[PS]Characteristics of Expert Behavior in Problem Solving and Workflow Strategy in Seismic Interpretation*

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Abstract

Over the past fifty years, reflection seismology has become an integral tool for visualizing the Earth's subsurface, and it is a key workforce skill in industries and academic pursuits that use this tool to image subsurface structures to locate resources, such as water, fossil fuels, and ores. Seismic data are often sparse and incomplete, making it necessary for geoscientists to make predictions and interpretations which are strongly influenced by experience, training and expertise. While the techniques and data quality in reflection seismology have been refined over the course of decades, the process of human interaction and successful problem-solving approaches with seismic data remain poorly documented and understood. This study was designed to advance understanding of the interactions, strategies, and techniques graduate geoscientists employ in the process of 2D seismic interpretation. This qualitative study was designed to record pre-professional, experienced participants in order to develop insights into emerging expert behavior in this task. Videos of participants were coded for co-occurrences of features that were identified by participants, the markings participants made, the order of common features among participants, physical interaction with the images, and time use between the different exercises resources provided to participants during interpretation. Information was also collected with a background survey and through interviews in order to gain insight into participant's experience with seismic interpretation. This information was used to place participants into different levels of expertise. Our results show that the lowest expertise group uses a less holistic approach with the available resources and is more hesitant to use written observations during their exercise. The high and medium groups also employed strategies that the low group did not to help them asses the seismic data set. Additionally, we were able to show and categorize the common elements among participants' interpretations, and offer a method to capture workflow strategies. The insights from this study will help guide future research to probe the practice of seismic interpretation, with the hope to provide instructors with new teaching methods and help create software advancements. Ultimately, the goal is to improve the efficiency of training geoscientists in seismic interpretation.

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Introduction

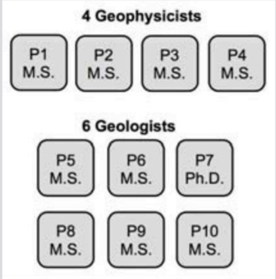
Over the past fifty years, reflection seismology has become an integral tool for visualizing the Earth's subsurface, and it is a key workforce skill in industries and academic pursuits that use this tool to image subsurface structures to locate resources, such as water, fossil fuels, and ores. Seismic data are often sparse and incomplete, making it necessary for geoscientists to make predictions and interpretations which are strongly influenced by experience, training and expertise.

While the techniques and data quality in reflection seismology have been refined over the course of decades, the process of human interaction and successful problem solving approaches with seismic data remain poorly documented and understood. This study seeks address this interaction employing a rigorous qualitative study rooted in an authentic context.

Research Design and Intent

Ten graduate students participated in this study, and all have seismic interpretation experience and are working toward a career in the petroleum industry. The participants are a combination of geologists and geophysicists at varying levels of ability and experience with their graduate programs and in industry. Participants are asked to geologically interpret two intersecting seismic lines over the course of an hour, and had both paper seismic lines as well as digital images (PDFs) of the same lines to work with.

The entire exercise was video-recorded from multiple angles to allow for detailed observations of workflow, gesture, and annotations made while the participants were engaged in interpretation. Immediately upon completion of the individual exercise, interviews were conducted with each participant to record their narrative of the process. Interviews lasted between 15 and 25 minutes and were semi-structured in nature. Questions seek to address and understand geological interpretations, interpretation confidence, additional desired, and the petroleum significance of any feature.



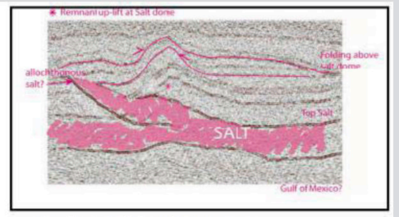
Participants	P1	P3	P7	P8	P4	P6	P2	P5	P9	P10
Experience Level - As designated by the Researcher	High	High	High	Medium-High	Medium	Medium	Medium-Low	Low	Low	Low
Self Assessment of Seismic Experience	Proficient	Novice	Novice	Proficient	Proficient	Novice	Novice	Novice	Novice	Novice
Thesis involves seismic interpretation	Yes	Yes	Yes	No	No	No	No	No	No	Yes*
Formal Training in Seismic Interpretation	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
IBA Seismic Interpretation	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes**	Yes**
Additional Experience	Industry Processing	Industry		Industry			Processing	Short Courses, Industry		

Prior Research

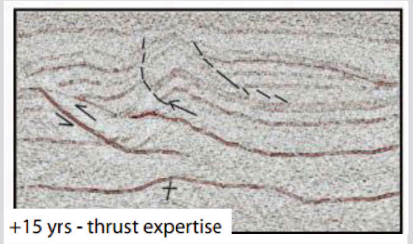
There is only limited work capturing participants engaged in the interpretation process.

Bond, Gibbs, Shipton, and Jones (2007)

Analyzed interpretations of 412 geoscientists



Student - PhD salt tectonics



+15 yrs - thrust expertise

Authors collected information from each participant on possible factors that they believed to influence interpretation

Factors influencing interpretation included:
- tectonic expertise
- breadth of expertise,
- the length of experience

Bond, Philo, Shipton (2011)
- Four Cohorts
  - Professional
  - Graduate
  - Two Undergraduate

Instructed to 'interpret the seismic section, by highlighting the main horizons and structural features, so you can identify an oil prospect, or place on the seismic section to bury hazardous waste'

- Synthetic Seismic Images
- Done in a group setting, influenced by others

Differences between Professional and Student Cohorts

1) **Students are focused on getting the right answer**
2) **Students, despite having the relevant geological knowledge, show a reluctance/ lack of confidence in applying interpretational techniques;**
3) **Students lack 'real world', more problem-based contexts for their interpretational reasoning, and have a limited sense of how to construct arguments and thereby advocate 'their' science**

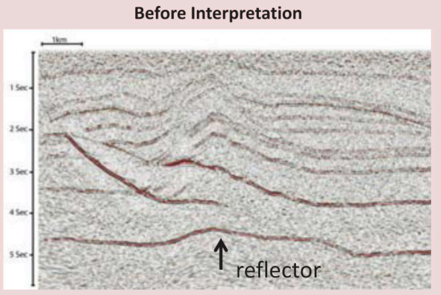
What is Reflection Seismology?

Artificial or natural energy waves move through the ground. Their interaction with the subsurface is used to collect an array of quantitative data

Used to locate resources, as well as gain a better understanding of the subsurface

(Yilmaz, 2001)

Before Interpretation



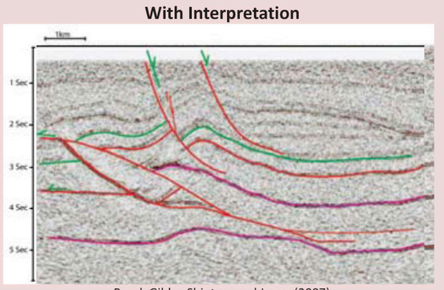
What is Seismic Interpretation?

They are predications based on observations of reflection seismology data

This may include lithology, geological structures, sedimentological relationships, and pore fluid type

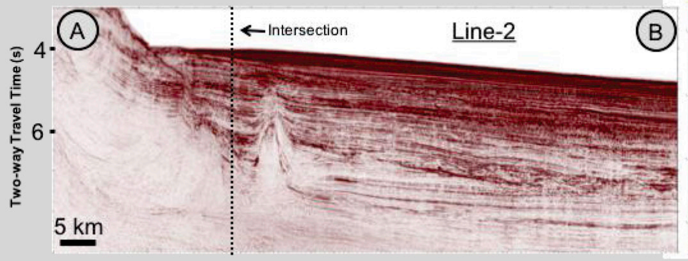
(Yilmaz, 2001)

With Interpretation

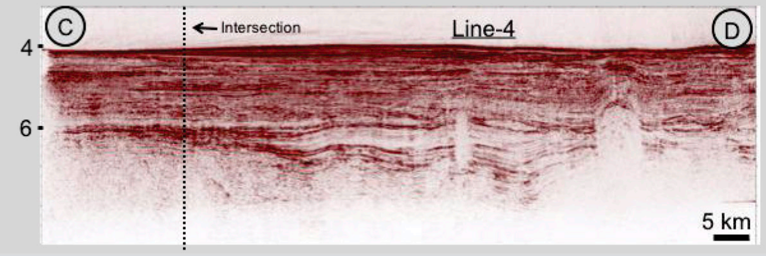


Bond, Gibbs, Shipton, and Jones (2007)

Seismic Data used in this Study

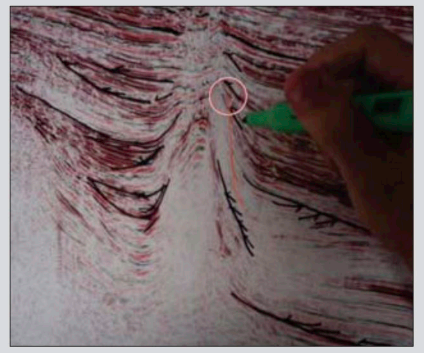


Map - showing the location and intersection of Line-2 and Line-4



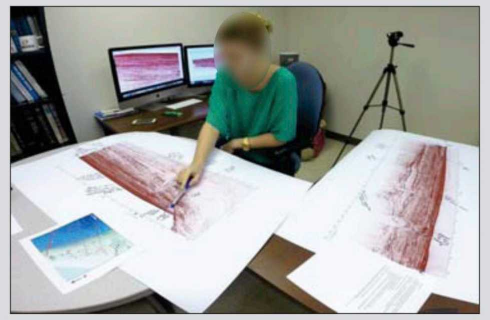
The map above show the locations of the two seismic lines and their intersection point. The lines were shot using ocean-bottom seismometers, offshore near the Carolinas. It also shows the locations of other seismic lines GeoPRISMS captured, but not used in this study.

During the exercise, participants are given two 2D seismic lines, line 1 & line 2. They are labeled with letters to show their orientation on the map above. Line 1 is perpendicular to the shore and captures a portion of the shelf margin.

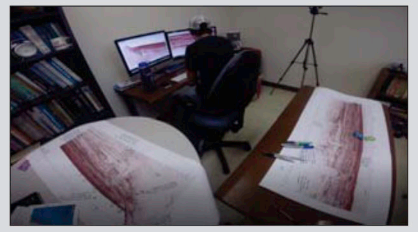


The image to the left was captured from video that was recorded during the eye-tracking exercise. The eye-tracking glasses provide the exact location the participants are observing, as well as the path along which they focus.

The image to the right was captured from video during the post-exercise interview. The participant is gesturing to Line 1, explaining an interpretation of a seismic feature. One of the other cameras capturing video can be seen, as well as the digital seismic lines on the computer screens providing the interpreter the ability to see smaller features.



Problem Statement



The *initial focus* of this research was to investigate geoscientists engaged in a seismic interpretation exercise

- Authentic Data involving Multiple Lines
- Less guidance on what they were to interpret
- Participants do their interpretations on their own

This study was designed to answer the following research questions:

(1) How do individual geoscientists work through and interact with a seismic data set?

(2) What techniques, practices, and strategies do individual geoscientists employ during seismic interpretation?

Theoretical Framework – Ethnography & Culture of Practice

Ethnography

- Seismic Interpretation as a Culture
  - Culture of Practice
- Naturalistic Style – meaning that the culture should be minimally biased by the intervention of the researcher
- Assumptions
  - Behavior can be understood
  - Applies to others in this culture
  - Researcher perspective is inherent throughout data collection and analysis

The Researchers' Perspectives

Jackson and Dobbs
- Imperial Barrel Award
- Short Courses
- Coursework

Riggs
- Industry engagement in field course design and assessment
- Consulting with industry on training and expertise development
- Short Courses

Data Analysis

Methodology - Thematic Analysis

- Flexible Approach for many Theoretical Frameworks
- Search for themes or patterns in the data relevant to research questions

(Braun and Clark, 2006)

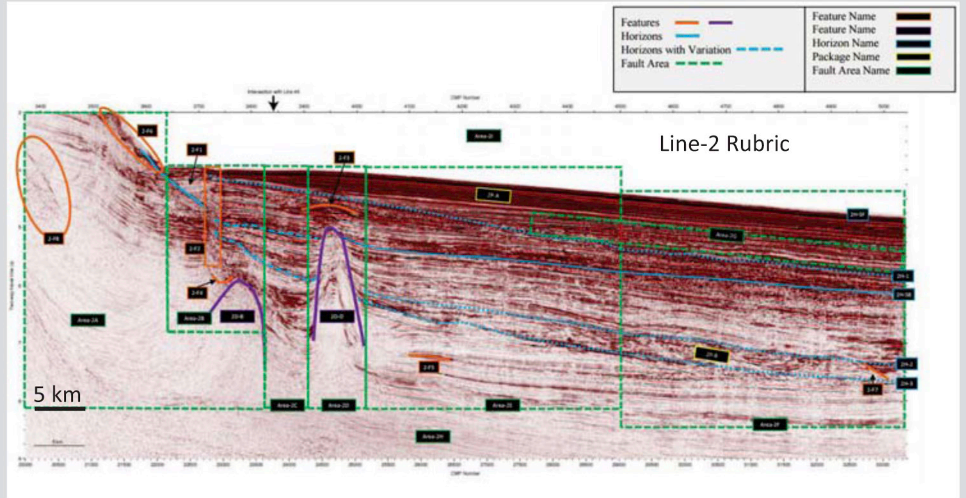
Trustworthiness of Data

An independent researcher in our group also coded a portion of the data in this study, and found 85% agreement, which was acceptable, especially given the complexity of the coding.

(QSR International, 2012)

Coding Rubrics

- Captures and names co-occurrences of features and horizons for second-pass coding
- Initially crowd-sourced from participants own actions
- Captures geophysical artifacts
- Fault areas aggregated (distribution of interpreted faults)
- Rubric for Line-4 was also made



The seismic lines in this research were provided by the **ENAM** Seismic Experiment, an initiative of **GeoPRISMS**.
Thanks to **Dr. Donna Shillington, LEDO** for this essential contribution to this ongoing research effort.

Results

Spatially Mapping Attention

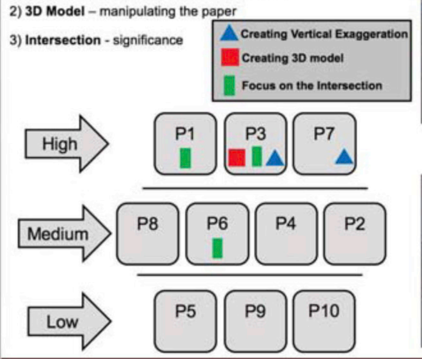
- 6 additional volunteers were recruited for an extension of this study that is still underway.
- Eye-tracking equipment captures the locations and durations of participant fixations on specific features. Warmer colors indicate areas where more time was spent observing.
- Preliminary analyses suggest that unique patterns can be derived from the gaze maps.
  - For example, the warmest areas in this snapshot occur at intersections of strata and diapir.

Expertise and Problem Solving

- Expertise or Experience?
- Subsequent in-depth interviews with all three of the participants designated as more expert explored the origin of these expert behaviors.
- Shown images of themselves exhibiting expert practice in their workflow, and asked to reflect on the experiences that built that behavior.
- All shared common types of transformative experiences that built expertise.
- Direct cognitive apprenticeship and deep observation/exposure to expert performance contributed to building expert behavior.
- **Experience does not necessarily impart expertise**, even in internship or short-course settings. Purposeful, techniques-driven inquiry and instruction built expert behavior – explicit and personal teaching of how and why, in problem solving,context is best.

Expertise and Problem Solving

1) **Vertical Exaggeration** – basic function in software that changes the vertical to horizontal aspect ratio
2) **3D Model** – manipulating the paper
3) **Intersection** - significance



Participant-7 creating vertical exaggeration

Participant-3 creating a 3D model and focus on the intersection point

Expertise and Problem Solving

1) Creating vertical exaggeration, the focus on the intersection, and creating a 3D model all correspond to those of higher expertise.

2) These are basic strategies, yet their application is unique primarily among the high group. The actual application may be indicator of expertise, as experts are more able to select the appropriate strategies to "problem solve" (Chi, 2006)

3) We do not know what they were using these techniques to do. Eye tracking and strategic interviewing may be able to provide this.
- P3 's creation of a 3D model may be even using spatial reasoning

Summary

Experience	High			Medium				Low		
Participant	P7	P1	P3	P8	P6	P4	P2	P5	P9	P10
Used Pencil	X		O	X			O			X
Vertical Exaggeration	X		X							
Created 3D Model			X							
Intersection		X	X		X					
Ghost Tracing		X	X		X			X		X

X = multiple times O = one time

Other techniques found but not related to expertise
- Use of pencil to make less permanent markings
- Ghost tracing

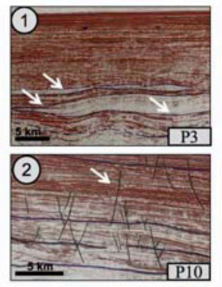
(Bond, Philo, & Shipton, 2011)

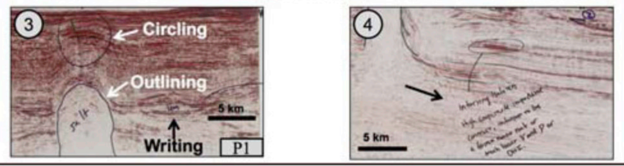
Interpretation Elements & Expertise

Interpretation Elements are the markings participants make on the paper seismic lines.

1. **Drawn horizons** – along reflectors or changes in reflector behavior
2. **Drawn vertical lines** (fault sticks)
3. **Identification of features,** which are circled or drawn to with an arrow usually accompanied with writing, or outlined
4. **Writing**

(Modified from Bond, C. Lunn, Shipton, A. Lunn, 2012)





Workflow - Findings

Rubric Established Order of Features

Five most interpreted features colored

- Preference for 8 of the participants to start with the most identified features
  - "front loaded"
- Three of the participants have a more spaced out distribution of the highlighted feature
- The data suggests that individuals have preferences to how they analyze the data
  - Cannot account for thought processes
  - Or eye movement
- Lots of variability in the order
- Was not able to establish a link to experience
- Expertise is subjective, often changing depending on the context (Clancey, 2006)
  - Take a more opportunistic approach to data collection to elicit thought processes

Conclusions

1. Self assessment of expertise is unreliable and limited, independent external measures of expertise are recommended

2. We have documented behaviors that are consistent with higher levels of expertise. These include:
   I. Holistic thinking, broad use of resources and time
   II. Application of certain problem solving techniques (interactions with the line), as experts are more able to select the appropriate strategies to "problem solve"
   III. Individuals with more expertise use more written observations to support their science

3. Coding data and workflows using a "crowd sourcing" technique developed in this study allow the use of participant data to indicate prominent and subtle yet potentially important features.

4. Workflows are individualized and variable and do not simply track with expertise level. Developing independent means to capture thought processes in their problem solving approaches may uncover expertise better than a log of steps.