Analysing Variability in Geophysical Data Interpretation by Monitoring Eye Gaze Movement

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SUMMARY

Geoscientific data interpretation is a highly subjective task as human intuition and biases play a significant role. Based on these interpretations, however, mining and petroleum industries make decisions with paramount financial implications. The aim of this study is to better understand variability in geophysical data interpretation between and within individuals. We examine the data observation pattern during interpretation using an eye tracker that captures the interpreter's eye gaze motion. Two preliminary experiments were conducted to analyse how individuals approached the task of identifying prescribed 'targets' in magnetic and seismic data respectively. Each experiment used five participants who have varying degrees of experience in these tasks.

The first experiment involved identifying responses from porphyry-style intrusive systems in magnetic data of an area from Reko Diq, Pakistan. The target responses are sub-circular positive magnetic anomalies surrounded by annular lows. The second experiment was to spot unconformities and faults in a seismic image using data from the Mentelle Basin in Western Australia.

The results show a significant variation in data observation patterns between interpreters. Some key findings include: a direct correlation between a higher target spotting success rate and a more systematic data search pattern; significant inconsistency in target spotting results when viewing a data in a different orientation; and a significant variation in the amount of time spent on noise dominated region.

Key words: geoscientific data interpretation, interpretation variability, eye tracker, data observation pattern

INTRODUCTION

Geoscientific data interpretation is a complex and highly subjective task. It demands the understanding of events in distant past using often incomplete and disparate datasets. For example, mineral explorers collect and interpret geological, geochemical, geophysical and remote sensing data to improve the understanding of the sub-surface geology and to predict and prioritise the locations of potential resources in the area being explored. The situation is further complicated by the fact that interpreters bring pre-suppositions and expectations to their interpretation (Frodeman 1995). The study reported here addresses the problem of variability in geophysical data interpretation which may propagate into decision uncertainty within the mineral and petroleum industry.

Only a few studies have been reported on understanding uncertainty in geoscientific data interpretation. Rankey and Mitchell (2003) discussed that seismic interpretations are influenced by the interpreter's biases based on previous experiences, preconceived notions, types of data available, data quality and geological understanding. A study by Bond et al. (2007) analysed the seismic interpretations of 412 interpreters using a synthetic seismic image. Their result showed that only 21% and 23% of the participants correctly identified the correct tectonic setting and three major faults respectively. The above mentioned researches demonstrated between-interpreter variability solely on seismic data. On the other hand, Wastell et al. (2011) reported that variability in mineral exploration decision-making is due to human predisposition such as rational thinking and cognitive closure. All of the above studies used interpretation outputs and interpreters' feedback to analyse interpreter variability. To our knowledge, there has been no study aiming to understand the process through which the interpretation is reached.

We aim to better understand interpretation variability by examining the data observation process as well as the interpretation output. This is achieved by monitoring human data interactions during interpretation using an eye tracker (ETS) that traces the eye gaze of the interpreter. While the use of an eye tracker is new to geoscientific research, it is widely used in the applications in human computer interactions (Prendinger et al. 2007) and video classification (Vilarino et al. 2007).

This study examines interpretation variability using two geological target-spotting exercises using magnetic and seismic datasets. Our preliminary experiments used five participants with varying degrees of interpretation experience for each of the exercises.

The first exercise was to identify porphyry footprints in magnetic data from the Reko Diq area in Pakistan, which is a region known to contain numerous occurrences of porphyry-style mineralization. A model footprint for these systems appears as an elevated sub-circular feature with surrounding annular lows (Holden et al. 2011). In this exercise, we identified a significant between-interpreter variation in target detection rate; and a correlation between a systematic data observation involving a sequential searching of neighbouring features and a high target detection rate. In addition, an experiment on viewing the data in different orientations demonstrated: within-interpreter inconsistencies; and the need for viewing the data in varying orientations to improve geological target spotting.

The second exercise was to spot unconformities and faults in a time-migrated seismic image acquired in the Mentelle Basin in Western Australia. This experimental result shows the level of seismic data interpretation experience is highly correlated with systematic data observation in sequentially searching for nearby features, and the length of time spent on the feature region in comparison to the noise dominated areas within the data. This suggests the need for training of seismic interpreters in the identification of noise.

METHOD AND RESULTS

Eye tracker system

This research used a Mobile Eye Tracker by Applied Science Laboratories (see Fig. 1). The tracker uses two video cameras and three infrared light emitting diodes (LED), which are mounted on a pair of standard safety-type glasses. Over one of the eyes there is a circular cutout in the perspex lens. This cutout allows for the placement of an adjustable monocle that reflects the infrared light beam from infrared light emitting diodes (LEDs) (which are placed in a triangular pattern) onto the eye surface. Eye gaze is determined by comparing the reflected infrared light from the eye and the pupil, which are captured by the first camera. Forward facing second camera provides an image of the interpreter's field-of-view (FoV).

The eye tracker followed the interpreter's eye movement in real time in order to identify the locations of focus with respect to the FoV camera. The mapping operations are then applied to transform the tracker FoV coordinate to the pixel location of the displayed image. Due to the head movement of the participants during interpretation, we developed a robust mapping technique based on image analysis. This involved the development of camera lens correction, data display boundary detection and computer homography for coordinate transform.

Figure 1. A participant wearing an eye tracker (left) and the experiment set up (right). Note that the EEG data is captured during the experiment but the result is not described in this paper.

Experimental setup

Five participants with varying levels of experience and expertise participated in this study. All had normal or corrected to normal vision. Participants were asked to be seated in front of a display monitor (20.6 inches) at a convenient distance (from 60 – 100cm and were then fitted with the ETS glasses. The calibration of the ETS system was performed by fixating their eyes at known locations and marking those locations on the FoV video.

The experiments consisted of two exercises: (1) porphyry detection within magnetic data; (2) unconformity and fault detection within seismic data. At the end of *Exercise 2*, we conducted an additional experiment where the participants were asked to again perform porphyry detection using the same data used in *Exercise 1* which was displayed in a different viewing orientation.

For each exercise, details pertaining to the experiment and the tasks to be performed were shown on the screen at the beginning. During the exercise, the participants were asked to press the button when a target is spotted while fixating their eye gaze at the target location. These user responses (keyboard clicks) were recorded for the analysis. All the users were asked to rank themselves (from 1 to 10) in their level of expertise for each of the task. The level of expertise however did not reflect the performance in terms of detection accuracy. Our result here is based on their performance rather than their self-assessment.

Exercise 1 - Porphyry detection on magnetic image

The task for this exercise was to identify potential copper-gold rich porphyry systems in the magnetic data. This exercise consisted of two data interpretation experiments, where the data was displayed in the original and a rotated viewing angle (which will be referred as 'inverted' in this paper). In the first task, the data was displayed using sun shading with the illumination inclination of 45º and the declination of 0º. For the other task, another image was generated with illumination inclination of 45º and the declination of 180º to ensure the same shading effect on features as the original viewing direction. Participants were allowed five minutes for each task and had a 30 minutes break where they were distracted with other exercises between these tasks.

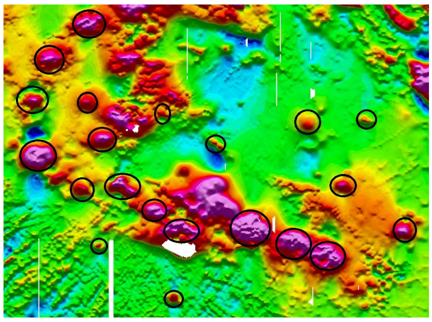

Figure 2. Known porphyry deposits in an area from Reko Diq, Pakistan outlined in black. Courtesy of Barrick Gold.

To quantitatively measure the target spotting accuracy, we required a ground-truthed data set. We used the known porphyry deposits in the region that contains magnetic footprints that are similar to the model described in (Holden et al. 2011) (Figure 2**).** Note that a couple of known deposits did not show a conventional magnetic signature. As this exercise only used magnetic data, they are not regarded as known porphyries.

Based on the responses by the participants, the number of porphyries identified without repetition (in some cases participants selected the same target multiple times) for the original and inverted magnetic image were calculated. Then theses two results were combined to calculate the total number of porphyries identified without repetition. The number of known porphyries identified by each participant was calculated (there are 21 known porphyries in that region) for those three categories. Based on these numbers recall rate was calculated using the following formula,

$$\text{Recall (R)} = N_{ik} / N_k$$

where, N_{ik} is the number of known porphyries identified by the participant.

N_k is the number of known porphyries in that region, which for our dataset, $N_k = 21$. Note that false positives cannot be determined here as exploration of the area is on-going, thus not all deposits are known.

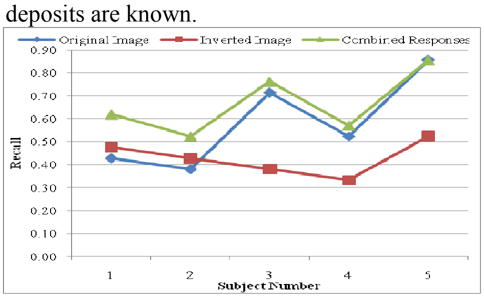

Figure 3. Recall rate versus subject for three different categories.

Results for the magnetic experiment include the following:

- ***Inconsistencies within individuals:*** For Subjects 3, 4 and 5, the recall rate for the inverted image was dropped by 36% to 47% from the original image (Figure 3), while for the others the recall rate has increased. This shows some participants performed well with the original image, while the others performed better with the inverted image.

- ***Effect on the combined recall rate by the viewing data in two orientations:*** All Subjects except Subject 5 have improved porphyry detection in the combined category than in the individual observation categories (Figure 3). This shows the observation of the images at different angles can increase overall performance.

- ***Training of low-achievers to improve their performance:*** Subjects 1 and 2 have increased their recall rate by 30% and 22%, respectively, in the combined category when compared to the individual observations of the images (Figure 3). This shows the low-achievers' performance can be increased significantly by using simple techniques in the presentation of the data. This will help in training of the interpreters.

- ***Variations amongst participants in observation pattern:*** The observation pattern shows two different strategies used by the participants.
  - Systematic observation - observing the images in a methodical way (Figure 5).
  - Random observation - observing the image in a random fashion (Figure 6).

  It is clear that the highest-achiever (Subject 5) (Figure 3) has travelled much less distance than the other subjects throughout the experiment, say for the final one (Figure 4). Sequential nature of observation is evident in the track plot of the eye gaze (Figure 5). For both the tasks Subject 5 started from the top-left corner and observed the data in anti-clock fashion. Even though all the participants travelled more distance towards their final responses, Subject 5 travelled comparatively less distance than others. The sequential nature of observation might have led Subject 5 to more easily and quickly spot the unexplored areas towards the end. But among the others, Subjects 1 and 3 travelled comparatively less distance in between the responses (Fig. 4). This indicates that the parts of their observations are also sequential, which resulted in identification of more porphyries with less repetition than other low-achievers. We noticed that false positives from some of the subjects, especially for Subject 5, corresponded well to the visual signature of a magnetic porphyry system.

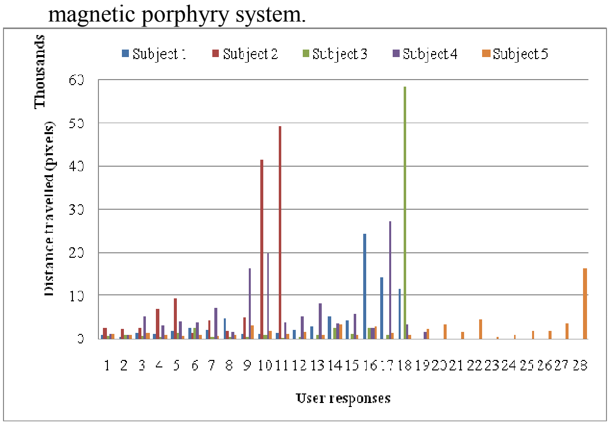

Figure 4. Distance travelled in between responses versus the responses for the original image by the participants.

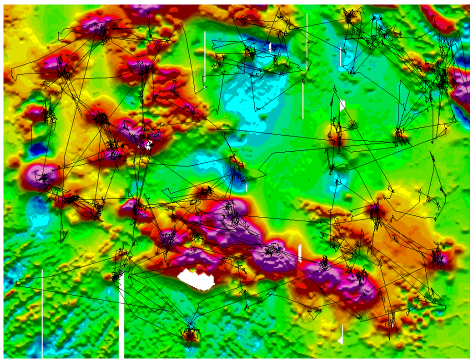

Figure 5. Eye-trace plots for the Subject 5's observation until the last response.

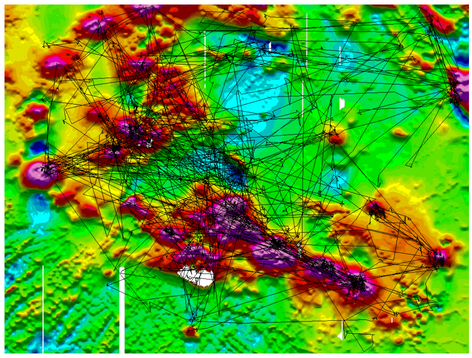

Figure 6. Eye-trace plot for the Subject 2's observation until the last response.

Experiment 2: Unconformities and faults in seismic data

Interpreters were shown the seismic profile for 100 seconds and their task was to spot unconformities and faults present in the image. We found that accurately quantifying interpretation performance rate was difficult due to the shape of the features, e.g. unconformities and faults being long linear features and many faults being close to each other. Thus we generated and analysed heat maps that represent the eye gaze visiting frequency for each location in the image along with the trace maps. Our findings are as follows:

- ***Significant variation in observation pattern:*** The data observation pattern varied significantly. Some subjects traced the features over a long distance before seeking others, while others sought features region-by-region focusing on a neighbourhood search (Figures 8 and 9). There seems to be no correlation between target spotting performance and the search method within our limited number of participants.

- ***Time spent on noise:*** Participants spent a significant amount of time on an area heavily contaminated by noise. Figure 7 shows the percentage of time for each participant on feature areas. This shows that participants spent up to 50% of the interpretation time spent on analysing noise. Training in dealing with noise for seems to be necessary for interpreters.

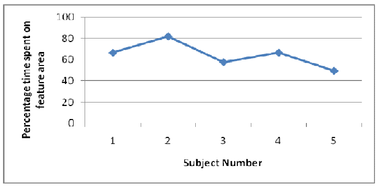

Figure 7. Percentage time spent on feature data.

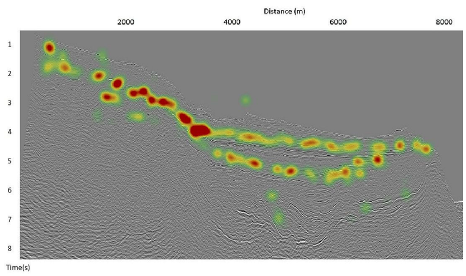

Figure 8. An eye gaze visiting frequency heat map for the seismic data experiment of a participant.

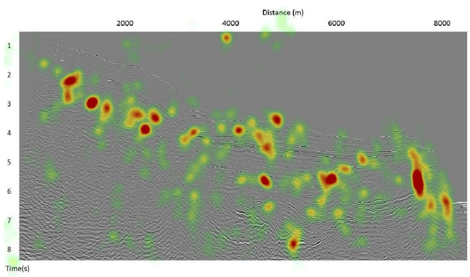

Figure 9. An eye gaze visiting frequency heat map for the seismic data experiment of a participant.

- ***Importance of the axes scale:*** It is noted that only one subject has checked the scale in the data and even that was towards the final response (Figure 9). This may be due to the fact that the scale was not highly relevant to the task.

CONCLUSIONS

We reported on a preliminary study to investigate the variability in geophysical data interpretation involving two different data sets. Five participants with varying levels of experience and expertise participated in this study. The observation patterns show a significant variation amongst interpreters. We found that there is a direct correlation between higher target spotting success rate and a more systematic observation pattern in magnetic data. There is a significant inconsistency within an individual in target spotting result when viewing a data in a different orientation. But there is a significant improvement in performance by low achievers when the magnetic images were observed from multiple angles. The seismic data observation pattern shows there is a considerable amount of time spent trying to understand noisy areas. These findings may provide practical guidance on how to train geophysical interpreters to improve their performance and accuracy. On-going research focuses on collecting data from larger number of participants to generate more conclusive evidence on variability based on their expertise and training background.

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