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Learning from the 2013 3-D Interpretation Hedberg Conference: How Geoscientists See 3-D

Bob Krantz

ConcocoPhillips Geoscience and Reservoir Engineering Technology, 600 North Dairy Ashford, Houston, Texas 77079, U.S.A. (e-mail: bob.krantz@conocophillips.com)

Carol Ormand

Science Education Resource Center, Carleton College, One North College St., Northfield, Minnesota 55057, U.S.A. (e-mail: cormand@carleton.edu)

Brett Freeman

Badley Geoscience Ltd., North Beck House, North Beck Ln., Hundleby, Spilsby, Lincolnshire, PE23 5NB, United Kingdom (e-mail: brett@badleys.co.uk)

ABSTRACT

Geologists as a group have and use above-average spatial thinking skills to interpret and communicate complex geologic structures. Interpretation challenges, especially with petroleum industry subsurface targets, come from abundant but still ambiguous data volumes, challenging geologic forms, powerful but difficult-to-learn software, and under prepared staff. In June 2013, 70 participants met in Reno to discuss these and related issues and to explore how spatial cognitive science can help us better understand and develop geologic interpretation skills, software tools, and education strategies. Industry interpreters and trainers, academic structural geologists, software developers, and cognitive scientists brought complementary perspectives to three days of presentations, posters, and discussions, plus a field day with interactive interpretation modules. This Hedberg conference provided new shared insights to the interpretation process, ideas for improving skill development, and abundant opportunities for further collaboration.

DEFINING THE INTERPRETATION CHALLENGE: THE VALUE OF MULTIDISCIPLINARY PERSPECTIVES

Academic geologists have long sought, and continue to seek, the best methods to educate future geologists. In recent decades, these efforts have included rigorous, quantitative classroom-based research on effective pedagogies. The development of students' spatial thinking skills is an emerging focus of this research, as educators have articulated its vital importance throughout the geoscience workforce, including the petroleum industry.

Cognitive scientists explore how people develop and apply spatial thinking skills to accurately perceive, understand, and communicate three-dimensional (3-D) (and four-dimensional [4-D]) relationships, and how these skills impact success in tasks ranging from navigation to surgery (e.g., Richardson et al., 1999; Hegarty et al., 2007). It is clear from this research that spatial skills are malleable, though how best to train these skills remains an area of active research. Some academic geologists are engaged in investigating the application of spatial cognitive concepts to improve teaching and student performance.

Petroleum industry professionals, particularly those with significant interpretation experience, are uniquely qualified to describe the spatial cognition challenges inherent in 3-D (and 4-D) subsurface interpretation. Collaborating with academic geologists allows industry to inform educators about the kinds of tasks newly hired geologists face. Collaborating with cognitive scientists provides industry professionals an opportunity to better understand the cognitive challenges of subsurface interpretation and to develop training strategies and tools informed by cognitive science. Conversely, working with professional geologists provides cognitive scientists a window into the minds of spatial thinking experts.

Software (and hardware) developers and users strive for effective 3-D visualization and interpretation software, which is widely used in the petroleum industry. Beyond the notion of a software product being solely used to achieve a technical outcome, software routinely represents the subsurface in a 3-D viewer or 3-D interpretation environment. To a large degree, subsurface geology is an obvious application for 3-D visualization where the benefits of cognitive off-loading (Dunn and Risko, 2015) are implicit (i.e., the geologist is freed from the mental process of imagining in 3-D because it is manifest on the screen). However, toolkits and visualization systems can actually overload the interpreter with the enormous amount of information that is available. Techniques for interactive visual culling and intuitive object hiding and retrieval are seen as a way forward to simplify both user experience and productivity.

The 2013 Hedberg conference drew participants from all of these groups and allowed them to share both established knowledge and current research and to look for connections and potential collaborations. Conference participants enjoyed three days of presentations and discussions, a field day with *in situ* investigations of interpretive process and spatial thinking, and direct assessment of spatial thinking skills. This volume is a concrete outcome of the conference.

KEY CONFERENCE FINDINGS

By the end of the conference, many of the participants expressed significant new insights. These included a new appreciation for the complexity of the interpretation mission, both geologically and cognitively; a deeper understanding of the distance and differences between novice and expert geoscientists exemplified by the approaches taken in 3-D interpretation; understanding the benefits of the cognitive processes and cognitive challenges of our work; and a desire to learn and apply research-proven strategies to help move people from novice to expert more efficiently.

Most academic geologists were impressed with the complexity and intellectually stimulating geology in typical industry subsurface projects. They were further impressed by the power of industry software to display and manipulate 3-D data. Geologists, both in academia and in industry, also recognized the key differences between traditional surface geologic mapping and interpreting subsurface 3-D structural frameworks. These differences emerged when academic and industry participants compared interpretations during the field exercises and highlighted contrasting strategies for spatial thinking. The cognitive scientists, while struggling to follow the nuances of geological interpretations, were quite impressed by the speed and facility with which geologists developed and discussed mental models of complex stratigraphic and structural systems. Conversely, geologists developed a greater appreciation for the cognitive challenges inherent in 3-D interpretation.

Novices and experts clearly interpret structures with different skills and strategies. Novices can be overwhelmed with information (and software) and struggle to build a 3-D mental model. Experts are more likely to rely on mental representations but may be misled by experience bias. Training methods must account for novice vs. expert abilities.

For the majority of the conference participants, the cognitive science perspective on what we do, how we do it, and how we can teach/train people to do what we do was completely new. A few key ideas generated a high level of interest. First among these is that spatial cognition improves with practice and degenerates with disuse. Furthermore, whatever we can do to reduce the cognitive demands of visualizing spatially complex datasets frees our minds to analyze and interpret the data. Strategies that are known to help with cognitive off-loading include gesturing, sketching, and working with computerized visualizations of the data. There are obvious implications in this for teaching and training the next generation of interpreters.

OPPORTUNITIES AND ACTIONS

Several key opportunities emerged during the conference, with strong support and commitments from participants. These opportunities include:

(1) Increasing awareness of the subsurface interpretation mission and methods across the academic geologic world. Participants recognized opportunities for collaboration in the design of teaching activities for undergraduates, including the use of simplified software that mimics some of the features of industry software. These collaborations will improve undergraduate geoscience education, introducing students to real 3-D data and real-world problems, and will also lead to better-prepared industry recruits.

(2) Encouraging industry interpreters to use 3-D interpretation environments as their default tools. Conference presentations illustrated how the use of 2-D environments creates cognitive challenges that inevitably lead to geologically implausible (or impossible) interpretations. It was recognized that some of the obstacles to wider adoption lay with a desire for manageable corporate policy, and perhaps general resistance to change, rather than always using the best tools for the job.

(4) Applying spatial cognitive science and informed pedagogy for interpretation tools, strategies, and training methods. For example:

Make use of analogy. Appropriate use of analogy allows us to develop our understanding of unfamiliar concepts by carefully constructed comparison to familiar ones. Teaching analogies can be as sophisticated as the use of surface exposures of structural systems (such as the Hat Creek fault zone) that mimic the behavior of subsurface systems.

Make use of gesture and sketching, to help with cognitive off-loading. Both gesture and sketching help us to visualize 3-D structures, freeing our cognitive resources to engage in analyzing those structures. These strategies (most of us use them completely naturally) can be particularly helpful in developing and testing hypotheses. We can gesture or sketch several different ideas, articulating what data would help us to choose from among them.

Make use of scaffolding. Start with less complex examples and build complexity as students or trainees develop the skills to handle them.

Consider these and other cognitive issues when designing the next generation of interpretation software and hardware.

(5) Pursuing further interdisciplinary and cross industry–academic collaborations. For example:

Software developers and cognitive scientists, working together, could develop interpretation hardware and software specifically designed for more intuitive use.

Industry and academic interpreters, working together, could leverage industry data to hone time-consuming techniques normally reserved for academic research into simpler, more productive workflows for industry.

Industry trainers and academic educators, working together, could develop and refine teaching and assessment methods designed to help students and trainees tackle the cognitive challenges inherent in 3-D analysis.

Industry interpreters, academic geologists, and cognitive scientists, working together, could refine our understanding of those cognitive challenges and also document how experts tackle them.

Academic geologists and cognitive scientists, working together, could refine the tools and methods we use to measure spatial thinking skills in our students and trainees.

As an outcome of this Hedberg conference, the new AAPG Petroleum Structure and Geomechanics Division has sponsored a new committee for structural interpretation. Initial enrollment includes many of the conference participants. To further promote industry–academic collaboration, we led a workshop, with other Hedberg conference participants, on 3-D seismic interpretation for faculty at the 2014 GSA Annual Meeting.

INTRODUCTION TO THE VOLUME

The chapters in this volume derive from presentations, discussions, and research conducted during the 2013 Hedberg conference on 3-D Structural Interpretation. Like the conference itself, these chapters provide an unusually broad spectrum of topics that have important connections and implications for geologic interpretation, and from an equally broad range of author affiliations and backgrounds. The volume is organized into four sections.

The first section includes papers focused on spatial thinking, geologic cognition, and 3-D visualization. Chapter 2 provides a review of spatial thinking skills, especially as applied in geology, how these skills have been assessed, whether spatial thinking can be improved through training, and where current research efforts are focused. Chapter 3 discusses the concepts of visual metaphors as applied to understanding, communicating, and teaching all aspects of structural geology, from descriptive analysis to kinematic and dynamic analysis. It shows how metaphors can inform and enhance 3-D (and 4-D) understanding of geologic structures and processes. Chapter 4 shows how a deceptively simple digital geologic tool can effectively engage learners and provide interactive and intuitive 3-D models including faults and folds that users can create and dissect. Reporting the results from tests taken by the Hedberg conference participants, Chapter 5 examine spatial abilities in geoscientists, especially expert structural geologists.

The second section contains three chapters that discuss aspects of geologic interpretation, especially in the subsurface. Chapter 6 addresses a broad view of interpretation, from early scientific thinking to current oil industry applications, and from general concepts to practical methods for producing accurate geologic models. Chapter 7 highlights the significance of the 3-D structural framework and argues for the importance of the complete geologic interpretation required to generate valid frameworks. It presents the basic steps leading to complete structural frameworks and shows examples. Chapter 8 discusses how specific geologic knowledge, in this case mechanical stratigraphy, can be integrated with other observations to inform an interpretation that goes beyond the resolution of seismic data.

The third section looks at the interpretations of fault systems, with a particular focus on the Hat Creek fault zone, the location for the Hedberg conference field sessions. Chapter 9 provides a comprehensive outcrop mapping and analysis of the Hat Creek system, showing how distinct phases of faulting over a short time span produced considerable complexity with fault elements and offsets equivalent to many subsurface hydrocarbon traps. Chapter 10 presents the method and results of a "subsurface" interpretation of the Hat Creek fault system, based on a synthetic 3-D seismic volume generated from the outcrop. The efficient workflows generate a complete 3-D framework suitable for typical oil industry applications. Chapter 11 presents an analysis of interpretative field sketches made by the Hedberg conference participants. The types of sketches made reflect the outcrop expression and task, as well as the backgrounds of the participants.

The fourth section considers how concepts of spatial thinking and geologic interpretation affect education and training. Chapter 12 describes a three-phase industry fault interpretation training course that builds progressively from 2-D seismic lines, through outcrop investigations, and ends with a 3-D digital model. The approach encourages 3-D thinking integrated with geologic concepts and also provides practical rules of thumb. Chapter 13 describes the importance of conceptual models in geologic reasoning, including both geometry and process, and how these models relate to structural interpretation. It suggests how these insights can improve approaches to geologic education and training.

Each of these chapters is worth reading for its own content. However, their greater value is as a collection of perspectives on 3-D structural interpretation. By considering the interpretation mission through each of the lenses provided here, we can better understand the unique challenges and opportunities we face, and can begin to explore new tools and methods for visualizing and analyzing 3-D structures.

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