Introducing the 2025 RING Meeting

Dear sponsors, dear colleagues, dear friends,

Writing the introduction of the RING Proceedings is always a great privilege and pleasure. It allows me to look back at another productive year for the RING Team, and to appreciate the high quality research in integrative numerical geology performed by the community. Many thanks to all contributors for sharing their work in this volume, and to all the sponsors of this Consortium for making this adventure possible!

We are aware that Industrial R&D is a challenging activity: limited budgets call for prioritizing actions, and the secrecy required to maintain a competitive edge often collides with the need for open scientific exchange that has always fed scientific and technological progress. Remaining on top of a research field is facilitated by today's wide accessibility to information, but the most relevant information may also become diluted. One of the main goals of RING and its annual meetings is to provide a space for scientific and technical exchange in geomodeling so that the whole community progresses. We are very appreciative to all RING sponsors for their support, which jointly allows us to run this annual event, and also to address long-term research questions while forming young numerical geoscientists.

This volume starts with two case studies. The first concerns the modeling of a highly deformed accretionary complex in easter Australia from the Loop/Monash team at Monash (AILLERES, GROSE & ARMIT, 2025). The second relates to a simpler artificial 3D geological domain created last year at ENSG called PEGGHy, whose size is comparable to an Olympic swimming pool (CUPILLARD & SAUSSE, 2025). As shown in the paper, this unique experimental platform opens the way to perform multiphysics experiments and to test data acquisition and imaging methods on a controlled environment.

Stratigraphic geometry is a fundamental component of subsurface architecture, which significantly controls vertical and lateral heterogeneity. However, the scale and resolution at which stratigraphic structures should be represented in geomodels is not obvious, and depends on the available data and on the modeling purpose. In the context of well-based stratigraphic interpretation, (LETELLIER, CAUMON & ROBIN, 2025) propose to use continuous wavelet transform of well logs to assist and manage uncertainties during the identification of stratigraphic sequences at multiple scales. This approach also introduces a new misfit function to compare distinct interpretations of the same well, which can be used in machine learning approaches. The problem of stratigraphic correlation between wells has received significant attention recently at RING. This year, Orléans colleagues discuss the difficulty and the conceptual challenges to perform stratigraphic correlations in carbonate rocks even at decametric scale, and use WeCo to generate multi-well correlation scenarios. In complement, we are pleased to announce the upcoming release of WeCo2, which provides a completely revamped implementation of our assisted correlation approach, and opens exciting perspectives both for users and new R&D projects. RING Consortium members can benefit from a WeCo2 training to try out this new version during this year's meeting. The consideration of reflection seismic images can considerably facilitate stratigraphic correlations; however, important stratigraphic variability may occur below seismic scale, and the seismic-to-well tie can be a challenging task. Therefore, our Eliis colleagues propose a global model deformation method to reconcile wells with depth-migrated images and the associated relative geological time (RGT) volume (Appel & Souche, 2025). We also introduce a probabilistic method to manage the local ill-posedness of the seismic-to-well-tie problem, and to downscale the seismic-scale RGT using well-scale stratigraphic correlation (Boucard, Caumon & Baville, 2025). Another way to perform this downscaling is to use transdimensional inversion to also honor flow data, as shown by Julien Herrero in previous RING Meetings. This year, two improvements are introduced in the transdimensional method. The first introduces Bézier splines in the parameterization of stratigraphic interfaces to depart from the classical planar assumption (Coutard et al., 2025); the second considers relative depth models to manage deformed layer piles, and a first but promising tests to handle stratigraphic unconformities (Herrero et al., 2025).

The interpolation of stratigraphic strata from interpreted points or lines has also been a significant research area for this Consortium since 1989. This year is no exception, with the introduction of a new anisotropic bending energy and its discretization on linear elements for implicit surface interpolation (Belhachmi, 2025). Accessibility and usability of modeling engines is also very important for the democratization of these techniques. This year, two presentations from BRGM (Quimerc'h et al., 2025) and Monash University (Mengelle Nicole, Ailleres & Grose, 2025) present QGIS plugins interfacing their implicit structural modelling libraries (ForGEO and LoopStructural, respectively).

This year's meeting also gives a significant room to artificial intelligence approaches to address subsurface modeling and interpretation tasks. Two of these contributions are based on 3-month MSc student projects from ENSG. The first one is RING's first incursion into large language models (Bodolec et al., 2025), which described the implementation of a retrieval augmented generation using the archive of GOCAD and RING proceedings. It also proposes a first benchmark and methodology to evaluate the quality of results. The second one (Gandon & Cupillard, 2025) propose a modified U-Net architecture that manages variable acquisition geometry for electric resistivity tomography. Promising results are obtained on the PEGGHy experimental platform mentioned above. Machine learning can also be used to analyze and characterize modeling results, as demonstrated by our BRGM colleagues (Laouici, Breuillard & Chamekh, 2025), who propose a CNN-based approach to process folded structural models. In all cases, the success of AI is generally contingent to the quality, relevance and comprehensiveness of the database used to train the model. The last contribution of this session (Fratani, Ogarko et al., 2025) addresses this aspect by describing the training set design for learning the associations between sparse fault observations.

The fault data association problem may also be tackled by expert geological rules described by a few parameters to explicitly represent geological knowledge. For this, we propose new fault data association rules dedicated to drillhole observations, which integrate probabilistic relationships between fault parameters (Fratani, Baville et al., 2025). This paper also introduces an updated data association simulation algorithm optimized to handle the huge number of observations as encountered in large mining data sets. Of course, the stochastic production of fault network or stratigraphic scenarios raises questions of visualization and analysis of the resulting model space. Therefore, (Baville, Fratani & Madelaine, 2025) study and compare two interesting graph similarity measures using multi-dimensional scaling.

Connecting observations is an important avenue to manage subsurface uncertainty, but it is not sufficient because of observation gaps and subscale features. Statistical point processes offer a rigorous way to characterize and simulate poorly known or unseen geological objects. However, the development of models adapted to the structures of interest and to the data at hand is needed to improve geological realism. For computational performance, efficient simulation methods are also required. The collaboration started a few years ago with Radu Stoica on these topics has been very productive. In this area, two contributions this year concern the inference of model parameters, with a paper that includes theoretical advances to manage observation gaps (GILLOT ET AL., 2025), and an application of the approximate Bayesian inference framework in stochastic fault interpretation of seismic images (CAUMON ET AL., 2025). When applying such stochastic modeling techniques, an important question is to judge about the representativity of the samples as compared to the variability between human interpreters. For this, we propose an updated version of a user study that considers the interpretation of ore deposits and hydrothermal alteration halos (MARCHAL ET AL., 2025). In this context, the structures and composition are related by the ore deposit model. To reproduce these relations, Paul Marchal presented the SalterRING method last year to jointly simulate structures and alteration zones. This year, he applies the approach to real data in the Athabasca basin (MARCHAL ET AL., 2025). Another contribution from Monash colleagues accounts for the relationships between structures and mineral composition using LoopsStructural, using structurally-controlled local anisotropy fields for geostatistical modeling (MENGELLE NICOLE, AILLERES & GROSE, 2025).

Geological interpretation, characterization and modeling form an essential aspect of subsurface studies, but cannot be separated from meshing and numerical simulations when it comes to predicting the subsurface behavior or solving inverse problems. The choice of appropriate numerical schemes for physical simulation is also tremendously important to ensure accuracy, stability and computational performance. On this aspect, Inria colleagues present a new efficient scheme to simulate large-scale incompressible fluid simulation with free surface using optimal transport (PLATEAU-HOLLEVILLE & LÉVY, 2025). Geometric accuracy is an essential aspect of this work, as in the approach of BRGM colleagues who propose a new "pragmatic method" based on CGAL to generate a sealed geological model from linearly approximated implicit models (LOPEZ ET AL., 2025). Doing this incrementally has been a long term objective for the RING Team, as it provides interesting avenues for locally adaptive simplification, fast model updates to reflect new data, and uncertainty assessment. This year, we present an algorithm implemented in MMG to incrementally insert a finite fault or fracture in a conformal tetrahedral mesh (BELHACHMI, CAUMON & DAPOGNY, 2025).

The three above works rely on and extend dedicated numerical geometric libraries that include advanced algorithms which took years of development. However, the integration of these tools in geomodeling systems may involve a steep learning curve for numerical geoscientists. To address this challenge (LÉVY, BORGESE & LI, 2025) propose a self-contained framework to automate the generation of user interface, facilitate the reuse of the Geogram C++ libraries, and integrate them with other libraries in high-level programming languages such as Python. An alternative to dynamic communication between software is the definition of appropriate interoperable formats to store and exchange data and geomodels. This year, our MIRA Geoscience colleagues, propose the open GEOH5 format library, designed to address this need for mining applications (CHAUVIN, HENSGEN & MCGAUGHEY, 2025). Beyond data and models, the storage of knowledge involved in interpretation and modelling tasks is a highly challenging task, for which our Orléans University colleagues propose a formalized workflow and ontology (LAURENT ET AL., 2025).

The last theme addressed in this volume relates to reservoir applications, where established modeling and meshing workflows are generally sub-optimal. Indeed, the generalized use of pillar grids imposes challenging compromises on grid resolution, which is always too coarse as compared to the level of information and needed accuracy at the wells, and too thin regarding the uncertainties and parameter sensitivity far from the wells. To address this limitation and facilitate history matching on low fidelity reservoir models, a very interesting method is proposed this year by our TotalEnergies colleagues to use hexahedral meshes refined close to the wells (RAGUENEL ET AL., 2025). Another challenge in simulation is the efficient, and accurate simulation of coupled physical phenomena. In this context (ZAKARI, 2025) proposes a comparison between the Sharfetter-Gummel method and control volume finite element method for geothermal simulation in porous media. However, equivalent medium approaches are seldom directly applicable in complex fractured and karstified media. For karsts, simulations can be run on graphs, but hydraulic conductivities are not necessarily well known. For this, our IFPEN colleagues propose a numerical method to rapidly compute effective properties of such systems for Darcy flows (NOETINGER, COLECCHIO-PUA & HOUSNI, 2025). To address cases where fluid velocities involve significant inertial and non-linear effects, our NorthEastern University and Melbourne University colleagues propose advanced numerical techniques that highlight important partitioning phenomena which cannot be captured by simpler flow models (MATTHAI & BUI, 2025).

Consistently integrating geophysical, geological and flow data to generate predictive subsurface morels remains an overarching challenge in our field. It calls for the integration of many types of data and for the development of effective approaches to avoid the pitfall of error propagation in deterministic interpretation → modeling → simulation workflows. Many of the above papers address this by generating models that represent uncertainty, but closing the loop and reducing uncertainty also calls for new data types, deep physical understanding, and effective inverse / assimilation methods. In terms of data type, this volume presents a self-potential inverse method, which provides interesting insights about geothermal processes in the subsurface and nice perspectives for further data integration (ESSA ET AL., 2025). When it comes to closing the gap between seismic imaging and geomodeling, we also propose an updated workflow based on homogenized full waveform inversion (RUGGIERO, CUPILLARD & CAUMON, 2025). The main novelty this year is to make fine-scale heterogeneities variable (in addition to fault parameters) when looking for models that match the deterministic elastic medium obtained by homogenizing the result of full waveform inversion. In complement, (CUPILLARD ET AL., 2025) propose a detailed study of wavefield accuracy in homogenized models. On a more general perspective, our BRGM colleagues propose a general and flexible python toolkit that gathers many methods to solve and process the results of subsurface data assimilation (CHASSAGNE, LANDES & LOHIER, 2025).

As mentioned earlier, the flow of ideas and open exchange has always been a mark of RING meetings. After writing this introduction, I am sure this year will be no exception, and I anticipate rich and inspiring discussions after the talks and during the breaks. As each year, the oral and poster presentations will be followed by training courses provided by AspenTech, SLB, and of course by the RING Team. I hope many of you will be able to attend these trainings, not only to bridge theory and practice but also to further interact and learn and give feedback.

I am eagerly looking forward to welcoming you again to Nancy and wish you a fruitful 2025 RING Meeting!

Guillaume Caumon.

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