Introducing the 2019 RING Meeting: 
30th RING-Gocad Consortium anniversary

Dear Colleagues, Dear Friends,

Thirty years ago, Jean-Laurent Mallet, then professor at the Nancy School of Geology (ENSG), started a research program for the Computer-Aided Design of Geological Objects. GeOCAD (which was soon to become gOcad) was centered on two key aspects: the use of discrete networks of Atoms forming curves, surfaces and volumes representing the geometry, connectivity and properties of all sorts of geological structures, and the Discrete Smooth Interpolation (DSI) method, a least-squares approach to interpolate the property values or the position of the Atoms from sparse data. The first years were dedicated to the development of a modeling software implementing this mathematical model and able to represent faulted and geometrically complex structures such as salt diapirs. In addition to this strong theoretical basis, Mallet also had the vision that graphical workstations would be essential tools for subsurface modeling, and that graphical user interface and state-of-the-art software technology would be key to obtain realistic subsurface models. Theoretical advances have, therefore, never been disconnected from software implementations and realistic applications. The definition of an extensible common framework such as DSI and the associated data model was also extremely useful and set a standard as a vector of teamwork integration, which is a difficult challenge in a group where students leave after getting their degree.

During the 1990’s, Gocad was being refactored and extended at a high pace by Prof. Mallet and his research team, helped by a maintenance team and by researchers and engineers from sponsoring organizations such as Jean-Claude Dulac, Dave DeBaun and Chuck Sword. Many surface construction and processing methods (local editing, cut, restoration), Stratigraphic Grids, Channels and Geostatistical algorithms were implemented during these years. Many contributions consisted of new DSI constraints accounting for various types of subsurface information or interpretation concepts. Most of this research formed the basis of the GOCAD software which was transferred to the spin-off company T-Surf in 1998 (which was acquired by Paradigm in 2006 and is now integrated in Emerson).

At the end of the 1990’s and during the 2000’s, the research team investigated many new axes. To name a few: ray tracing on triangulated surfaces and tetrahedral meshes; implicit structural modeling, model deformation and structural uncertainties; stratigraphic gridding and tetrahedral meshing; discrete fracture modeling; seismic interpretation; impedance inversion; fracture characterization and modeling; connecting geomodelling to physical finite element simulators; visualization; model queries; geostatistics and data analysis.

I would like to briefly mention two of these research threads. First, a significant effort was devoted to Generalized Maps (G-Maps), a formal topological framework to represent and edit geometric objects with a set of basic building blocks (named darts) having well-defined mathematical properties. The promise of G-Maps was to provide a unifying framework for robust and mathematically proven modeling operations, so a large
effort was undertaken to reimplement the data model and algorithms within this framework. A related contribution was the automation of the faulted stratigraphic grid management, and the introduction of new approaches for Voronoi-type unstructured grids, years before they could be accepted in commercial flow simulators. Eventually, the approach was dropped as it was not efficient enough in terms of memory usage, but it clearly contributed to the team’s expertise and it still reflect our aspiration to rest on solid mathematical theories to advance geomodelling technology.

Another very important aspect in these years was the development of stratigraphic coordinates, which started in 1996 with a paper by Mallet, Shtuka and Donner entitled: From \((x, y, z)\) Euclidian Coordinates to \((u, v, w)\) Curvilinear Coordinates. This marked the beginning of a long quest to characterize the subsurface in the depositional space which culminated in the development of the Geochron model by Jean-Laurent Mallet and his students. After he retired in 2006, Jean-Laurent Mallet spent significant time refining and developing the Geochron theory, as attested in his 2014 EAGE book. The benefits of this general framework are still being investigated today, see for example this year’s paper by Anne-Laure Tertois and Jean-Laurent Mallet (Emerson) on the use of GeoChron to perform structural restoration.

In 2007, right after Jean-Laurent Mallet retired from the university, I had the significant honor and took the challenge to become the scientific leader of the Consortium. Since then, the team has keep the spirit of multidisciplinary geomodelling research while increasing its academic outputs. Two guiding principles have been driving our research. First, the need to further formalize and increase the level of geological knowledge incorporated in geomodelling. Second, the need to better characterize and reduce subsurface uncertainty at the appropriate scale. In 2015, this has led us to redefine ourselves as the Research for Integrative Numerical Geology (RING) team, and to state our vision that “a geomodel in the 21st century should help geoscientists to explore subsurface uncertainties, to test geological scenarios, to integrate across several physical simulators at the appropriate scale and finally to support decisions”. More precisely, we have focused our efforts on the following geological objects: faults, fractures and strata, sedimentary objects associated to channels and karsts. We also have developed new approaches to mesh these objects and came to realize that meshing shall generally imply model simplifications. Finally, we developed physical simulation approaches to analyze, test and validate geomodels, with a focus on structural restoration which was recently extended to geomechanics, flow and geophysics.

These objectives and research themes are well represented in this year’s proceedings, which contains a wide range of complementary modeling approaches. It starts with a review paper on structural modeling and uncertainties, published in Advanced in Geophysics at the end of 2018 by Florian Wellmann (RWTH Aachen) & Guillaume Caumon (RING). We hope it will provide a useful state of the art and help geomodelers and geophysicists to make links between existing geomodelling approaches. The second paper in these proceedings describes the current stage of a collaborative benchmark project for implicit structural modeling, which aims at running several interpolation techniques on the same natural data sets.

In addition to these papers revisiting and discussing previous structural modeling works, this year includes several new methodological contributions. In the field of implicit structural modeling, Morgan Thierry-
Coudon (RING MSc student) et al. present a finite element approach, while Lachlan Grose (Monash) et al. address the difficult problem of sequentially integrating fault kinematics in structural modeling.

As horizon geometry may significantly be affected by faults, it can be important to address uncertainty about the fault network itself. During the past 10 years RING has proposed innovative approaches to generate fault frameworks having variable connectivity during the PhDs of Nicolas Cherpeau, Charline Julio and Gabriel Godefroy. This year, Paul Marchal (RING MSc student) et al. introduce new rules to account for horizon displacement and fault-related alteration in stochastic fault network modeling in the graph-based framework pioneered during the PhD of Gabriel Godefroy. Paul applies this method for fault modeling in unconformity-related Uranium deposits in Saskatchewan. In deterministic modeling, Kateryna Poliakovska (RING MSc student) et al. propose a geomodelling study of rare earth mineral deposits, also in Saskatchewan.

Salt can also be a significant source of structural complexity in the subsurface. For this, Nicolas Clausolles (RING PhD student) presents significant improvements to handle welds in stochastic salt interpretation. He uses the seismic simulation suite SIGMA developed by Modeste Irakarama to assess the impact of these scenarios on seismic imaging. As the stochastic salt modeling must be localized in the seismic picture before stochastic modeling, Capucine Legentil (RING MSc student) presents her work on multi-scale image analysis methods to appropriately segment the seismic image.

For a given structural framework, significant layering complexity may exist while not necessarily being visible in seismic images. For the last few years, RING has been working on stochastic well correlation precisely to address this source of uncertainty. The methods and rules proposed during the PhD of Florent Lallier and Jonathan Edwards have both shown that several stratigraphic scenarios could be obtained and propagated to layer geometry by combining borehole observations and interpretations. Last year, Christophe Antoine proposed a new promising implementation of the core algorithm more suitable to address a large number of boreholes. This year, Paul Baville (RING PhD student co-sponsored by Equinor) et al. presents a new stratigraphic correlation rule to account for depositional environments as identified from core facies and for regional sediment transport directions.

For smaller sedimentological objects, seismic images may not always provide a detailed and univocal picture, although some architectural elements may be identified locally. The use of outcrop analogs is, therefore, very important to constrain subsurface models. This is illustrated in the work of Vanessa Engelke (Universidade do Vale do Rio dos Sinos) who proposes a geostatistical methodology to complement the outcrop data. This problem has motivated RING to propose novel pseudo-genetic stochastic modeling approaches for channels during the last decade (PhDs of Jérémy Ruiu, Guillaume Rongier and Marion Parquer). This has led to a compact NURBS-based volumetric channel description, an original generation algorithm based on L-Systems and a reverse migration method which starts from abandoned meanders to reconstruct paleo-channels and the associated structures (ChaRMigS). This year, we have worked on two fronts. Léonore Gallot-Duval (RING MSc student) et al. propose image features to identify truncations (erosions) on satellite images. Arnaud Cayrol (RING MSc student) et al. improve ChaRMigS to honor borehole data indicating either abandoned channels (shale plugs) or lateral accretion (point bars).
Considering the temporal evolution was also performed at RING for fracture models during the PhDs of Vincent Henrion and François Bonneau. Indeed, it is a powerful way to reproduce realistic spatial features by accounting for the interactions between geological objects. This year, Mattia Martinelli (Milano Bicocca) et al. present some applications of fracture modeling for determining representative elementary volumes on a naturally fractured outcrop characterized at multiple scales. Soumia Hamlaoui (Aix-Marseille Université) et al. introduce a Gocad plugin to characterize fracture properties both on natural analogs and on numerical models. To automate this task, Rahul Prabhakaran (TU Delft) et al. propose to train a Graphical Convolutional Network on outcrop data; this network can then generate discrete fracture networks having the same features. As the characterization of fracture on natural objects is notably difficult and only provides the final stage of the system, we have also worked recently on the application of the discrete element method (DEM) on geomodels and on the links between seismicity and fractured media. This year, François Bonneau (RING) et al. present recent advances to generate a suitable DEM medium using a new method inspired by computer graphics. Benjamin Chauvin (Harvard) et al. also use the DEM to understand the initiation and the growth of conjugate reverse faults. Celia Louarn (RING MSc student) looks from the spatio-temporal analysis of rupture events by proposing a web-based application. Corentin Gouache (RING PhD student sponsored by CCR) also proposes a statistical characterization of natural seismicity catalogues to assess the frequency of seismic events. We see these works as important and complementary milestones to understand the evolution of fractures in time.

Another area where pseudo-genetic reasoning can be helpful is that of karst and hydrothermal alteration modeling. This was pioneered at RING by Vincent Henrion who proposed the ODSIM method, and was then taken over by Pauline Collon, who recently made significant contributions in karst characterization and modeling. This year, Yeda Backheuser (Petrobras) and Mathieu Moriss (Emerson) describe a methodology to generate karts networks using prior geological knowledge based on ODSIM. In karst modeling, however, the variability in diameter and shape of karst conduits is, however, seldom accounted for. This year, Yves Frantz (RING PhD student) et al. propose a geostatistical characterization of karst conduits on a number of analog models, that can be then used for modeling purposes.

To validate and test geomodels, a significant focus of the Consortium has been dedicated to structural restoration. After early approaches based on geometric considerations and nicely illustrated by Tertois & Mallet in this volume, the so-called geomechanical approaches have used elastic behavior with geometric boundary conditions. This year, Melchior Schuh-Senlis (RING PhD student) et al. introduce a new physical formulation of the problem using viscous material using a reverse-time particle-in-cell approach, which should allow for a better management of large deformations, especially in the modeling of faults and of salt-related deformation.

Another validation strategy is to confront geomodels with geophysical data. For example, Eevaliisa Laine (GTK) et al. present a case study computing potential fields on mineral deposit models. Computing a seismic image from a geomodel can also be very useful to improve interpretation skills or to quantitatively check an interpretation. This year, Luiz Felipe Oliveira (Universidade do Vale do Rio dos Sinos) et al. present a Gocad plugin to perform this task, and Ariane Silveira (Universidade do Vale do Rio dos Sinos) et al. showcase an application of the approach to turbidite deposits. At RING, this topic has been addressed by Modeste.
Irakarama (RING), who defended his PhD in April 2019. In this volume, Dr. Irakarama presents his recent advances in the quest for appropriate misfit functions to rank structural models from synthetic seismic data. Also on the link between seismic images and geological structures, Paul Cupillard (RING) proposes a new inverse method based on homogenization. Seismic applications consider the Earth as elastic; this was also the approach taken in Antoine Mazuyer’s PhD to forecast the stress state consistently with geomodel heterogeneities and borehole observations. This year, Nicolas Mastio (RING PhD student fully sponsored by Total) et al. present a new time-lapse seismic inversion method characterizing anisotropic effects during reservoir production. The application of this method to a real test case shows some intriguing results as compared to classical geomechanical models.

As discussed above, the generation of multiple models is a useful way to capture and reduce subsurface uncertainty. However, it raises significant visualization challenges. This topic was previously addressed by RING during the PhDs of Luc Buatois and Thomas Viard, but we have not been doing research on this recently. Therefore, we are very pleased this year to include the latest advances of Björn Zehner (BGR) on the visualization of geomodel uncertainty. Another related challenge is to capture knowledge and processes associated to model building. Georg Semmler (TU Freiberg) presents a new text-based database system for this purpose.

For many modeling purposes, creating a computational mesh representing geological heterogeneities while providing a suitable element shape can be challenging. Therefore, various meshing and model simplification methods have been proposed in the course of the PhDs of Romain Merland, Jeanne Pellerin, Arnaud Botella and Pierre Anquez. This year, Dr. Pierre Anquez (who defended his PhD in June) et al. present recent results to assess the impact of model simplification strategies on seismic wave propagation and two-phase flow in fractured media. After his PhD defense, Pierre joined Arnaud Botella to start Geode Solutions, a new company developing meshing software libraries and services. Based on the RINGMesh project, they present the new C++ OpenGeode library, which provides a set of data structures for boundary representations and meshes.

As computational physicists know, there is more to physical modeling than an accurate representation of geological objects. Indeed, appropriate discretization schemes should be used. For this, Margaux Raguenel (RING PhD student) et al. present a connection between the RINGMesh library and the multi-physics simulation library CSMP++, and she applies it to the generation of several hydrogeological / geothermal scenarios in Guadeloupe. Stephan Matthai (U. Melbourne) et al. also use CSMP++ to demonstrate that the type of mesh and of discretization method can have a significant impact on flow forecast in heterogeneous formations. In complement to these works, Mustapha Zakari (RING) presents a new Control Volume Finite Element (CVFE) code adapted to fractured media, which we plan to use for future work on upscaling in unstructured or structured meshes. Alternatively, Tawfiq Rajeh (PhD student, IMFT) et al. proposes a graph-based method to simulate flow in fractured media, with a particular focus on performance. Efficiency is also the main concern of Laurianne Bouard (PhD student, IFPEN and Univ. Côte d’Azur) et al., who propose a multi-resolution scheme to compress corner-point hexahedral grids for flow applications. Finally, Pauline Collon (RING) et al. propose a new code for multiple advection, dispersion and storage in one-dimensional karst conduits.

Now comes the time to conclude this short overview of 30 years of research and of this year’s proceedings. Overall, in the course of the last 30 years, over 100 peer-reviewed journal papers have been produced by the
research group in the frame of the Consortium. 77 PhD students and more than 130 Master students have graduated, which illustrates the significant role of this Consortium in developing the *skills of digital geoscientists* for the last three decades. Let me heartfully thank them and all the other team members for their implication and for the outstanding work atmosphere they have created.

This introduction illustrates the diversity of topics addressed by the RING Consortium, and is necessarily incomplete. I invite all Consortium members to learn more by consulting this volume and the proceedings archive available on the Consortium web site. This diversity is part of RING’s DNA: we are convinced that integration is a necessity to approach a complex system such as the Earth’s subsurface. This is also why we value *collaboration and exchange of technical expertise*. I would therefore like to deeply thank the many collaborators and friends who have contributed to this project by sharing ideas, papers, data and knowledge. I also take this opportunity to thank ASGA for its effective consortium management since 1989. Finally, I sincerely acknowledge the *financial support* of the past and present industrial and academic sponsors of the RING-GOCAD Consortium, without whom this adventure would not be possible.

I wish you a memorable and fruitful 2019 RING Meeting!

Guillaume Caumon.