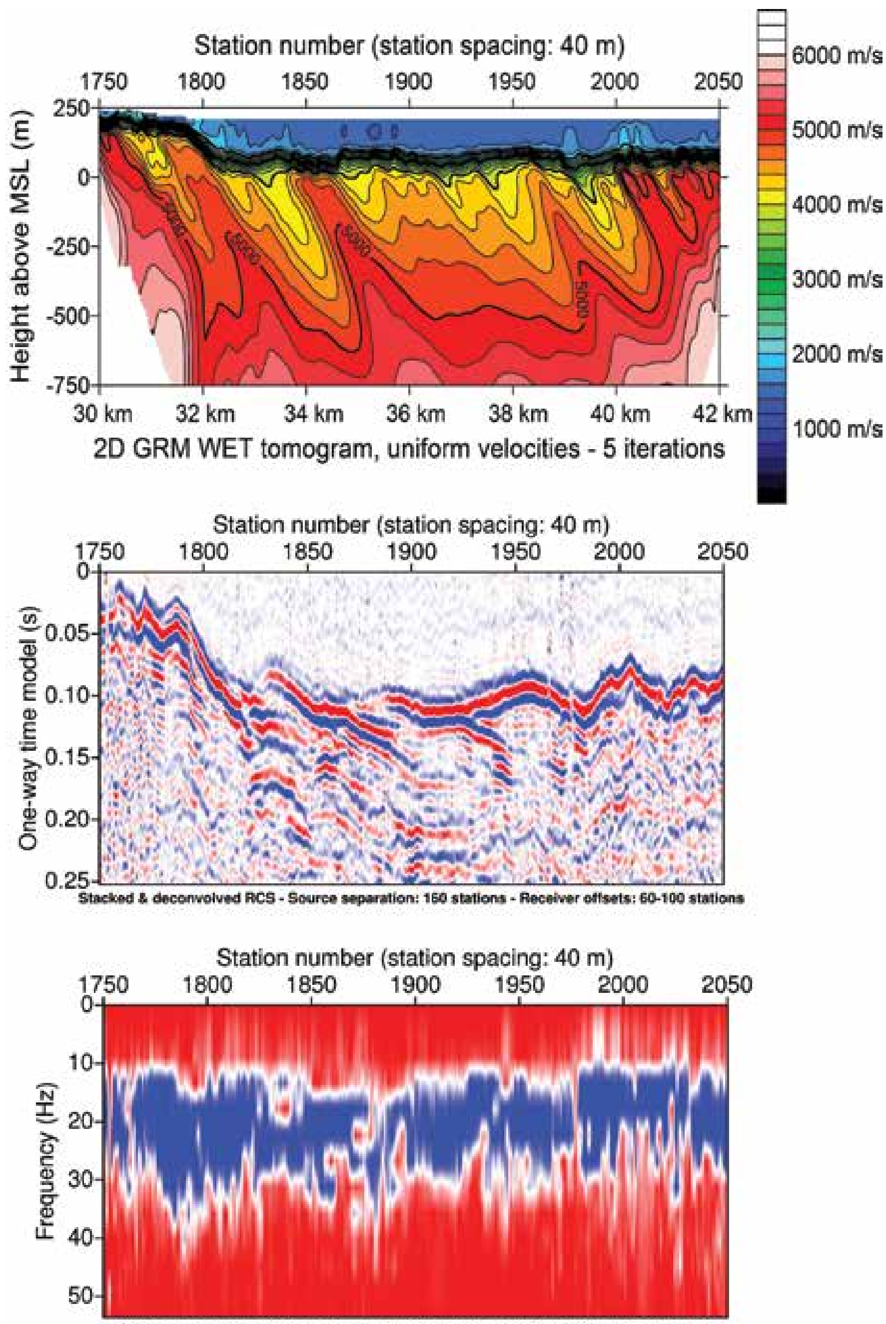

Figure 8: 2D GRM WET tomogram which accommodates dipping interfaces, the stacked and deconvolved RCS, and the spectral analysis of the RCS.

Improving Discovery with More Accurate Models

The Lachlan and numerous other case studies demonstrate that if a low resolution starting model is used, then the final result will usually be a low resolution tomogram. Only the most elementary of geological models are facilitated with the generally poor resolution of most default 1D tomograms. Whereas the sequence of alternating low and high seismic velocities in the sub-weathering in the 2D GRM WET tomograms in Figures 2 and 8 support a series of thrusts, only the most simplistic structural interpretation is suggested with the relatively featureless model of the seismic velocities in the 1D WET tomogram in Figure 2. Such low resolution tomograms do not facilitate exploration and discovery.

It can be argued that the widespread implementation of diving wave tomography has done little to reduce risk because it has not directly addressed the critical issue of generating more accurate tomograms. It has simply avoided the problem by producing a plethora of tomograms exhibiting the same familiar featureless horizontal layering, through the use of low resolution 1D starting models (Lamb et al, 2012). Such tomograms can facilitate complacency through expedient comparisons with bore holes (Brojerdi et al, 2014). Nevertheless, the low resolution tomograms are vigorously defended by erroneously employing misfit errors, which are a measure of the precision of the model parameters, as a measure of the validity or the accuracy of the model. It constitutes the wrong solution to the wrong problem.

The conversation must begin with the recognition of the difference between accuracy and precision. Accuracy is the measure by which the validity of any model is assessed. By contrast, precision is the measure by which the optimizing of the model parameters with model-based inversion is assessed.

It can be argued that non-uniqueness, whereby a multiplicity of models can exhibit comparable precision, constitutes the geophysicist's "elephant in the room." Misfit errors do not "prove" that any model is either accurate or "correct." Instead, misfit errors only demonstrate that the model parameters are consistent with the data. Accordingly, it is imperative that all exploration geophysicists routinely directly address the fundamental reality of non-uniqueness by explicitly demonstrating the range of models which can fit the data, that is, the model space (Palmer, 2015), and then validating the starting model selected, rather than characterizing the inversion process as being trapped in so-called "local minimums."

An essential component for explicitly addressing accuracy is the greater use of more effective methods of quality assurance. As a minimum, this study advocates the presentation of the starting model. Ideally, intermediate stages, which demonstrate the progressive evolution of the final tomogram, should also be presented. Furthermore, this study does not support the use of manual ray tracing methods, because of the lack of effective methods of quality assurance, as well as the fact that any model updates are usually made at the discretion of the practitioner, that is, they are not objective.

In addition to better quality assurance with Backus-Gilbert appraisal, this study strongly advocates the proper investigation of full waveform refraction methods. In short, the other 50% of the data, especially the amplitudes and the spectra, offer unrealized opportunities for substantially improving routine spatial resolution and characterization of the regolith, as well as addressing accuracy and validating the model.

The seemingly endless series of model studies, which seek to validate the routine use of refraction tomography in the near surface, are indicative of a profession which still has reservations with the technology. Notwithstanding, blind tests, such as Zelt et al (2013), demonstrate that the refraction tomography component, whereby the starting model is systematically updated, is both a mature and a reliable technology. However, such studies still fail to make a meaningful acknowledgement of the importance of the starting model. They fail to recognize either the distinction between accuracy and precision, or more importantly, the significance of non-uniqueness. The efficacy of refraction tomography will not be resolved definitively by digging the hole deeper with repeated tests of sets of traveltime data which represent ever more complex synthetic models. By contrast, most field data usually generate more realistic and more interesting challenges.

This study demonstrates the efficacy of various qualitative and quantitative traveltime and full waveform methods for both detailed model generation and model validation. Nevertheless, none of these or any comparable method is employed in any routine near surface seismic refraction operation. It can be concluded that most current implementations of near surface refraction seismology can be viewed as representative of a low resolution 50 year old technology, refraction tomography notwithstanding.

Can more accurate models improve discovery in near surface refraction seismology? The Lachlan case study, which exhibits both small and large scale variations in depths and seismic velocities in a moderately complex structural environment, demonstrates once again, that refraction tomography does not automatically converge to a single “accurate” high resolution tomogram. Instead, it demonstrates that if you do not look for it, then you will not find it! It can be concluded that it is past time to place greater emphasis on accuracy and model generation, in order to facilitate more effective exploration and discovery.

Acknowledgements

The data used in this study were recorded by Geoscience Australia in conjunction with the Geological Survey of New South Wales, and are now on open file. I am grateful for the support provided by the Geoscience Australia personnel, especially Leonie Jones, Tim Barton and Bruce Goleby. Furthermore, special recognition is due to Barry Drummond for his leadership in championing deep crustal seismic studies. I thank Leonie Jones for the processed seismic reflection section in Figure 5.

Editor's Note

Dr. Palmer has provided the Lachlan traveltime dataset to *Fast*TIMES, and those wanting to obtain an electronic file of this dataset should contact Barry Allred (Barry.Allred@ars.usda.gov).

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COMPARISON OF TWO GPR SURVEYS WITH DIFFERENT GRID SPACINGS TO IDENTIFY UNMARKED GRAVES IN A 19TH CENTURY CEMETERY AT SNYDER COUNTY, PA

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Abstract

Ground-penetrating radar (GPR) is a geophysical survey tool with many archaeological applications, including the search for graves. A 400 megahertz GPR was employed to locate unmarked graves and buried headstones in a neglected Pennsylvania cemetery dating from the 19th century. The site was initially scanned using a grid pattern with 50 cm spacing transects. A smaller site within the cemetery was then selected and scanned at 30 cm spacing transects to determine whether or not this will improve the accuracy of the findings. Supplementary perpendicular transects were added in the second case. A number of potential sources of error were identified and their consequences were outlined. The additional orthogonal transects improved significantly the quality of the data. Optimal data were obtained from tightly-spaced transects drawn short, as longer transects tended to introduce a "shifting" effect which reduced data quality and produced the illusion of supernumerary graves. The results are applicable to the search for graves and, more broadly, the use of GPR to identify and locate other subsurface features.

Introduction

Ground-penetrating radar (GPR) is a non-invasive method of geophysical investigation that provides information on subsurface discontinuities including buried objects, soil disruption and void spaces. The process of surveying a site is not time consuming, and even large grids can often be scanned in less than a day. Traditionally the site under examination is divided into a grid, with transects spaced at relatively small distances usually less than one meter (Conyers and Goodman, 1997; Conyers and Cameron, 1998; Conyers 2006). The GPR antenna is often mounted on a wheeled cart and drawn along transects across the ground (Doolittle and Bellantoni 2010). An attached 'control unit' displays the raw data and allows the user to manipulate operational parameters for better imaging. The GPR system is generally used with a survey wheel yet when the exploration is performed over a large area; a GPS is a better choice.

Keywords: Ground-Penetrating Radar, Geophysical Techniques, Unmarked Graves, Burial, Cemetery.

The radar antenna emits a pulse of electromagnetic energy, some of which travels into the ground and is reflected back to the antenna due to differing electromagnetic properties between the soil and a buried object (Fiedler et al. 2009; Watters and Hunter, 2004; Ruffell, 2005). A greater difference in electromagnetic properties produces a stronger reflection and a more apparent signal on the radargram (Doolittle and Bellantoni 2010). Reflections are recorded mainly as hyperbolas, with the peak of the curve indicating the approximate location of the buried object. A single hyperbola, however, supplies little data on the geometry or orientation of the object below the ground. Multiple transects are needed to construct a pseudo three-dimensional image of the subsurface using computer software and thereby determine the size and shape of targeted objects.

The GPR device transmits electromagnetic pulses and measures their two-way travel time (TWTT) elapsing between the surface to a targeted object buried in ground and back to the surface. TWTT varies depending upon a number of factors, including the dielectric permittivity (ε) of the surveyed material. This factor is most strongly controlled by water content in the soil (e.g. Topp et al. 1980). It varies also upon the subsurface continuity of the soil: the extent to which it has been disturbed and the amount of 'noise' or interfering background objects such as sizable stones, large roots or any other item with significant dielectric discrepancy (Lunt et al. 2005).

The TWTT data, stored as radargrams is converted to depth using computer programs to enable interpretation of the data and modeling of the site (Conyers 2006, Schmelzbach et al. 2011). A survey wheel or GPS device are used to correlate observed features on the radargram to their exact location. This correlation is used to produce three-dimensional images and models of the study area's subsurface features, which can be of great use to archaeologists (e.g. Bevan 1991, Nuzzo et al. 2002).

A GPR practice has a wide range of applications, including infrastructure stability evaluation, groundwater flow monitoring, and paleontology (e.g. Saarenketo and Scullion 2000, Doolittle et al. 2006, Tinelli et al. 2012). Its portability and noninvasive nature have led to its increasingly widespread use in archaeological investigations since the 1970s (e.g. Kenyon 1977, Radar 1980). More specifically, it has frequently been deployed to locate unmarked graves in both archaeological and forensic settings (e.g. Fiedler et al. 2009, Doolittle and Bellantoni 2010). It is particularly well suited for locating graves, as under optimal conditions it is capable of discerning relevant details such as grave orientation, burial depth, and grave size (Conyers 2004). However, its effectiveness at locating graves is dependent upon a number of factors including soil type, climate, soil moisture, taphonomy and age of the burial and is thus highly site-specific (Conyers and Cameron 1998, Doolittle and Bellantoni 2010).

The present study focuses on a technique used to improve the identification of lost graves at the Sharon Lutheran Cemetery (SLC) of Selinsgrove, PA (Figure 1). This technique is based on the utilization of two different resolutions, or transects spacing, using a GPR survey with a 400 MHz antenna. The first survey consisted of parallel transects spaced 50 cm apart and oriented north-south across the entirety of the cemetery (62 m × 49.5 m). A second survey performed on a smaller lot (10m by 10 m) within the cemetery was later selected for experimental comparison. Grid transects in this lot were spaced only 30 cm apart. The combination of the two surveys proved effective in locating graves and headstones. The large survey provided better results in demonstrating the general layout and density distribution of the graves but introduced greater error in the form of transect shifting and proved less precise in identifying the sizes of the graves. The small-lot survey provided better insight on the exact limit of each individual grave and proved a valuable supplement to the first survey.

Two broad categories of reflections were apparent in the resulting data. The first, at the most shallow limit of the profile, was from the headstones which were either apparent at the surface or shallowly covered by soil. The second reflection was from the graves themselves, most of which are about 1 to 1.5 meters below the surface. These data enabled the location of headstones which were fully covered by soil, headstones which had shifted and thus no longer correctly marked the location of the internment beneath, and graves without any marker.

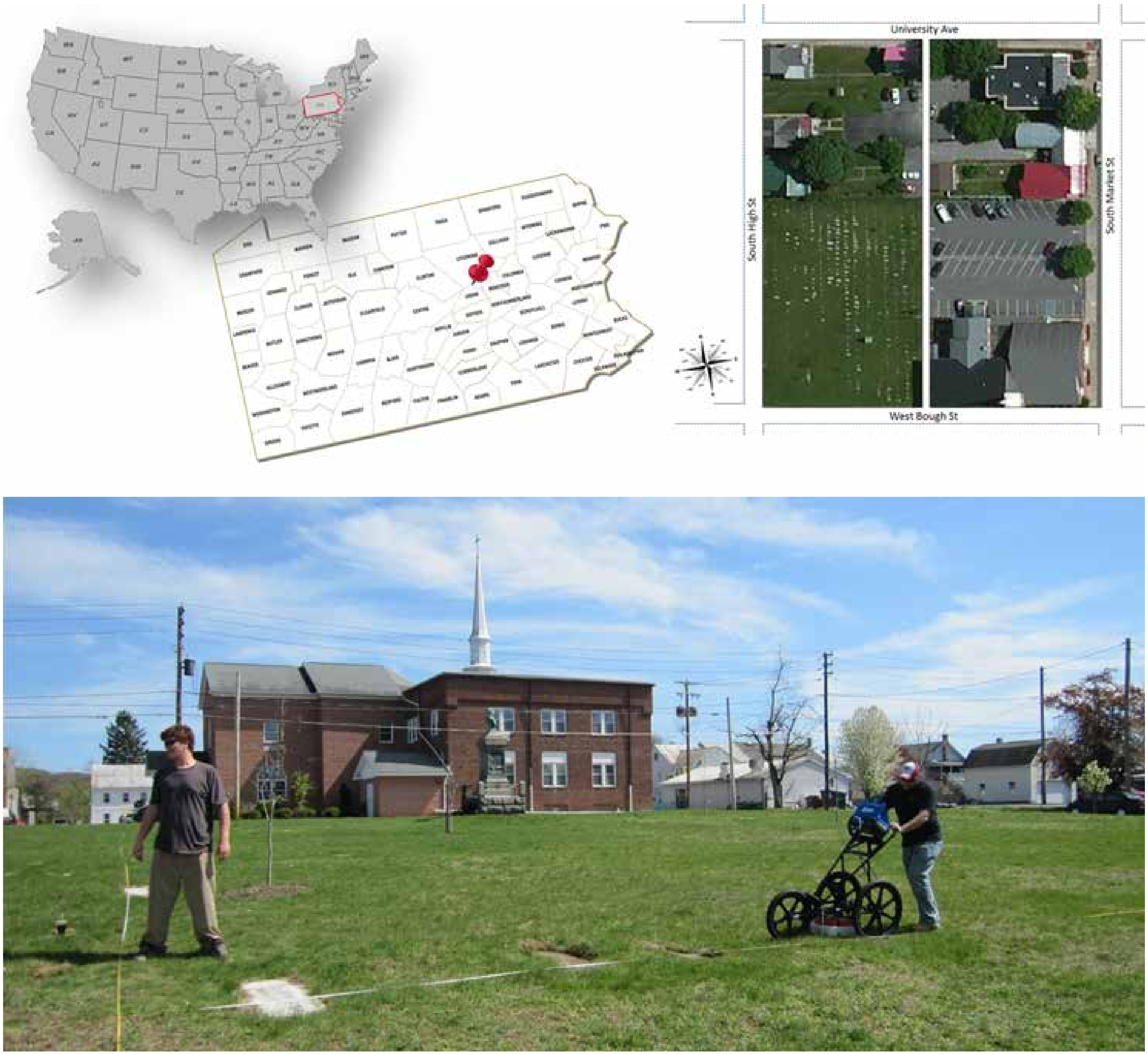

Figure 1: Sharon Lutheran Cemetery, Selinsgrove, PA.

Site History and Description

Sharon Lutheran Cemetery (SLC) is located in a suburban area and is bordered by streets on three sides and by housing to the north. The cemetery itself runs in a roughly north-south direction, while graves are oriented in an east-west direction with the foot of the burial slab pointed towards the east.

The deed for Sharon Lutheran Church was signed in 1800, and local records indicate that the original wooden church structure was built in 1803. This was torn down and replaced with a brick edifice in 1884. The following year, a monument to Governor Simon Snyder (1759 - 1819), after whom Snyder County is named, was erected in the cemetery. Aside from several small saplings, this remains the only standing structure in the burial field.

Many church records are fragmentary or nonexistent; burial records, of particular interest for this examination, could not be recovered. In lieu of verifiable records, a physical survey of the cemetery was conducted to map out headstones visible at the surface and to record names and dates of internment. Though imperfect (as many of the headstones have sunk beneath the topsoil or been lost entirely), this proved to be the only way of gathering data about the site's history.

The dates on visible headstones suggest that the cemetery was particularly active between 1801 and 1896, the date of the last apparent internment. Most of the headstones from the early 19th century are inscribed in German, reflecting the area's original European heritage. There is a transition from German to English inscriptions around 1830, after which the grave markers are primarily engraved in English. The cemetery reached an apparent peak of activity between 1852 and 1856, where the number of burials reached an average of 7 per year. The survey also revealed multiple clusters of burials by family name. Figure 2 illustrates the number of internments per year for the cemetery's full span of apparent activity.

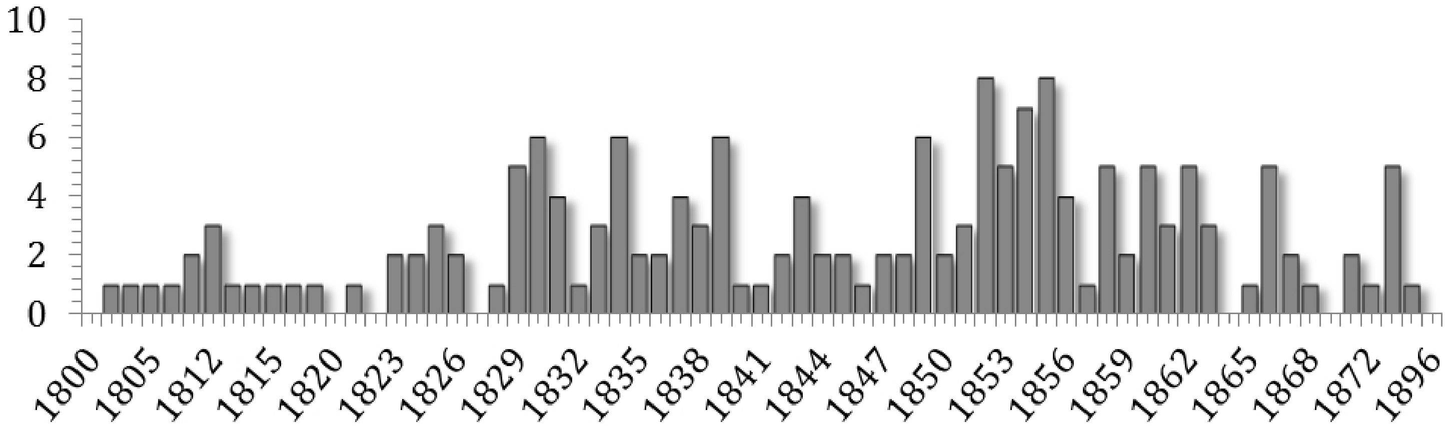

Figure 2: Chronological burial trend in the Sharon Lutheran Church cemetery.

Headstones in the cemetery appear to have originally stood upright. At some point all stones were laid down, in which position they remain. Interviews with church officials indicate this may have occurred at some point in the middle of the 20th century, when landscapers reportedly moved the stones out of the way in order to facilitate grounds keeping on multiple occasions. Some of the stones may have been shifted from their original locations at this time, and there is no way of verifying that all headstones correctly identify those interred beneath. If true, this may also account for some of the stones missing from the cemetery.

The first GPR survey, conducted at the request of the church pastor, was performed in three stages and was completed in April of 2012. The second GPR survey was performed in March of 2013 on a 10 m by 10 m testing area to determine whether 30 cm spacing between surveying lines would add more resolution to visualize the graves.

Materials and Methods

The Sharon Lutheran Church cemetery measures 62 m × 49.5 m. In the first survey, the graveyard was divided into three large, irregularly-sized grids and surveyed over the course of three separate days with scanning transects placed at 50 centimeters. This first survey was performed along parallel lines oriented north-south to intersect graves perpendicular to the long axis. A second survey was performed in smaller site (10 m x 10 m) with transects spaced at 30 centimeters, with the expectation that tighter transects would produce higher-resolution imagery. The second survey was performed along a grid with two sets of perpendicular lines. A 400 MHz GPR antenna with an SIR-3000 command unit was employed for all surveys. Data were collected using a cart with an integrated survey wheel encoder at an average of 512 samples per scan and 120 scans per second. Each sample consisted of 16 bits.

The dielectric constant of the soil was determined using a simple trial-and-error method. A subsurface headstone was located and its actual depth was determined using a probe. The spot was then scanned repeatedly. For each scan, a different dielectric constant was input into the command unit. The depth estimate of the buried headstone provided by the resulting radargrams was found to match known depth obtained via the ground probe when a dielectric constant of 8 was used. This value was henceforth utilized for the following surveys.

The first survey (Site 1) consisted of a 31 m by 49.5 m grid which covered the northern half of the cemetery. The second half of the site was divided into two segments measuring 31 m by 31 m (Site 2) and 31 m by 18.5 m (Site 3) (Figure 3). All segments were scanned using 50 cm transects. A total of 199 scans (101 on Site 1, 37 on Site 2 and 61 on Site 3) were collected. Only north-south parallel transects were drawn in the first survey. Separate 3D models were created for the interpretation of data for each section of the cemetery and in the end a super 3D grid combining all three sections was produced.

To provide a point of comparison, and to more precisely determine the ideal transect spacing for an archaeological investigation of this type, a second survey was carried out in later time. This second survey was performed over a small experimental 10 m^2 site and located within Site 1 of the first survey (Figure 3). Reflection transects were drawn more tightly-spaced for a total of 68 profiles within the grid. East-west transects were also performed, bisecting north-south transects, in order to further pinpoint the boundaries of the graves and buried headstones.

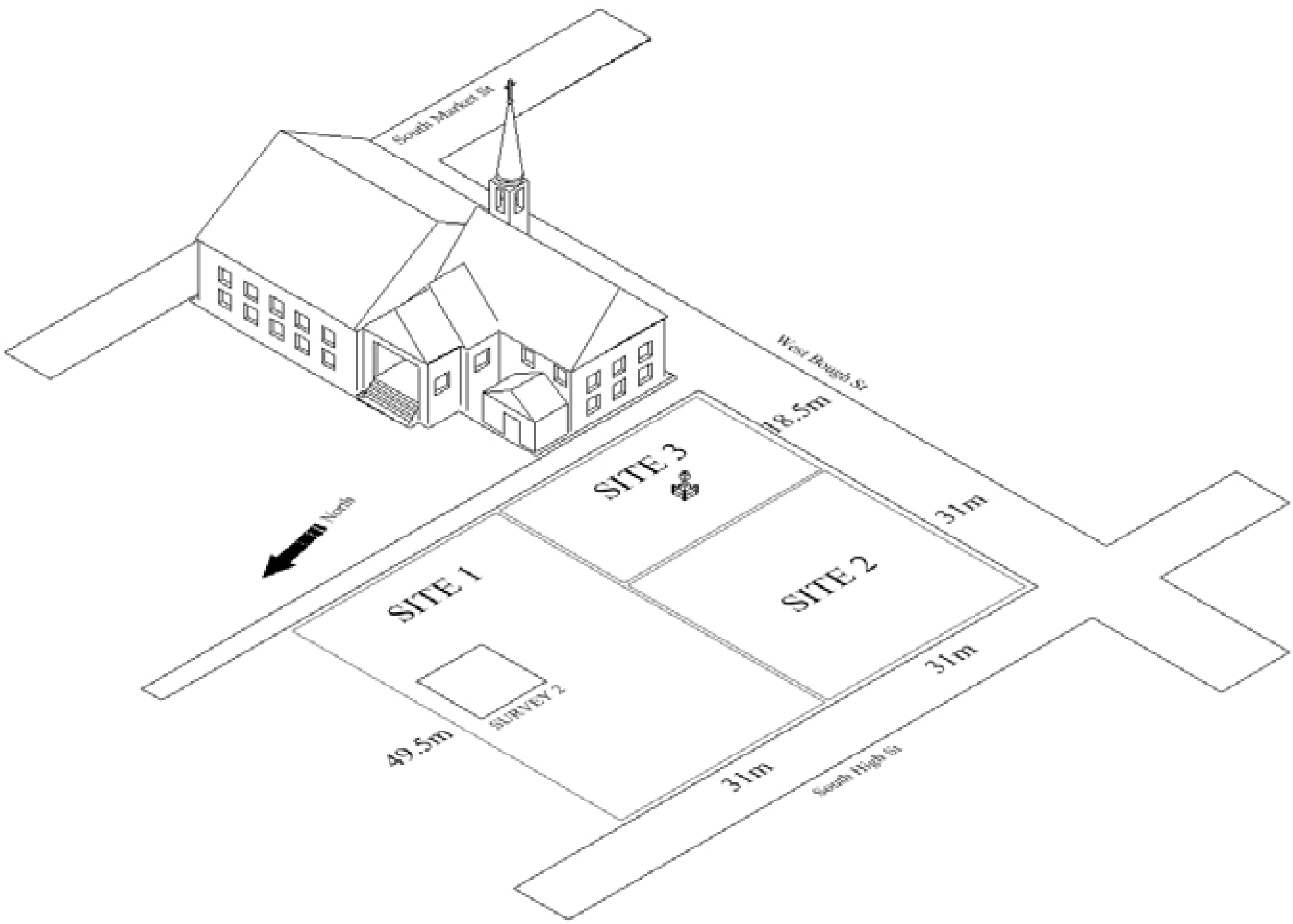

Figure 3: Drawing of Sharon Lutheran Church showing the first GPR Survey with the three sites surveyed taken at 50 cm spacing and the 10×10 m^2 site of the second survey within Site 1.

Radargrams were processed using RADAN-7 by GSSI and the GPR Viewer software (Conyers, 2013). GPR Viewer was developed by United States Geological Survey in cooperation with the University of Denver and the U.S. Army Corps of Engineers for the purpose of viewing, manipulating and processing GPR reflection data. It has been updated several times and is now written in C language compiled with Visual Studio 2008.

All transect profiles were compiled into a three-dimensional image, and the 3D models of the cemetery was created using Quick3D collection mode on the SIR-3000 unit. Additionally, a row of graves marked by visible headstones at the surface were selected and counted to verify the GPR-generated map after the data collection.

Results and Discussion

The combination of the two GPR surveys designed for this study proved to be an effective geophysical technique in identifying the unmarked graves in SLC. The contour map from the three sites of SLC, generated using transects spaced at 50 cm, is shown in Figure 4. The overall density of graves on the contour map is similar to that seen in the aerial photo of the cemetery (Figure 1). The general paucity of apparent graves in the southwest corner (Site 2) can be attributed to the age of this portion of the cemetery. The visual survey of the site suggested that the oldest graves, dating to the beginning of the 19th century, were located in this corner (Figure 2). These internments have had more time to collapse and settle; their dielectric properties have become more similar to that of the soil and thus they produce less of a reflection on the radargrams. In contrast, Site 3 in the southeast corner contained the most recent graves, some barely more than a century old. This explains the significantly bolder reflections on the contour map - the graves are less settled and therefore generate more marked hyperbolas. The apparently high density of graves in Site 1 is explained below.

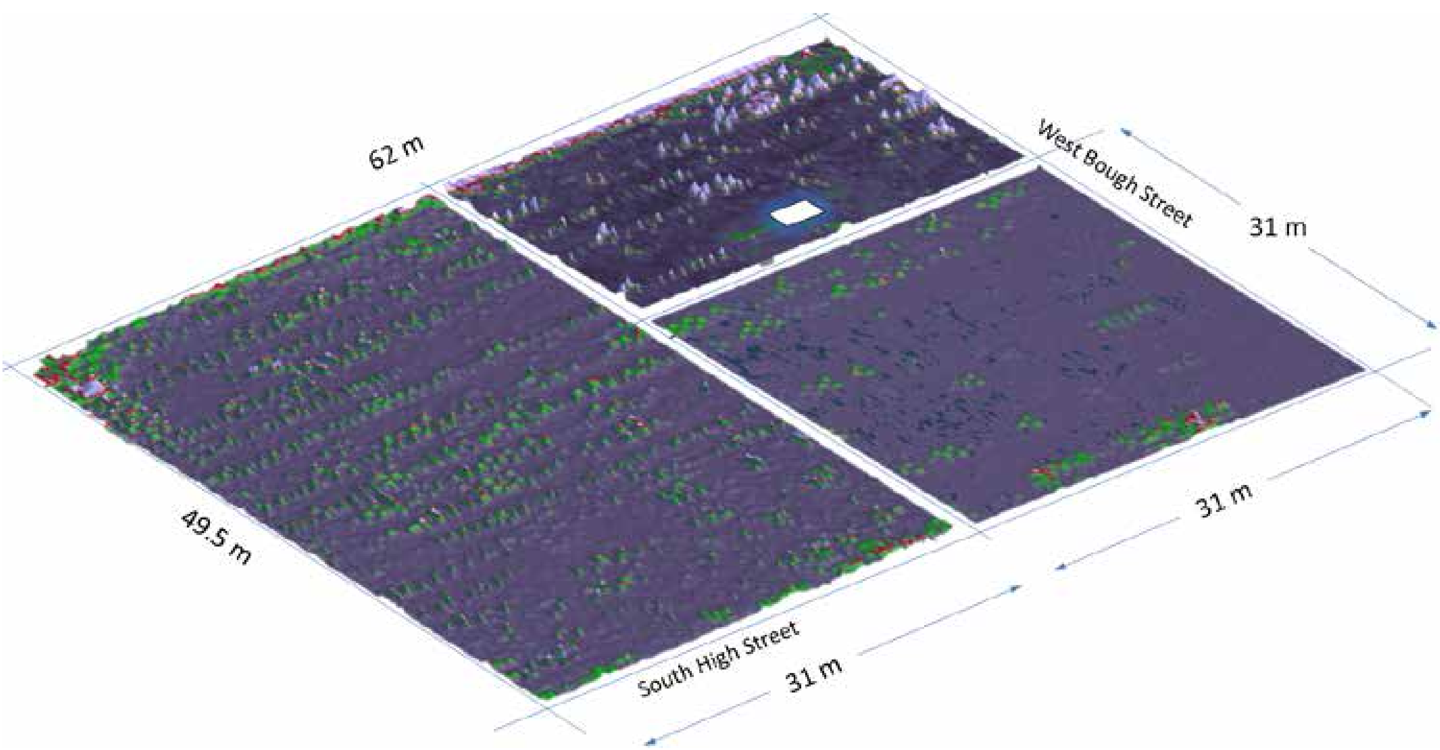

Figure 4: Contour map of the entire Sharon Lutheran Church cemetery generated using 50 cm spacing radargrams transects.

For this exploration, 201 transects were surveyed along the north-south direction (Figure 3). Radargrams of each survey line were analyzed individually and compiled in 3D diagrams. The results indicate that, in many cases, the grave marker has shifted and no longer accurately represents the location of the burial location and in other locations the grave marker has been lost entirely. Four cases were highlighted and summarized in Table 1 and illustrated in one of the radargrams, given in Figure 5. Though the initial survey performed with 50 cm spacing was proved to be sufficient to make several useful observations about the layout of the cemetery, the methods employed proved vulnerable to two conditions that altered the quality of the reflections.

TABLE 1: Summary of the four cases as identified by the GPR survey

Case 1:	Grave located directly beneath headstone
Case 2:	Shifted headstone, leaving grave unmarked
Case 3:	Headstone without grave beneath it
Case 4:	Grave present without headstone above

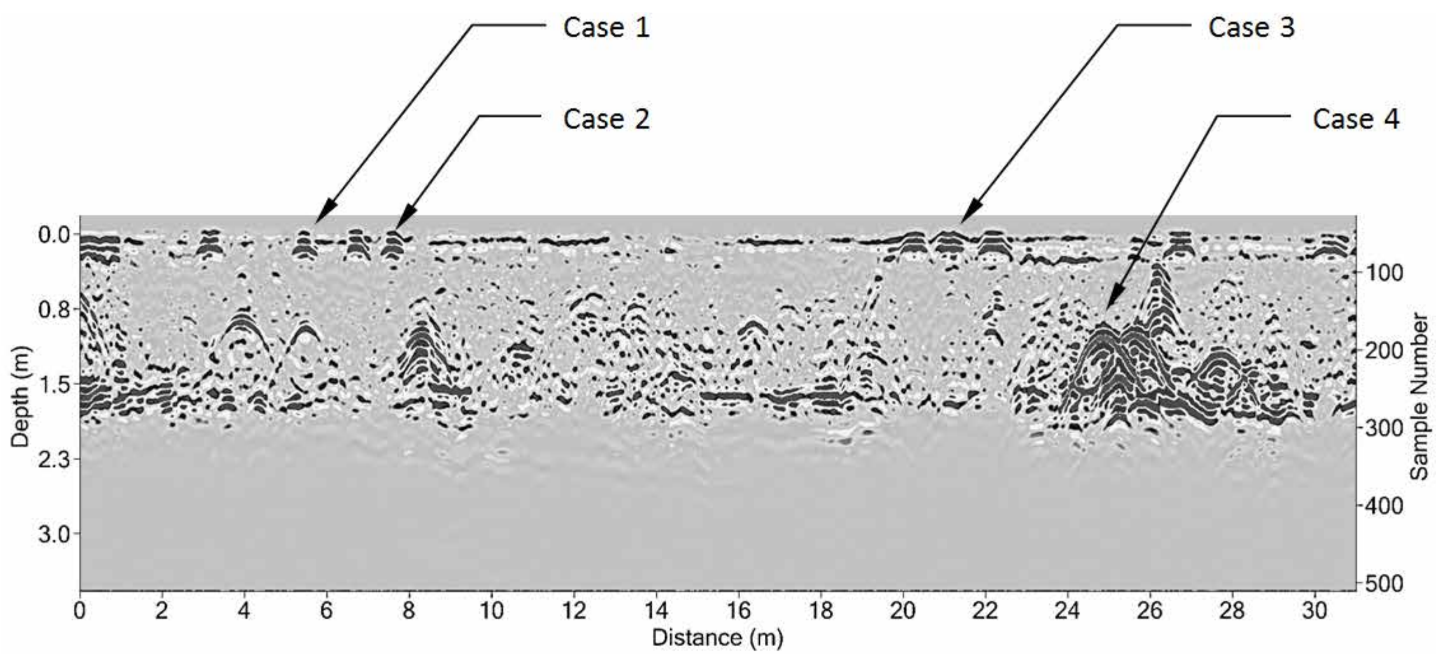

Figure 5: GPR Radargram showing the four cases presented in Table 1, a grave cluster and a buried headstone.

The first is introduced as the survey wheel moves along the uneven terrain of the cemetery. As the survey wheel rises and falls over small bumps and divots in the surface, it records different ground distances of the same straight lines with the same start- and end-points on the grid. Also, because the survey was performed in a zig-zag back and forth manner, the adjustment of individual transects to construct the 3D model caused some certain radargram profiles to be stretched which caused distortion and visible shifting in some areas of the 3D model. Consequently, if the cemetery is assumed perfectly flat, the interpretation of the 3D models and slicing through these models can lead to potential errors. In this case, the same grave scanned with multiple GPR crossings perpendicularly to its elongated position will generate multiple apparent hyperbolas shifted laterally. The interpolation of these hyperbolas by RADAN7 can make a single grave appear as two or even three visible segments in some cases which can be interpreted as individual graves (Figure 6). The extent of separation of these individual segments of a single grave depends on the degree of shifting which depends on the degree of terrain's roughness of the surveyed line. A perfunctory overview of the data can thus create the illusion of multiple objects or obscure the location of the target object in the subsurface. This was apparent in Figure 4, where the density of graves in Site 1 appears much higher than would be expected from an aerial photograph of the site. Many of these seeming 'graves,' however, are artifacts – the same internment split into two or three peaks due to the shifting effect.

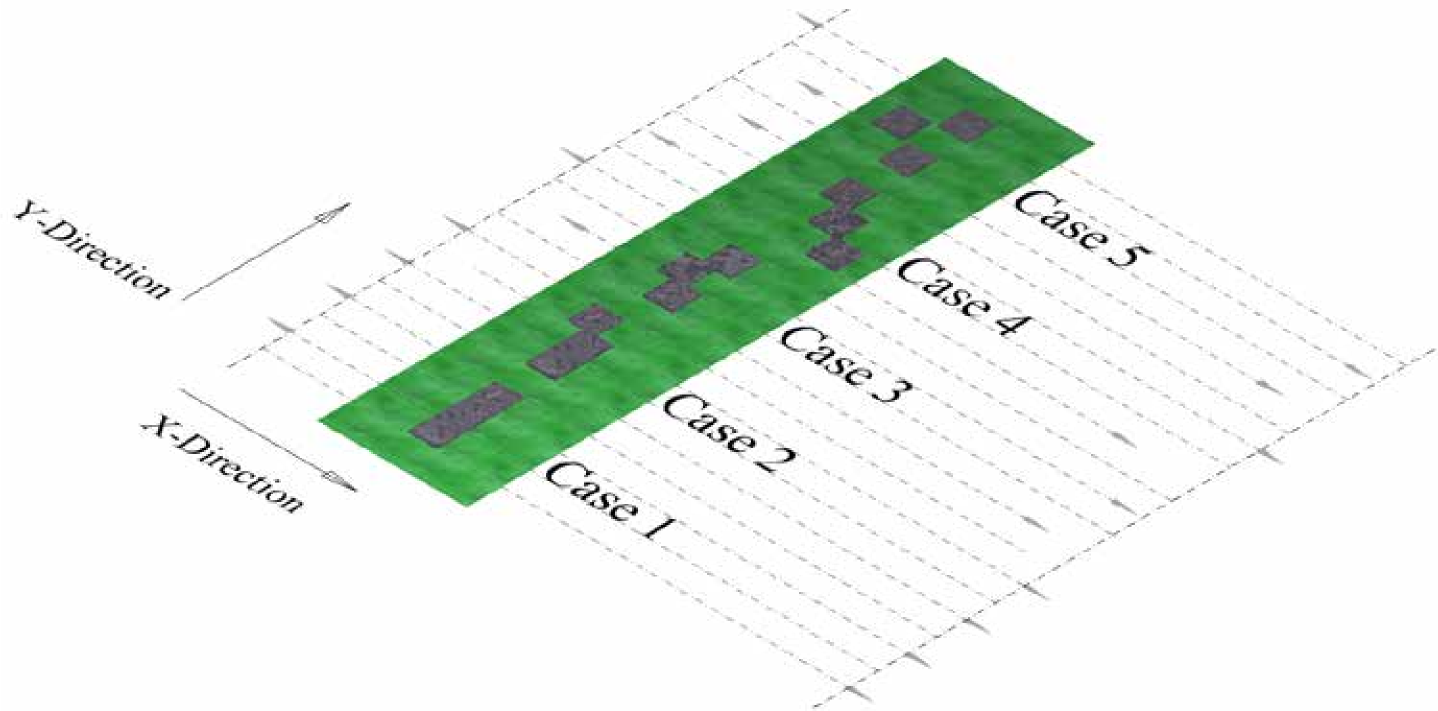

Figure 6: Sketch illustrating the observed shifting in longer GPR lines caused by the uneven ground-surface which makes parallel transects with the same start- and end-points appears to be different.

These artifacts may be negligible when the transect length is small, but become more significant as the length of the transect increases. Commercially available software, which automatically aligns the recorded transects by distance, can thus introduce considerable alterations to the dataset. Because only parallel survey lines were taken into consideration and these lines were perpendicular to the elongation of the graves, changing the spacing of transects did not help in reducing this error. Surveys with shorter survey lines (10 m as opposed to 49.5 m) and closely-spaced transects taken in the two perpendicular direction were found to work more precisely and tend to minimize this effect. The second influence arose from the spacing of transects. Results of this study have shown that more narrowly-spaced transects alone enabled more precise delineation of the graves and provided more details. Furthermore, the addition of perpendicular survey lines has improved this precision. The 10 by 10 m^2 survey was performed with 30 cm spacing and a same number of equally-spaced survey lines were taken perpendicular to create a 3D diagram. This procedure improved the precision and eliminated the shifting effect observed in the large survey (Figure 7)

The shifting effect was negligible in the 10x10 m^2 survey test. With the survey wheel covering smaller distances, errors introduced by the uneven ground do not amount to a significant deviation from the estimated transect length. The number of graves and headstones visible in the contour map matched the visible headstones. Headstones visible at the surface were found to align precisely with their locations on the map, and no phantom graves were found to have been created due to shifting. This stands in contrast to Figure 4, which shows more artifact graves.

The 3D survey completed with 30 cm spacing provides a better methodology of identification of the unmarked graves. The addition of the second set of perpendicular lines makes it easy to identify the graves than if it was scanned by just one set of parallel lines. This is significant. It is possible that the graves not currently visible in Site 2 and which appear entirely lost would be detected if a small survey was performed with small intercrossing transects.

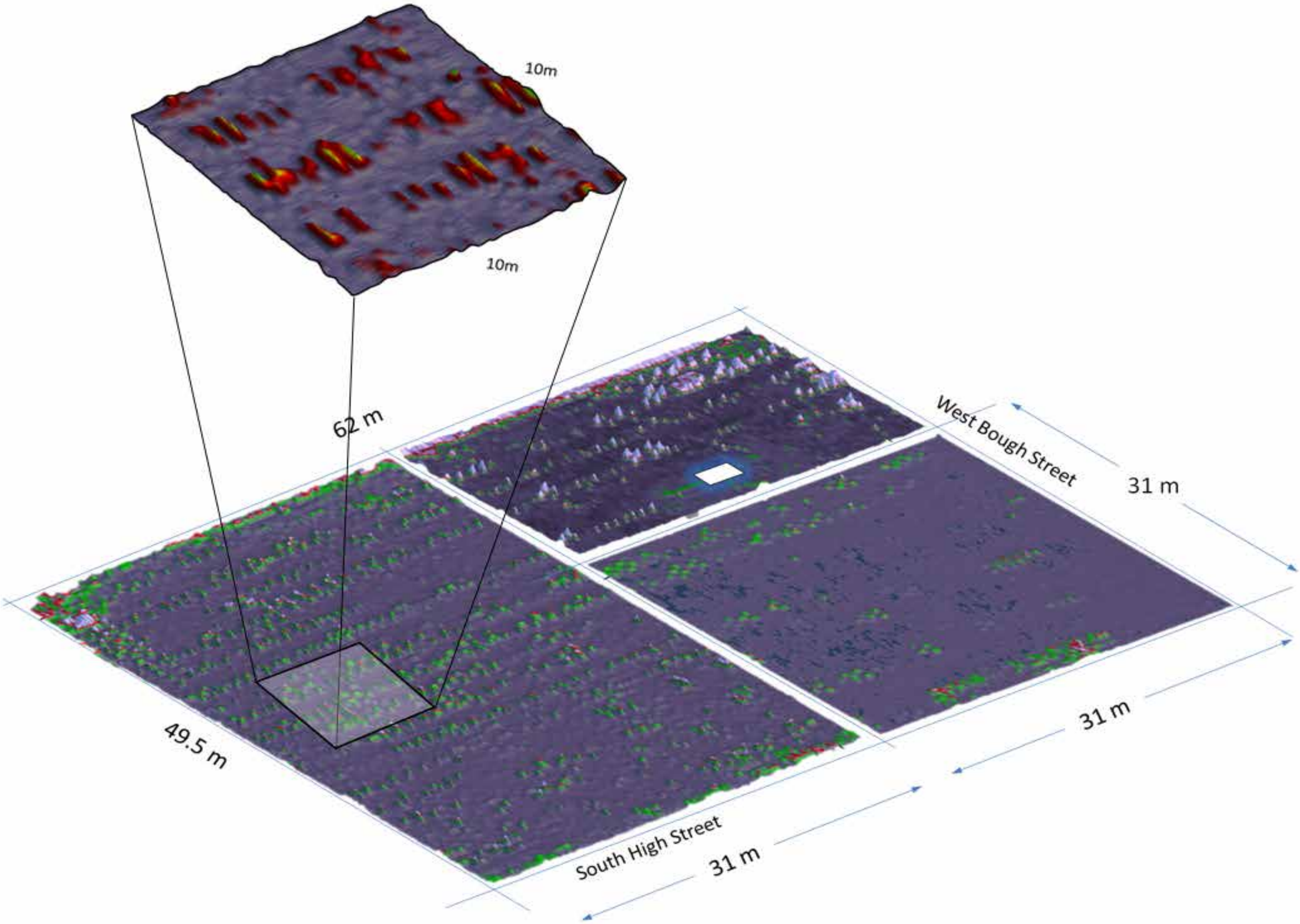

Figure 7: 3D contour maps of the two surveys generated using 50 cm spaced parallel lines (bottom map) and 3D grid survey in which transects were spaced at 30 cm (upper map).

Conclusion

GPR surveys performed in SLC were successful in pinpointing the location of a number of unmarked or mismarked graves. Survey 1, broken into three uneven sites with scanning transects spaced 50 cm apart, produced a large-scale contour map of the cemetery's subsurface features and indicated the locations of unmarked graves, buried headstones, and graves whose headstones had shifted. It proved vulnerable to two conditions - namely, 'shifting' in the radargrams introduced by the effect of uneven terrain on the survey wheel and the spacing of transects.

More narrowly-spaced grid transects, performed in Survey 2 were found to produce more precise imagery. Adding perpendicular transects was found to further improve the resolution of the resulting contour map; however, this had no effect on the 'shifting' noted above. Only shortening the length of transects, as in Survey 2, was found to ameliorate this influence. Longer GPR transects are therefore not recommended in rough terrains unless specific independent steps are taken to locate the instrument along the line and therefore ensure precise correspondence between collected data and physical topography. This becomes more important when the goal of the survey is the creation of 3D diagram. In this study a 31 m long transect shows shifting of individual radargrams in the contour display (Figure 4). This phenomenon is less visible in the 10 m^2 small survey test (Figure 7). Decreasing the space between transects was found to be useful yet less significant factor when compared to the length of transects. These results suggest that parallel scans should be employed alongside perpendicular scans as a supplemental mode of data analyses.

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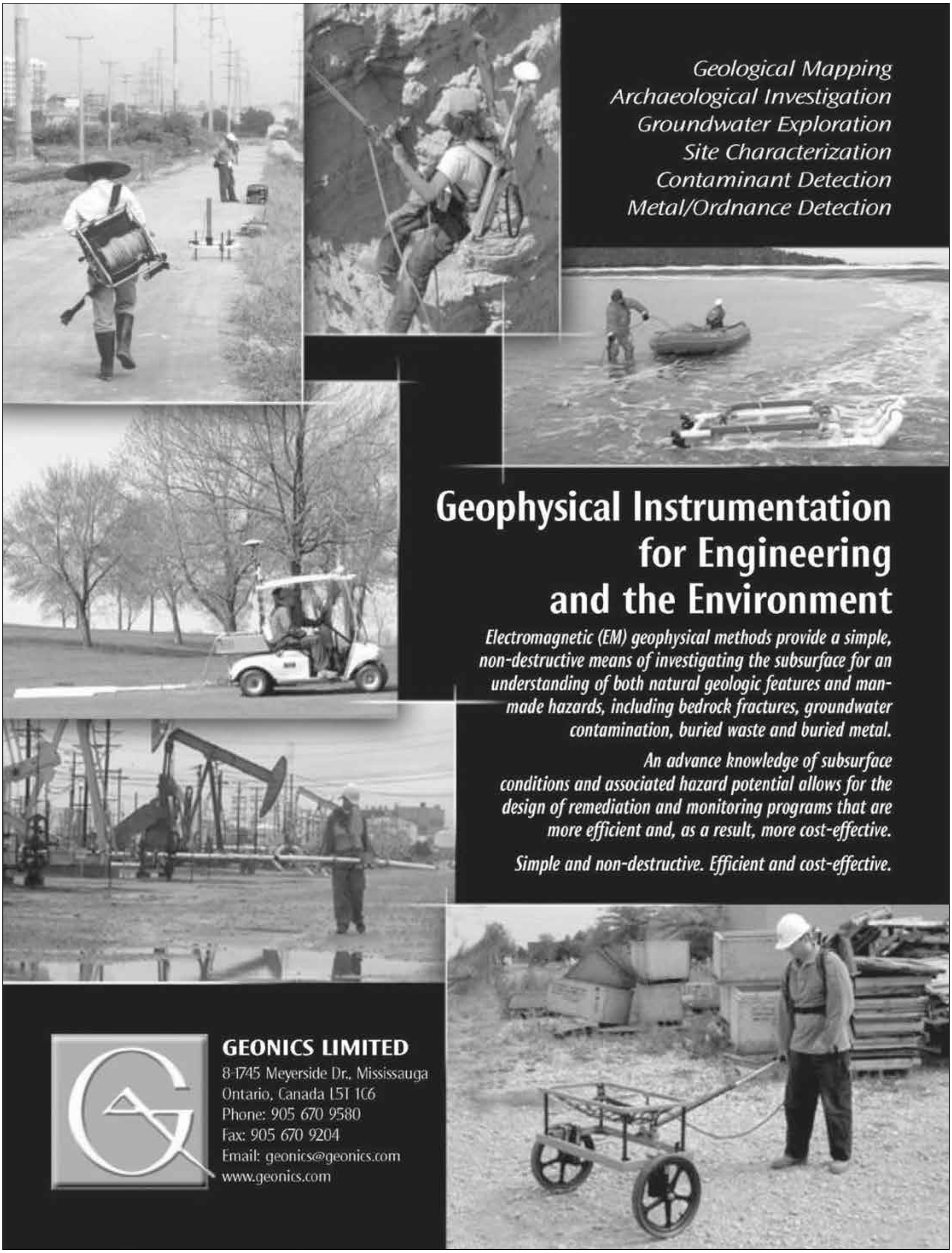
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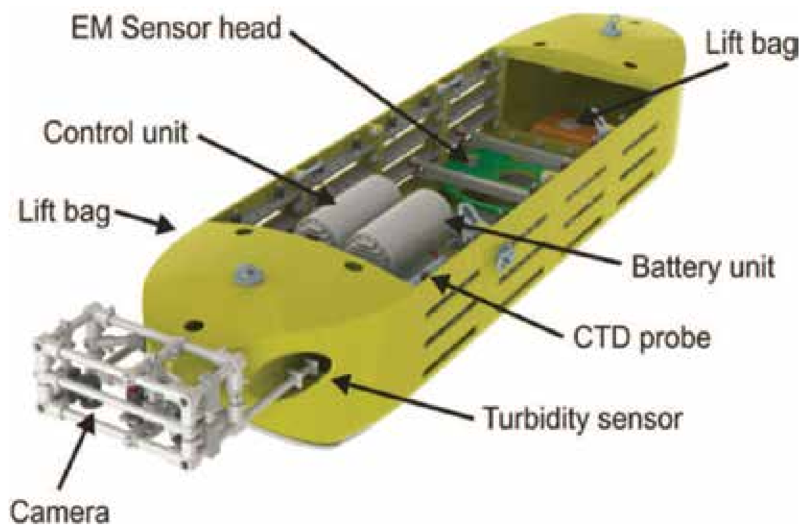
Geophex sensor returns to the sea

The world's largest frequency-domain EM undersea sensor is returning to the Indian ocean in October 2015 to continue its mission of discovering and mapping seafloor massive sulfides deposits. These deposits, which precipitate from hydrothermal vent systems on the ocean floor, contain high grades of valuable metals such as copper, gold, silver, and rare earth elements.

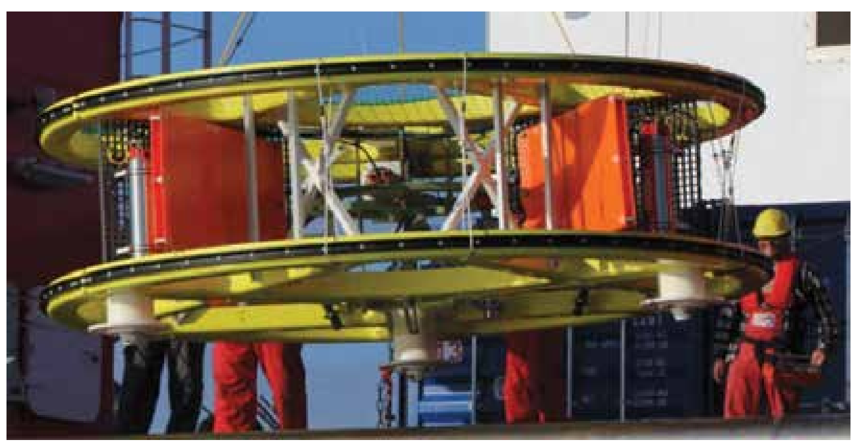
Working with the University of Bremen (Germany), Geophex had previously designed and built an EM sensor for the University's NERIDIS III benthic profiler sled (right).



NERIDIS III

Geophex provided a 1-meter diameter fiberglass coil assembly containing the transmit, bucking, receive and reference coils typical of our GEM-3 instruments. The coil assemblies are built to withstand undersea pressures without additional protection. The electronics were housed in a separate pressure vessel.

The new instrument, dubbed the Golden Eye deep sea electromagnetic profiler, is much larger. It was developed for the University of Bremen and the German Federal Institute for Geosciences and Natural Resources (BGR) to perform Controlled Source Electromagnetic (CSEM) imaging at depths of up to 5,000 meters.

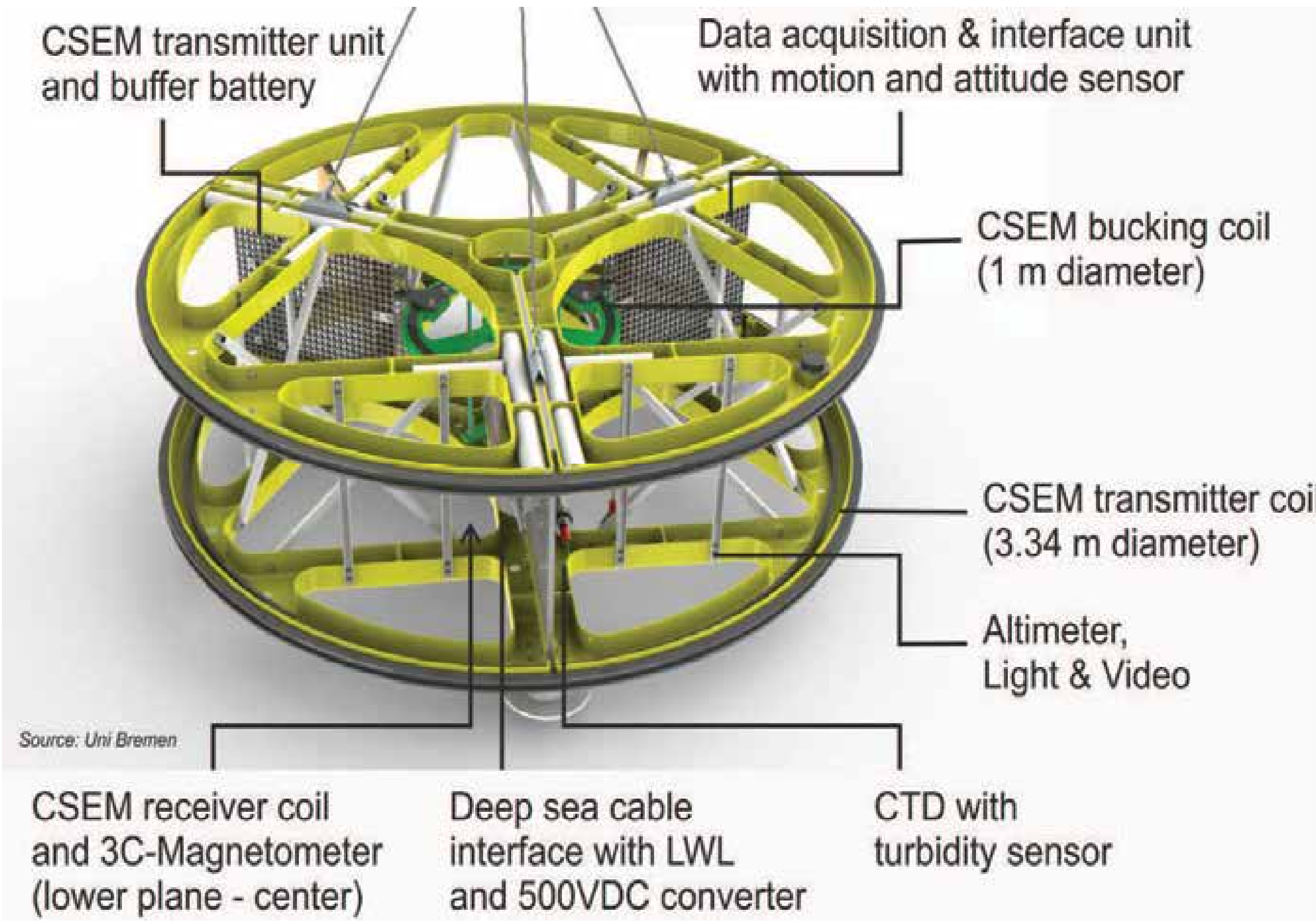


Goldeneye being launched

The Golden Eye lands on the seafloor, or glides with just above it, to allow high resolution EM mapping of electrical conductivity and magnetic susceptibility of the subsurface. Several frequencies between 15 Hz and 20,000 Hz can be combined and jointly inverted to resolve the resistivity structure of the topmost 5 to 10 meters below seafloor. More information on the University's marine electromagnetics program can be found at www.geophysik.uni-bremen.de

The Golden Eye sensor, like the NERIDIS III and a previous undersea sensor developed for KIGAM (Korea Institute of Geoscience and Mineral resources), uses Geophex's patented GEM-3 sensor configuration. The transmitter winding is wired in series with a separate 'bucking' coil. The bucking coil creates a localized field of opposite polarity which cancels out the main transmit field in the vicinity of the receive coil, allowing the use of a highly sensitive receiver.

The sensor, which is primarily made of fiberglass components, can be disassembled for transport. The upper and lower discs (yellow) are bolted together with non-conducting rods, panels and fasteners. The discs themselves are made up of three sections that can be disassembled. The pressure vessels containing the various electronics are mounted vertically to minimize their electromagnetic influence. The transmitter coil is made up of 8 turns of wire which are wound onto the structure after it has been assembled.



For more information on custom EM sensors for air, land and sea, contact Geophex.

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INDUSTRY NEWS

New Cableless Seismograph from Geostuff

Geostuff is introducing the AnySeis™ seismic system that operates without cables. This will give the geophysicist the flexibility to operate at any geophone spacing, with any number of channels, and in any configuration. The system consists of a number of integrated modules containing the geophone, analog-to-digital converter, telemetry and power circuitry in a compact package. The units connect with a simple, two-conductor wire which can be speaker wire or AC lamp cord.

Standard geophone cables are costly, difficult to repair, and especially limited by their fixed station spacing. Having a fixed number of takeouts makes it cumbersome to do rollalong. The AnySeis™ eliminates all the problems common to the multi-conductor cables. In addition, the AnySeis™ makes it easy to cross roads, streams, and railroad tracks.

The two-conductor wire connects to the module at any point on the line through a pair of steel pins called a "vampire tap" at any point along the line. For CMP surveys, a few of the units can be moved from the beginning to the end of the line, eliminating rollalong switches and extension cables.

Under development for over five years, the system uses an industry-standard, 32-bit converter, meeting the quality requirements expected of a modern exploration seismograph. A variety of geophones can be supplied with the unit, from 2 Hz to 40 Hz, and they can be field replaced by the geophysicist to support multiply survey applications. The standard 15-Hz can be used in vertical or horizontal orientation. Because it eliminates the cost of seismic cables, the system is price competitive with conventional systems.

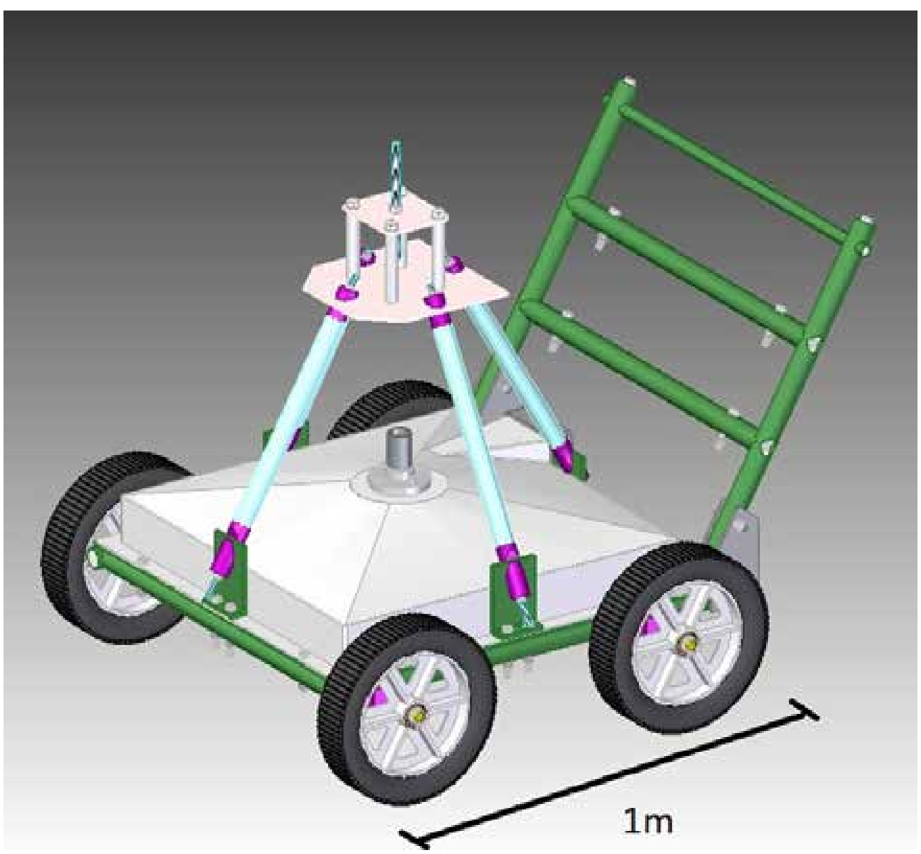
For more information on the AnySeis™, go to www.geostuff.com. For a thorough discussion of the benefits of eliminating geophone cables, watch this PowerPoint at http://geostuff.com/AnySeisPPT.pdf.

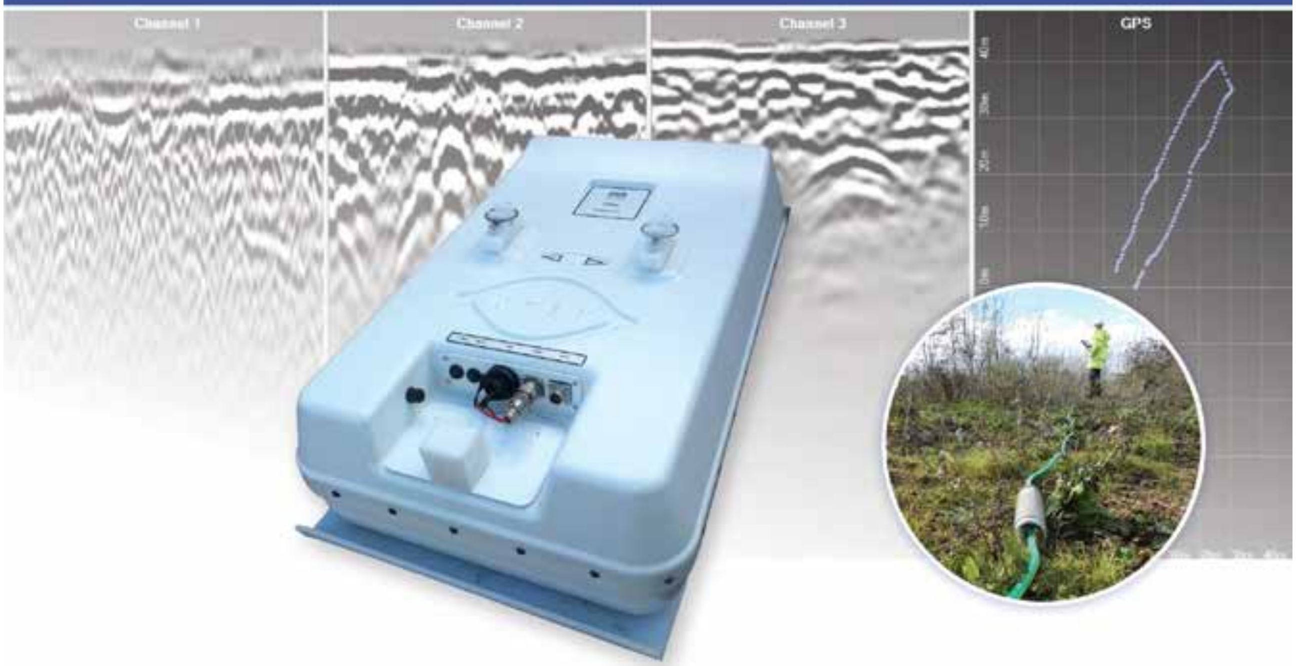
Geometrics Introduces New XTEM TADS 2x2 Instrument for UXO Surveys

The Geometrics XTEM TADS 2x2 is the successor to the Geometrics MetalMapper. Both systems use advanced electromagnetic induction sensors to distinguish unexploded ordinance (UXO) from scrap metal. These innovative sensors, which have been developed and demonstrated over the past 15 years by government and private organizations, could save billions of dollars in unexploded ordinance cleanup costs at former training ranges. Before the use of these advanced EM techniques, a munitions site was mapped with a metal detector and all detected metallic objects were investigated by digging. Previous studies show that less 1% of these objects were UXO items of interest. The majority of what was dug is scrap metal, bits of shrapnel, or trash. The advanced EM technique used by the XTEM TADS 2x2 and MetalMapper allow geophysicists to identify UXO targets of interest among the scrap, significantly reducing the amount of items which are investigated by digging. This reduction in digging translates to a large cost savings for the project.

The XTEM TADS 2x2 builds on the success of the MetalMapper by offering a smaller, lighter, and easier to deploy geophysical platform. The electronics and cables have been upgraded to more reliable and rugged geophysical instrumentation standards. The system can be deployed as a man-portable unit or as a vehicle-towed array. The new acquisition software is designed to be easy to operate on a tablet PC or laptop. Data files are written in an open-source HDF5 format. These files are easy to integrate with the Geosoft Oasis Montaj package used for data inversion.

The XTEM TADS 2x2 instrument will be ready for customers in early 2016. For more information including case studies and pricing please contact the Geometrics EM Sales team at EMSales@geometrics.com.





Geomatrix Earth Science Ltd is the European and US marketing agents for Utsi Electronics Ltd, a UK based Ground Penetrating Radar manufacturer. We are looking to establish a US sales agency to represent the full Usti Electronic GPR range in response to the release of the new multi-frequency Ground Penetrating Radar (GPR) system called Trivue.

Trivue comprises three bistatic bow tie antenna (250MHz, 500MHz and 1GHz central frequency) oriented around an identical common mid-point, and housed within a light weight rugged casing no larger than a standard 250MHz bowtie shielded antenna.

With a bandwidth of 125MHz-2GHz the system analyses the subsurface in great detail and ensures an operator is equipped for all eventualities.

The high pulse repetition frequency coupled with unique stacking functions permit the three different frequency datasets to be recorded without cross talk. The record length for each channel is selected independently, permitting the operator to have complete control over data acquisition.

All electronics are within the antenna and data is transferred via wired or wireless network to a Windows rugged laptop or tablet. The intuitive user interface and versatile display tools help an operator to quickly and easily analyse data in the field and implement quality control measures.

In addition to the Trivue Usti Electronics offer a flexible inline range of unshielded low frequency (15MHz to 80MHz central frequency) GPR systems for geological exploration. These systems offer real-time analogue to digital electronics for superior stacking capabilities. The receiver automatically identifies the pulse repetition rate, eliminating the requirement of a reference cable making recording WARR records for velocity analysis quick and simple.

For further information please contact matt@geomatrix.co.uk.

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Geophysical Survey Systems, Inc.

FOR IMMEDIATE RELEASE

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GSSI Announces D50 300/800 Dual-Frequency Antenna – Ideal for Utility, Archaeological and Environmental Surveys

GSSI, the world's leading manufacturer of ground penetrating radar (GPR) equipment, announces its new model D50 300/800 MHz dual-frequency antenna, ideal for locating a variety of metallic and non-metallic targets. The combination of two frequencies allows users to locate targets at depths of up to 7 meters (21 feet), making it a good choice for utility, archaeological and environmental surveys. GSSI antennas feature the highest signal-to-noise ratio of any antenna available in the industry, providing the highest quality data with clear and accurate results.

The 300/800 MHz dual-frequency antenna is GSSI's first digital antenna. Its typical range is 4 meters (12 feet), with a maximum range of 7 meters (21 feet). Weighing in at 12 pounds (5 kilograms), the antenna dimensions are 13.2x12.2x5.9 inches (33.5x31x15 centimeters.)

When used with GSSI's popular UtilityScan® DF GPR system, the innovative dual-frequency antenna and touch screen monitor together allow users to simultaneously view shallow and deep targets in a single scan. The UtilityScan DF also has new software features that allow users to input colored markers while using a GPS unit to aid in subsurface target classification.

The UtilityScan DF equipped with the D50 300/800 MHz dual-frequency antenna offers a non-intrusive way of examining the subsurface for such common environmental hazards as soil contamination, underground storage tanks and drums. This flexible equipment can also delineate landfills and pathways for contaminant flow, as well as conduct hydrogeologic investigations, including water table mapping.

###

About GSSI

Geophysical Survey Systems, Inc. is the world leader in the development, manufacture, and sale of ground penetrating radar (GPR) equipment, primarily for the concrete inspection, utility mapping and locating, road and bridge deck evaluation, geophysics, and archaeology markets. Our equipment is used all over the world to explore the subsurface of the earth and to inspect infrastructure systems non-destructively. GSSI created the first commercial GPR system nearly 45 years ago and continues to provide the widest range and highest quality GPR equipment available today.

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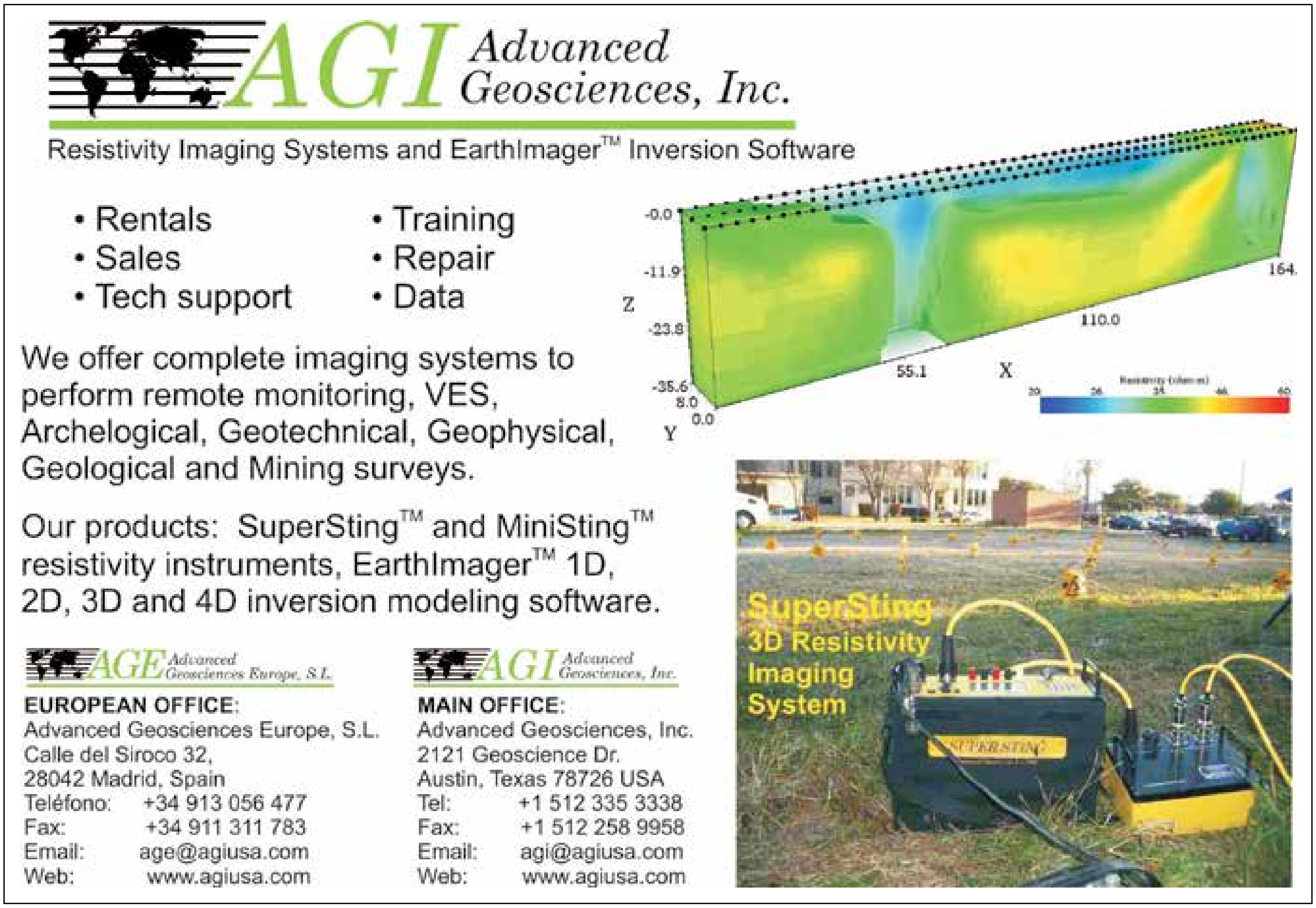
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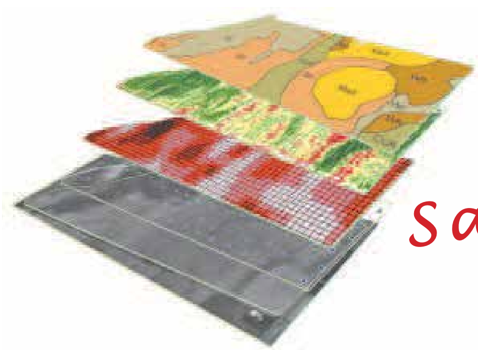

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COMING EVENTS AND ANNOUNCEMENTS

Call For Sessions:

Please send suggestions for possible sessions to Technical Chair Charles Stoyer, Interpex Limited, Golden CO, charles@interpex.com.

Planned sessions include:

APPLICATIONS FOCUS

Agricultural Geophysics
Archeological Geophysics
Engineering Geophysics
Geophysics and Geologic Hazards
Geophysics Applied to Water Resources
Geophysics in Climate and Critical Zone Studies
Geophysics for Contaminant and Site Remediation
Geophysics in the Oilfield: Contaminants, Water Demand, Induced Seismicity, and Hydraulic Fracturing
Integrated Near Surface Geophysics Case Histories
Material Property Measurements
Mining and Reclamation Geophysics
Non-technical Issues and Barriers to Applications of Geophysics
Polar and Planetary Geophysics
Transportation and Infrastructure Geophysics
UXO and UXO Sensor Technology

METHODS FOCUS

Airborne Geophysics, Remote Sensing, and UAV (Drone)-based Surveys
Borehole Geophysics
Electromagnetics and Magnetotellurics
Geophysical Database Management
GPR and EMI in Complex Environments: Emerging Concepts, Methods, and Data Analysis
GPR Instruments, Acquisition, Processing, and Analysis
Gravity and Magnetic Methods: Engineering and Environmental Applications
HVSR and Passive Seismology
Near Surface Geophysical Data Analyses, Integration, and Processing
Near Surface Geophysical Sensor Technology
Near Surface Geophysics across Hydrologic Interfaces: Imaging Hyporheic, Lacustrine, Shallow Marine, and Underwater Environments
Near Surface Seismic Reflection and Refraction
NMR for Near-surface Investigations (Development and Applications)
Novel Environmental/NS Geophysics Methods
Resistivity/Induced Polarization/Self-Potential Methods and Applications
Shallow Marine and Underwater Geophysics
Surface-wave Seismology for Engineering and Environmental Geophysics (Ken Stokoe Honorary Session)

Workshops planned:

Drones for Geology, chaired by Ron Bell, IGS Denver
Dams and Levees Summit, chaired by Willam E. Doll, Battelle

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COMING EVENTS AND ANNOUNCEMENTS

SAGEEP 2016 – Short Course

*GEO*DRONE*OLOGY*

Date: March 20th, 2016
Time: 8:00 AM to 5:00 PM
Location: Downtown Denver Marriott
Denver, CO
Short Course Coordinator:
Ronald S. Bell, President
Aerobotic Geophysical Systems, LLC

<u>Short Course Description:</u>

Small Unmanned Aircraft Systems (sUAS) equipped with lightweight cameras and geophysical sensors are rapidly emerging as the preferred tool for performing many of the data acquisition tasks commonly accomplished in surface and subsurface geological investigations. The advantages gained from the using these lightweight, low flying airborne robots are many ranging from increased speed acquisition speed, enhanced resolution, and access to remote locations to enhanced safety for field staff, huge data volumes, and repeatable surveys ultimately culminating in a dramatic reduction in the cost per data point. Advances in robotic and sensor technology as well as the evolution in the regulations governing the air space will undoubtedly create numerous opportunities for geoscientists to apply small UAS to the business of studying the environmental impact of human activity, advancing sustainable resource management initiatives, and spurring innovation in the exploration for extractable energy, minerals, and groundwater. The "Geo Drones" will be as important to the practice of geology as a rock hammer, a Brunton, and the drill bit.

This short course is designed to provide the participants with the latest information on small unmanned aircraft systems (sUAS), the state of the art in imaging and geophysical sensor technology, and the regulatory framework governing sUAS in addition to case studies about the application and use of sUAS for geoscientific data acquisition and geological mapping. There will be an emphasis on the practical implementation of drones for photogrammetry, multispectral and hyperspectral imaging, magnetometry, and electromagnetic conductivity mapping.

The short course will wrap up with a discussion on the issues and the likely future technology developments pertaining to application of drones for geology.

Who should attend?

<u>*Every*</u> practicing geophysicist, geologist, civil engineer, geotechnical engineer, project manager, or environmental scientist wishing to learn more about how to integrate airborne robots for geophysical data acquisition and geological mapping into their business or research activities.

COMING EVENTS AND ANNOUNCEMENTS

SAGEEP 2016 – Short Course

The Business of Operating Small Unmanned Aircraft Systems

Date: March 24th, 2016 – Thursday
Time: 8:00 AM to 5:00 PM
Location: Downtown Denver Marriott – Denver, CO

Short Course Instructor: *Bernd Lutz, Ph.D.*
CEO, bizUAS Corp

<u>Short Course Description:</u>

Small Unmanned Aircraft Systems (sUAS) equipped with lightweight cameras and specialized sensors are being used as a cost effective tool for asset inspections (e.g. utility power masts, solar farms, wind turbines, cell towers) as well as engineering and scientific investigations (e.g., surveying, point clouds, 3D modeling, atmospheric and environmental). This short course is designed to provide the participants with the latest information on:

- aircraft types and use cases,
- the practical aspects of aircraft operations,
- mission planning expectations and tips,
- post-processing of geo-spatial data a brief review of available cameras and sensor technologies,
- insurance requirements,
- how and where small UAS can be legally used,
- how to obtain a Certificate of Authorization (COA) for commercial purposes, and
- the requirements for piloting a sUAS in US airspace.

Who should register? Project Managers, geologists, geophysicists, civil engineers, geotechnical engineers, environmental scientists, and anyone wishing to learn more about using unmanned aircraft systems (UAS) for commercial industrial applications.

Course Agenda:

Introduction - overview of who will present and what we will be accomplishing
Small UAS - The types, capabilities, and limitations of small UAS; what to examine and expect.
The Sensors: a review of the cameras and other sensors adapted for use with sUAS.
The FAA: The basics of how and where to legally use UAS
Piloting a UAS: Mission specialists: the requirements and obligations of UAS operators.
Wrap up: The current issues and future developments.

Instructor Bio: *see next page*

COMING EVENTS AND ANNOUNCEMENTS

Instructor for SAGEEP 2016 Short Course:
"The Business of Operating Small Unmanned Aircraft Systems

BIO -- **Bernd Lutz, PhD**

Bernd is the CEO of bizUAS Corp (business Unmanned Aircraft Solutions). bizUAS is the North and South American distributor for service-drone, a German manufacturer of industrial-grade, mission-proven Unmanned Aircraft Systems (UAS). Using service-drone and other UAS platforms along with best-of-class sensors and supporting components, bizUAS develops and distributes commercial UAS applications for photogrammetry, inspections, and surveillance.

Bernd is a serial entrepreneur and technology visionary. Out of eight companies he has co-founded, seven were divested to strategic acquirers and one, Provide Commerce, did a successful IPO on the NASDAQ National Market at over $500M market cap. As an Angel Investor, venture capitalist, and consultant he has experienced the challenges of a dozen startups first hand. During his corporate career of over 20 years, Bernd held executive positions in enterprise software development, high-tech C-level management consulting, international capital formation and M&A, and cross-border business development with IBM, Sykes Enterprises, Intrado, Proflowers.com, and GVC Capital. Outside of high-tech, Bernd was involved in various projects in Mexico, South America, and India, incl. resort real estate development with Sera Resorts and establishing distribution channels for solar home systems.

Bernd holds a Ph.D. in Information Technology from the Universität Stuttgart, Germany and an MBA from the University of Colorado.

Ground Truthing and Geophysics for Offshore Engineering

A year on from the EAGE's Applied Shallow Marine Geophysics conference in Barcelona the SUT will hold its 8th international conference - 'Smarter Solutions for Future Offshore Developments'. The event will take place from 12th to 14th September 2017 at the historic Royal Geographical Society and Natural History Museum in South Kensington London under the direction of the Offshore Site Investigation and Geotechnics (OSIG) group who have again requested input from the EAGE.

The conference series, which has run since 1979, offers a unique opportunity for geotechnical engineers, geoscientists and academics specialising in offshore topics to share their knowledge and experience. In addition to hosting the prestigious McClelland Lecture, the 2017 conference will focus on new research and developments in site investigation data acquisition, evaluation and integration, geotechnical analysis and design as well as field operational experience. A Special Issue of the EAGE Near Surface Geophysics journal will be published preceding the conference with selected papers to be presented at a session on shallow geophysics. The aim is to expand significantly the boundaries of knowledge and practice in offshore geotechnics and geoscience and emphasise their complementary nature.

The challenges currently faced by the offshore oil & gas industry call for innovative approaches to improve efficiency and rigour in practice, while the offshore renewable energy industry has identified and addressed through major research programmes the key technical issues that must be solved to support its growing strength. High profile international incidents have also occurred across all sectors in recent years that posed significant data acquisition, engineering and operational challenges.

The SUT and the EAGE are calling for high quality papers that report on the above topics and other developments, set out new research findings and present innovative ideas as to how the sector can improve efficiency, develop more collaborative approaches and offer innovation towards Smarter Solutions for Future Offshore Developments.

Instructions for conference paper abstracts with conference themes are detailed below. Authors whose abstracts are subsequently selected for possible inclusion as a full manuscript in the EAGE Near Surface Geophysics Special Issue should see 'Guidance for Authors' at www.nsg.eage.org and http://mc.manuscriptcentral.com/nsg.

Call for Papers

- 200 word abstracts should be submitted in English and in 'Microsoft Word' format, using the abstract template which can be downloaded from www.sut.org/event/osig2017. Please do not send 'pdf' format abstracts.
- All abstracts should be emailed to osig2017@sut.org no later than 29th February 2016; a notice of receipt will be emailed by return.
- All primary authors will be notified of their abstract status by 30th April 2016. Technical paper instructions to successful authors will also be provided at this time.
- Successful authors are requested to submit draft papers for review by 30th November 2016.
- Following comments, final publication quality papers are required by 30th April 2017.

To aid administration, authors are requested to select the primary categories and keywords for their abstract from the following list: shallow geology & geohazards, seabed slopes, diapirs & slides, hydrates & shallow gas, seismic hazards & tsunamis, tophole drilling & well engineering, advances in geophysical data collection (including use of AUV) & processing, geotechnical site investigation & characterisation, learning from offshore incidents to reduce ground risk, foundation research, design, construction & monitoring, data integration & ground modelling, efficiencies through optimisation & performance based design, piled foundations, suction installed foundations, gravity based foundations, jack-up rig foundations, anchoring, cyclic & seismic loading of foundations, scour assessment & monitoring, pipeline & cable seabed engineering, risers & seabed interaction, environmental & ecological impacts of seabed engineering, decommissioning and seabed clean up, working in polar environments, climate change effects, deep sea mining, monitoring & overburden integrity for carbon storage. It should be noted that these categories are tentative and the committee will consider all abstracts relevant to offshore site investigation, geophysics & geotechnics, including relevant case studies. Please indicate in your covering letter if you wish your paper to be considered for inclusion in the special issue of Near Surface Geophysics.

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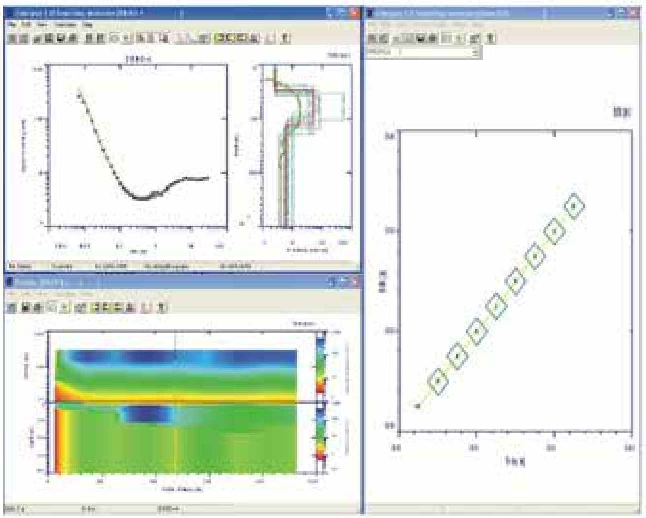

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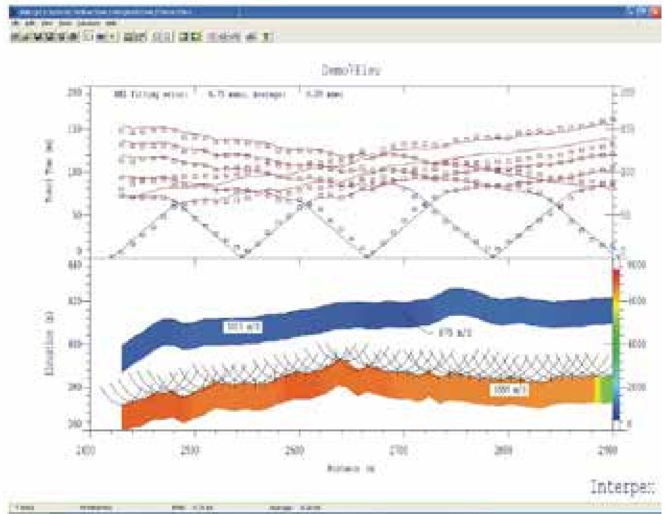

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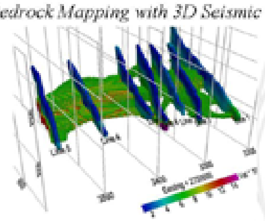

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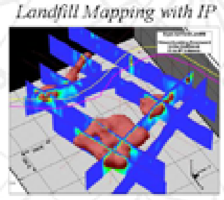

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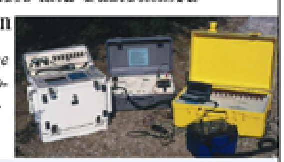

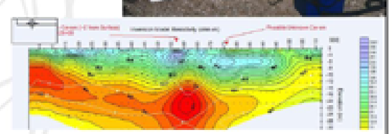

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952.832.2616
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Environmental and Engineering Geophysical Society	Renew or Join Online at www.EEGS.org
2016 Individual Membership Application	

Individual Membership Categories

EEGS is the premier organization for geophysics applied to engineering and environmental problems. Our multi-disciplinary blend of professionals from the private sector, academia, and government offers a unique opportunity to network with researchers, practitioners, and users of near-surface geophysical methods.

Memberships include access to the *Journal of Environmental & Engineering Geophysics (JEEG)*, proceedings archives of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), and our quarterly electronic newsletter, *FastTIMES*. Members also enjoy complimentary access to SEG's technical program expanded abstracts, as well as discounted SAGEEP registration fees, books and other educational publications. EEGS offers a variety of membership categories tailored to fit your needs. Please select (circle) your membership category and indicate your willingness to support student members below:

☐ **Yes, I wish to sponsor _______ student(s) @ $20 each to be included in my membership payment.**

Individual Members

Individual members are invited to sponsor student members. Simply indicate the number of students you'd like to support (at $20 each) to encourage growth in this important segment of EEGS' membership.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Individual	$90	$130

Retired Members

Your opportunity to stay connected and support the only organization focusing on near surface geophysics. Retired members are invited to sponsor student members. Simply indicate the number of students you'd like to support (at $20 each) to encourage growth in this important segment of EEGS' membership.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Retired (*Must be Approved by EEGS Board of Directors)*	$50	$130

Introductory Members

If you have not been a member of EEGS before, we offer a reduced rate (electronic JEEG option) for new members to enjoy all the benefits of individual membership (except vote or hold office) for one year.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Introductory	$50	$130

Lifetime Members

New! Support EEGS, receive benefits on an ongoing basis and never renew again! Members of this category enjoy all the benefits of Individual membership.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Lifetime Member	$995	$995

Developing World Members

Those wishing to join this category of EEGS membership are invited to check the list of countries to determine qualification.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Developing World *(List of qualifying countries next page)*	$50	$130

Student Members

Students represent EEGS' future and we offer complimentary membership subsidized by Corporate Student Sponsor Members and those who sponsor students. Student members enjoy all the benefits of individual membership (except to vote or hold office). Available for all students in an accredited university up to one year post-graduation. Please submit a copy of your student ID and indicate your projected date of graduation: ___ /____ (Month/Year). New! Students in year two beyond graduation are offered a special rate for 1 year.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Student up to 1 Year Post Graduation **(Grad Date: Mo/Yr.: ___/___)**	$ 0	$90
Student - Year Two Post Graduation	$50	$90

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 $130.00 if you would like the printed, quarterly *Journal of Environmental & Engineering Geophysics* (*JEEG*) mailed to you). To receive a printed *JEEG* as a benefit of membership, select the Developing World Printed membership category on the membership application form.

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Algeria
Angola
Armenia
Azerbaijan
Bangladesh
Belize
Benin
Bhutan
Bolivia
Burkina Faso
Burundi
Cambodia
Cameroon
Cape Verde
Central African Republic
Chad
China
Comoros
Congo, Dem. Rep.
Congo, Rep.
Djibouti
Ecuador
Egypt
El Salvador
Eritrea
Ethiopia
Gambia
Georgia
Ghana
Guatemala
Guinea-Bissau
GuyanaHaiti
Honduras
India
Indonesia
Iran
Iraq
Ivory Coast
Jordan
Kenya
Kiribati
Kosovo
Kyrgyz Republic
Lao PDR
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Liberia
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CONTACT INFORMATION

Salutation **First Name** **Middle Initial** **Last Name**

Company/Organization **Title**

Street Address **City** **State/Province** **Zip Code** **Country**

Direct Phone **Mobile Phone** **Fax**

Email **Website**

ABOUT ME: INTERESTS & EXPERTISE

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

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

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

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Corporate Contribution Total: $ ____________________

Foundation Total: $ ____________________

PAYMENT INFORMATION

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

☐ **AmEx** ☐ **Discover**

Subtotals

Membership: $ ____________________

Student Sponsorship: $ ____________________

Foundation Contributions: $ ____________________

Grand Total: $ ____________________

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Card Number **Exp. Date** **CVV #:**

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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.

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☐ **Yes, I wish to support ____ student(s) at $20 each to be included in my membership payment.**

Category	2016 Electronic JEEG	2016 Basic Rate (print JEEG)	2016 Basic + Web Ad Package
Corporate Student Sponsor *Includes one (1) individual membership, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES and Sponsorship of 10 student memberships*	$310	$340	$840
Corporate Donor *Includes one (1) individual EEGS membership, one (1) full conference registration to SAGEEP, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES*	$660	$690	$1190
Corporate Associate *Includes two (2) individual EEGS memberships, an exhibit booth and registration at SAGEEP, the ability to insert marketing materials in the SAGEEP delegate packets, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES*	$2410	$2440	$2940
Corporate Benefactor *Includes two (2) individual memberships to EEGS, two (2) exhibit booths and registrations at SAGEEP, the ability to insert marketing materials in the SAGEEP delegate packets, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES*	$4010	$4040	$4540
Website Advertising	Purchase Separately		Package Rates include both website ad locations
One (1) Pop-Under, scrolling marquee style ad with tag line on Home page, logo linked to Company web site	$600/yr.	$600/yr.	
One (1) Button sized ad, linked logo, right rail on each web page	$250/yr.	$250/yr.	

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Company/Organization	Title

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Email	Website

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☐ Geophysical Contractor	☐ Geotechnical	☐ Gravity	☐ AWWA	☐ Student
☐ Equipment Manufacturer	☐ Geo. Infrastructure	☐ Ground Penetrating Radar	☐ AGU	
☐ Software Manufacturer	☐ Groundwater	☐ Magnetics	☐ EAGE	
☐ Research/Academia	☐ Hazardous Waste	☐ Marine Geophysics	☐ EERI	
☐ Government Agency	☐ Humanitarian Geo.	☐ Remote Sensing	☐ GeoInstitute	
☐ Other	☐ Mining	☐ Seismic	☐ GSA	
	☐ Shallow Oil & Gas	☐ Other	☐ NGWA	
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	☐ Other		☐ SSA	
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Foundation Total: $ ____________

PAYMENT INFORMATION

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

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Subtotals

Membership: $ ____________

Student Sponsorship: $ ____________

Foundation Contributions: $ ____________

Grand Total: $ ____________

Card Number **Exp. Date**

Name on Card **CVV#**

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.

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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!

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			Member	Non-Member
	0036	2014 (CD-ROM)	$75	$100
	0034	2013 (CD-ROM)	$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

			Member	Non-Member
	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

	0039	2013 Agricultural Geophysics: Methods Employed and Recent Applications - Barry Allred, Bruce Smith, et al.	$35	$45
	0038	2010 Processing Seismic Refraction Tomography Data (including CD-ROM) - William Doll	$35	$45
	0037	2011 Application of Time Domain Electromagnetics to Ground-water Studies – David V. Fitterman	$20	$30
	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	***New Pricing!!*** Advances in Near-surface Seismology and Ground Penetrating Radar—R. Miller, J.Bradford, K.Holliger Special Pricing Available for Limited Time—through March 25, 2015—end of SAGEEP 2015!	$79	$99
	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

MISCELLANEOUS ITEMS CONTINUED ON NEXT PAGE...

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Publications Order Form (Page Two)

		EEGS T-shirt (X-Large) Please circle: white/gray	$10	$10
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***Journal of Environmental and Engineering Geophysics* (JEEG) Back Issue Order Information:**
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Qt.	Year	Issue	Qt.	Year	Issue	Qt.	Year	Issue
	1995	JEEG 0/1 - July		**2004**	JEEG 9/1- March		**2009**	JEEG 14/1 - March
		JEEG 0/2 - January			JEEG 9/2 - June			JEEG 14/2 - June
	1996	JEEG 1/1 - April			JEEG 9/3 - September			JEEG 14/3 - September
		JEEG 1/2 - August			JEEG 9/4 - December			JEEG 14/4 - December
		JEEG 1/3 - December		**2005**	JEEG 10/1 - March		**2010**	JEEG 15/1 - March
	1998	JEEG 3/2 - June			JEEG 10/2 - June			JEEG 15/2 - June
		JEEG 3/3 - September			JEEG 10/3 - September			JEEG 15/3 - September
		JEEG 3/4 - December			JEEG 10/4 - December			JEEG 15/4 - December
	1999	JEEG 4/1 – March		**2006**	JEEG 11/1 - March		**2011**	JEEG 16/1 - March
		JEEG 4/2 - June			JEEG 11/2 - June			JEEG 16/2 - June
		JEEG 4/3 - September			JEEG 11/3 - September			JEEG 16/3 - September
		JEEG 4/4 - December			JEEG 11/4 - December			JEEG 16/4 - December
	2000	JEEG 5/3 - September		**2007**	JEEG 12/1 - March		**2012**	JEEG 17/1 - March
		JEEG 5/4 - December			JEEG 12/2 - June			JEEG 17/2 - June
	2001	JEEG 6/1 - March			JEEG 12/3 - September			JEEG 17/3 - September
		JEEG 6/3 - September			JEEG 12/4 - December			JEEG 17/4 - December
		JEEG 6/4 - December		**2008**	JEEG 13/1 - March		**2013**	JEEG 18/1 - March
	2003	JEEG 8/1- March			JEEG 13/2 - June			JEEG 18/2 - June
		JEEG 8/2 - June			JEEG 13/3 - September			JEEG 18/3 - September
		JEEG 8/3 - September			JEEG 13/4 - December			JEEG 18/4 - December
		JEEG 8/4 - December					**2014**	JEEG 19/1 - March
								JEEG 19/2 - June
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2015 Merchandise Order Form

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SAGEEP 2015 T-shirt (Medium)			$18	$18	
SAGEEP 2015 T-shirt (Large)			$18	$18	
SAGEEP 2015 T-shirt (XLarge)			$18	$18	
SAGEEP 2015 T-shirt (XXLarge)			$18	$18	
EEGS T-shirt (XLarge)			$10	$10	
EEGS Lapel Pin			$3	$3	

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TOTAL ORDER:

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