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Preface to the Special Issue on "The 22nd Electromagnetic Induction Workshop, Weimar, Germany"

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The international Electromagnetic (EM) Induction Workshops of IAGA Working Group I.2 (now Division VI of IAGA) are the premier events for researchers around the world to exchange latest developments in the field of geophysical electromagnetism. The Workshop in Weimar, Germany, was held over seven days, from 24 to 30 August 2014. It was attended by 377 delegates from 43 countries who submitted a total of 371 abstracts. The scientific programme was organised by an International Program Committee of the Working Group.

Highlights of both this and previous workshops have been the review talks from invited, internationally acclaimed scientists. Themes for these review talks vary from workshop to workshop. They highlight recent advances in the rapidly evolving fields of electromagnetic induction, including important new directions of research as well as results focusing on geological targets. The review papers presented at the workshops have traditionally been published as Special Issues of Surveys in Geophysics or Geophysical Surveys since the 1978 workshop in Murnau, Germany. This latest Special Issue on the 22nd Electromagnetic Induction Workshop in Weimar, Germany, includes the following review papers:

1. Anne Neska—Conductivity Anomalies in Central Europe.
2. Catherine Constable—Earth's Electromagnetic Environment.
3. Rita Streich—Controlled-Source Electromagnetic Approaches for Hydrocarbon Exploration and Monitoring on Land.

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4. Wiebke Heise and Susan Ellis—On the Coupling of Geodynamic and Resistivity Models: A Progress Report and the Way Forward.
5. Oleg Pankratov and Alexey Kuvshinov—Applied mathematics in EM studies with special emphasis on an uncertainty quantification and 3-D integral equation modelling.
6. Amir Khan—On Earth's mantle constitution and structure from joint analysis of geophysical and laboratory-based data: An example.

The review paper by Anne Neska examines existing and new research conducted to decipher and explain regional scale zones of high electrical conductivity in Central Europe. The earliest research in this area dates back to the times when electromagnetic deep sounding methods were developed in the late fifties of the last century. The study areas comprise the region of the Trans-European Suture Zone (i.e. the south Baltic region and Poland), the North German Basin, the German and Czech Variscides, the Pannonian Basin (Hungary), and the Polish, Slovakian, Ukrainian, and Romanian Carpathians. (High)-conductivity anomalies are linked to deep sedimentary basin fill, asthenospheric upwelling, and particularly a number of prominent conductors located in the middle crust to tectonic boundaries that developed during various stages of mountain building. There is, however, still significant debate with respect to the interpretation of some of the anomalies. While the North German Conductivity Anomaly appears to be caused by extraordinarily well-conducting sediments, the interpretation is less clear for the zone between the suture and the deformation front of the Caledonian orogeny. According to the author, there are still regions in Central Europe which require the acquisition of additional data, such the Carpathians or the Alpides, for which hardly any (magnetotelluric) data exist.

Catherine Constable reports on the natural spectrum of electromagnetic field variations surrounding the Earth, describing major differences in both the physical origin and structure of the signals. So-called extremely low-frequency (ELF, 3 Hz–3 kHz) electromagnetic signals are generated in the form of sferics, lightning, and whistlers which can extend to frequencies as high as the VLF range (3–30 kHz). The roughly spherical dielectric cavity bounded by the ground and the ionosphere produces the Schumann resonance at around 8 Hz and its harmonics. A transverse resonance occurs at $\sim$1.7–2.0 kHz arising from reflection off the variable height lower boundary of the ionosphere. The size of the EM signals in this frequency range is controlled by the strength of the global electric circuit and influenced by numerous external processes. The author suggests that mapping the locations and power of global thunderstorm activity using global electromagnetic networks could become important for monitoring and detecting changes in the mesosphere which may in turn be associated with global climate change. More work is needed to address the complexities of ionospheric structure in global lightning studies. The detection of Schumann resonance signals by satellites at over 400 km altitude draws attention to the diffuse boundary for the ionosphere and the associated gradual increase in electrical conductivity with altitude.

Rita Streich's paper gives an overview of controlled source electromagnetic methods for hydrocarbon exploration and monitoring on land. Due to the diversity of techniques and approaches, her review is focused on surface-based techniques, excluding airborne EM and well logging. After describing succinctly the main points of land EM history, she reviews different approaches to face key topics and questions such as resolution, noise, and quantitative data interpretation. The first topic covered the challenge of detecting (thin) resistors, finding optimum source–receiver configurations, using time or frequency domain systems, and considering different canonical models and different exploration targets. She also describes attempts to enhance sensitivity for particular targets using different orientations of sources and receivers. Noise is a serious problem for EM measurements. Thus, the review illustrates strategies for noise reduction, in particular robust processing techniques, increasing the power of the source and also how to exploit noise as a source. Rita Streich then discusses EM data interpretation results, showing the evolution from qualitative modelling and 1D calculations to 3D imaging and multi-physics joint inversions. She completes her review by assessing the potential of EM for monitoring and reporting critically synthetic studies and field applications. She concludes that land EM needs further development to offer its full potential in the future.

Wiebke Heise and Susan Ellis report on the coupling of geodynamic and resistivity models. Due to the complexity and novelty of the approach, this contribution is not a classical review but rather a progress report. Magnetotelluric (MT) studies describe the structure of crust and mantle in terms of electrical conductivity, while geodynamic modelling predicts the deformation and evolution of crust and mantle subject to plate tectonic processes. An integration of MT with geodynamic modelling requires relationships between conductivity and rheological parameters, such as viscosity and melt fraction, which are largely unknown or poorly understood. But conductivity models can define lithological variations, fault locations and/or zones of partial melt which can be used to construct the initial conditions in geodynamic models. The authors discuss examples which attempt a more quantitative comparison, such as a study from the Himalayan continental collision zone where MT suggests partial melt in the lower crust. In cases where partial melt is present, conductive anomalies have a variety of causes, which have to be evaluated within the tectonic context. It is therefore not straightforward to use indicators for melt fraction or fluid content from conductivity models to constrain the rheological response to tectonic forcing in geodynamic models. Iterations between predictions from geodynamic and MT models can potentially yield tighter constraints on deformation processes. The authors suggest that more laboratory measurements of conductivity (especially under deformation) are needed to constrain the relationships between conductivity, composition, fluid content, and other parameters needed by geodynamic modellers. A positive outlook is an example that directly uses MT results as constraints within geodynamic models of ore bodies.

The review paper by Oleg Pankratov and Alexey Kuvshinov covers the very topical issue of determining the level of confidence, or uncertainty, on model parameters. Increasing, large 3D models can be generated deterministically from the inversion of EM data sets in a routine and tractable manner, but there is much less emphasis on what these models can really tell us about the Earth. In the first part of the paper, the authors discuss the stochastic Bayesian formulation of the inverse problem and the classical Metropolis–Hastings algorithmic approach to determining parameter uncertainty. The authors emphasise that the Metropolis–Hastings approach requires many forward computations which can make it appear prohibitive in terms of computer time and resources. In the second part of the paper, the authors outline several modifications of the Metropolis–Hastings algorithm that significantly accelerate sampling of the posterior probability distribution. The review outlines, very clearly, the workflow to implement these changes, and it will be exciting to see this approach applied to real and complex EM data sets. Finally, the review discusses the state of the art in 3D EM forward modelling, particularly using integral equation methods. The integral equation approach is much less common than finite-difference and finite-element methods that have dominated 3D EM modelling over the last few decades. The authors show, however, that integral equation methods have some distinct computational advantages and are well suited to stochastic determination of model parameter uncertainty.

Finally, Amir Khan's paper describes a quantitative approach that combines data and results from mineral physics, petrological analysis of mantle minerals, and geophysical inverse calculations for making inferences about structure and constitution of Earth's mantle. This approach shows the advantages of consistent integration of different disciplines across the Earth sciences. Although the paper adopts the form of a tutorial presenting a specific approach rather than a review of all related studies, it also contains a number of review elements that offer a deep understanding of the electrical conductivity and the state of the mantle. The author reports in detail how the connection between geophysical data, physical rock properties (electrical conductivity), and material properties (thermochemical state) is provided by the thermodynamics of the mantle. The methodology is illustrated with a specific example that corresponds to invert a set of long-period electromagnetic responses retrieving information on mantle composition, temperature, and water content. The author notes that the results derived here are dependent on the choice of the experimental data sets; he also states that, like other methods, the approach leads to further work, mainly incorporating the collection and refinement of laboratory experimental parameters.