

Eye-Tracking Investigations Exploring How Students Learn Geology from
Photographs *and* The Structural Setting of Hydrothermal Gold Deposits in
the San Antonio Area, B.C.S., MX

by

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A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

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May 2011

ABSTRACT

Geoscience educators commonly teach geology by projecting a photograph in front of the class. Geologic photographs often contain animals, people, and inanimate objects that help convey the scale of features in the photograph. Although scale items seem innocuous to instructors and other experts, the presence of such items is distracting and has a profound effect on student learning behavior. To evaluate how students visually interact with distracting scale items in photographs and to determine if cueing or signaling is an effective means to direct students to pertinent information, students were eye tracked while looking at geologically-rich photographs. Eye-tracking data revealed that learners primarily looked at the center of an image, focused on faces of both humans and animals if they were present, and repeatedly returned to looking at the scale item (distractor) for the duration an image was displayed. The presence of a distractor caused learners to look at less of an image than when a distractor was not present. Learners who received signaling tended to look at the distractor less, look at the geology more, and surveyed more of the photograph than learners who did not receive signaling.

The San Antonio area in the southern part of the Baja California Peninsula is host to hydrothermal gold deposits. A field study, including drill-core analysis and detailed geologic mapping, was conducted to determine the types of mineralization present, the types of structures present, and the relationship between the two. This investigation revealed that two phases of mineralization have occurred in the area; the first is hydrothermal deposition of gold associated

with sulfide deposits and the second is oxidation of sulfides to hematite, goethite, and jarosite. Mineralization varies as a function of depth, whereas sulfides occurring at depth, while minerals indicative of oxidation are limited to shallow depths. A structural analysis revealed that the oldest structures in the study area include low-grade to medium-grade metamorphic foliation and ductile mylonitic shear zones overprinted by brittle-ductile mylonitic fabrics, which were later overprinted by brittle deformation. Both primary and secondary mineralization in the area is restricted to the later brittle features. Alteration-bearing structures have an average NNW strike consistent with northeast-southwest-directed extension, whereas unaltered structures have an average NNE strike consistent with more recent northwest-southeast-directed extension.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my advisor, Dr. Stephen Reynolds, for his support and guidance during my Ph.D. dissertation work. Steve was more than just an advisor, he was a friend. I would also like to thank my committee members, Dr. Ramón Arrowsmith, Dr. Michelene Chi, Dr. Michael Piburn, and Dr. Steven Semken for their willingness to review this work and offer suggestions.

I would also like to extend my gratitude to Melvin Herdrick, John Reynolds, and Gary Freeman for their help and guidance while working in Mexico and for sharing borehole logs, technical reports, and GIS data. I would like to thank Julia Johnson for allowing her students to participate in the geocognition research, without which this dissertation would not have been possible.

I would also like to thank Melanie Busch for her contributions to my research. She not only spent weeks analyzing and measuring outcrops in Mexico, but she was a constant source of reflection and discussion while conducting education research. She edited manuscripts, provided insights into statistical methods, and provided emotional support when needed.

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PREFACE

The process of communicating the results of science is equally or more important than the process of doing science. Commonly, illustrations and inscriptions necessary to convey ideas and results (graphs, charts, 3D models, and photographs) are complex. Even an inscription as common as a geologic map is incredibly complex, requiring a scale, geographic coordinates, and a key or legend.

My own geology research involves measuring the orientation of structures in an area, mapping units, denoting the presence and type of mineralization and alteration, compiling previous research, and making inferences about the nature of gold emplacement and, ultimately, recommending locations for exploration and mining. To convey this information to investors, company owners, and fellow scientists, it is necessary to produce geologic maps, schematic diagrams of drill core, cross sections, and annotated sketches. It is the complex nature of graphics used by me and other geologists, which provides an opportune area for visualization research, which is a second research interest of mine.

As a scientist and an educator, I am interested in exploring ways to improve my own ability to visually convey ideas as well as student understanding of geologic content. I have taught and sat in many lecture-style geology classes in which a photograph is projected in front of the class and the instructor begins to talk about the geologic feature or process present in the photograph. The assumption is that students can identify the feature being discussed and mentally

map the content being delivered from the lecturer onto the photograph. Often, this is not the case.

It is through the combination of my two types of research, geology and geocognition, that I am beginning to understand not only how to explore our world, but how to explain it. This dissertation, therefore, presents research from both disciplines. It is divided into three chapters; the first two chapters describe the results of eye-tracking research designed to explore how students look at photographs, how students interact with distractors in photographs, and how we can use attention-directing cues or signaling to assist students in disembedding geologically pertinent content from photographs. The third chapter presents the result of a structural geology study, which included geologic mapping, measuring structures in outcrop and drill core, and constructing geologic cross sections to determine the relationship between gold mineralization and geologic structures in the San Antonio area in the southern portion of the Baja California Sur, MX.

Chapter 1, *Assessing how visual distractors in landscape photographs influence geology student learning behavior*, explores how students look at geologic photographs accompanied by narration. A common practice in the geological sciences is to include a human or object, like a rock hammer, in a photograph so that viewers can discern the scale of geologic features. Chapter 1 presents the result of an eye-tracking investigation in which we eye tracked 170 students and analyzed their visual behaviors while looking at a series of photographs with distractors and without distractors.

Chapter 2, *The impact of explicit visual signaling on student ability to disembed relevant features from geologic photographs*, explores how effective cueing is at directing students to look at geology that has greater relevance. Past research has found that cueing or signaling has been successful at directing novice learners to salient items in a photograph or animation. Chapter 2 presents results from an eye-tracking study in which we eye tracked 50 participants who looked at geologically rich landscape photographs. Visual directive cues were added to the photographs in an effort to increase students' focus on geologically relevant portions of the photograph. We compared the visual behaviors of students who received signaling with those who did not receive signaling to determine the effectiveness of signaling.

Chapter 3, *Structural setting of hydrothermal gold deposits in the San Antonio area, B.C.S., MX*, presents a detailed geologic map, a series of cross sections, schematic illustrations of drill core, and the results of a structural analysis. Gold exploration in the San Antonio area of the Baja California Peninsula has been occurring since the 1500s. Recently, in 2005, a mining company (Pediment Exploration) obtained mineral rights to three concessions nestled in the Las Colinas Mining District near the town of San Antonio. In 2007, Pediment Exploration contracted us to conduct a study to determine the controls of gold mineralization and make recommendations for future exploration. Chapter 3 presents the result of that study.

Chapter 1

ASSESSING HOW VISUAL DISTRACTORS IN LANDSCAPE PHOTOGRAPHS INFLUENCE GEOLOGY STUDENT LEARNING BEHAVIORS

Abstract

Commonly geoscience educators teach geology by projecting a photograph in front of the class. Frequently geologic photographs contain items including animals, people, and inanimate objects that help convey the scale features in the photograph. Although scale items seem innocuous to instructors, the presence of such items is distracting and has a profound effect on student learning behavior. To evaluate how students visually interact with distracting scale items, students were eye tracked while looking at geologically-rich photographs. Eye-tracking data revealed that learners primarily looked at the center of an image, focused on faces of both animals and humans if they were present, and repeatedly returned to looking at the distractor for the duration an image was displayed. The presence of a distractor caused learners to look at less of an image than when a distractor was not present. Additionally, learners had a tendency to fixate on the focus of the gaze of a human in the photograph.

1. Introduction

Visualizations have an important role in geology and have led to the development of a visual language among geologists (Rudwick, 1976). Geologists use multiple representations, in their research and teaching, to understand and convey geologic information to both professionals and students (Libarkin and Brick, 2002; Lowe, 2003; Reynolds et al., 2005). As pressure in schools to lower spending increases, fieldtrips are becoming less common. As a result new ways and techniques are constantly being developed to teach students geology. Multiple representations have become common and range from schematic diagrams to simple computer animations to immersive 3D environments (Edelson and Gordin, 1997; Chen, 2004; Reynolds et al., 2005; Johnson et al., 2006). The main staple of geology education, however, is photographs, which are used to illustrate geologic features, processes, landscapes, and hypothetical sequences of events.

Central to the premise of teaching with photographs is the idea that students can recognize, in a photograph, the key geologic features or processes. This is difficult for some students due to a lack of understanding or an inaccurate mental model of geologic concepts. Student difficulty in creating accurate mental models may originate from either the inaccurate selection of pertinent information from pictures, text, or diagrams or the inability to organize salient information in a meaningful way (Lowe, 2003; Schnotz and Bannert, 2003). Additionally, in many cases students may fail to make proper connections and inferences in a photograph due to misuse of their cognitive resources or from distractors inherent in learning materials (Sneider and Shiffrin, 1977; Baigrie, 1996).

Common classroom practice in geology is for an instructor to project a photograph of a geologic landscape in front of a class in order to illustrate the geologic features in the photograph. These photographs more often than not require an object or person present to represent relative scale. As teachers, we assume that students are focused on the geologic content being discussed, which may not always be the case. Objects included in a photograph for scale, along with the rich, often extraneous, details of landscape photographs, may be distracting to learners and may cause selective-attention deficit, thereby preventing the viewer from learning key content. Selective-attention deficit comes in two forms: divided-attention deficit, where the participant's attention is unconsciously split between multiple stimuli, or focused-attention deficit, where the participant consciously knows what information is relevant, but cannot ignore the irrelevant stimuli. In both cases performance is reduced due to high cognitive load (Schneider and Shiffrin, 1977). It is often difficult for students to disembed pertinent, scientific information (Lowe, 2002). Students may not be able to distinguish relevant targets, such as faults and folds, from distractors or other non-related items appearing in the frame (Scneider and Shiffrin, 1977; Mayer, 2003).

In order to determine if learning deficits occur due to typical items used for scale in photos, we use eye-tracking technology to answer several questions. How do students search for meaningful information in a geologically rich photograph? What are the effects, if any, of having a scale object in a photograph? In addition to answering these questions we explore student-learning outcomes

based on their interactions with distractors and present suggestions and best practices for teaching with photographs.

Our research shows that students primarily look at the center of an image and that the presence of a distractor not only has a profound effect on how an individual examines a photograph, but how much of a photograph is examined. Additionally, if a human is used for scale, the face of the human is a location for high visual activity, drawing the student's attention away from more pertinent features.

2. Background

2.1 Obtaining information

Searching photographs, creating mental models, and learning from photographs requires various cognitive processes including scanning, organizing and interpreting, building mental models, and integrating information from short- to long-term memory. The first step in understanding a photograph is gathering information from the photograph, which is done by a combination of saccades, or rapid movements of the eye, and fixations, areas that hold our visual attention (Buswell, 1935; Abrams, 1992; Babcock et al., 2002; Hyönä, 2010). The visual field of the human eye can be broken up into three areas, the foveal, the parafoveal, and the periphery. The fovea is located in the central portion of the macular region of the retina and has the highest visual acuity. The parafovea is a belt of cells surrounding the fovea with a range of 2 to 10 degrees and has less visual acuity. The periphery is the area outside of the central-ten-degree area of vision, is optimal for detecting low light levels and motion, but lacks visual acuity. Although the fovea has the highest visual acuity of the eye, it has a limited field of vision (approximately 2 degrees); therefore, it is necessary to move the eye in order to place the fovea over desired stimuli (Rayner, 1998).

When an individual fixates on an object in a photograph, meaningful information is gained about the structure of the object, color of the object, size of the object, inferred motion if any, and relative location of the object (Doll, 1993; Wolfe, 1993). As we combine information across many fixations we begin to piece together the picture as a whole.

The two main ways in which humans place the fovea over desired stimuli are automatic-detection search and controlled search. When we are not mindfully searching a photograph in a controlled manner, we are using automatic detection. Research has shown that there is a large similarity between observed automatic-detection search patterns and ideal, probability-based search patterns (Findlay and Gilchrist, 1998; Najemnik and Geisler, 2005). In general, during the initial survey of an image, humans will use a series of medium saccades to search for information. Search using medium saccades is an ideal behavior based on the probability of an object's location. Once the gaze is fixated on a location, the probability of a target being next to the initial fixation or far from or on the other side of a display is less than the probability of a target being a medium distance away. Therefore, to search for a target with the maximum probability of finding it, medium-length saccades are appropriate (Najemnik and Geisler, 2005). As a result, what may appear as a random series of fixations, may actually be an ordered, efficient way to search a photograph.

Controlled search is the process of mindfully fixating on an image in a serial, planned fashion. It is capacity limited, meaning that we can only store a limited number of targets in working memory. Controlled search often manifests itself in the systematic "reading" of a photograph or serial comparison (Schneider and Shiffrin, 1977). Although controlled search is a mindful process by which the participant consciously controls their eye movement and attention, this type of search may become an automatic-detection search, once the strategy is taught and rehearsed. A good example of this type of behavior is when an individual has

been trained to recognize certain visual inputs, such as a fault. Learned inputs may then elicit automatic attention responses, which direct attention to the target and enable a correct detection (Schneider and Shiffrin, 1977).

Other research has shown that increasing the viewing time of a stimulus, such as a photograph, causes fixation length to increase and saccade length to decrease. This signifies initial global survey of a scene (long saccades) followed by the collection of finer details (short saccades), usually corresponding to information-rich objects. Additionally, humans tend to focus on 1) elements like faces and people rather than background elements (Buswell, 1935; Mackworth and Morandi, 1967; Noton and Stark, 1971; Babcock et al., 2002) or 2) visually poignant items, such as edges or corners (Duchowski, 2002; Canham and Hegarty, 2010).

2.2 Organizing, interpreting, and forming mental models

According to Paivio's Dual Coding Theory (1986), there are two information processing systems, one to process nonverbal objects (the imagery system) and one for processing language (the verbal system). These two systems create unique representations for each type of information. Visual information is thought to be transformed first into a visual-mental model of the image and then into a mental representation of the image, which becomes meaningful by applying schemata based on everyday perceptions and previous knowledge and experiences (Schnotz and Bannert, 2003). Although the two information processing subsystems (verbal and visual) are distinct, they are functionally interconnected; therefore, one system can activate the other system (Paivio, 1986). Additionally,

Allopenna et al. (1998) conducted research in which students were given verbal instructions while viewing images. During their experiment, eye movement was monitored. Their research showed that visual processing continued uninterrupted while students received verbal instructions, strengthening the argument for dual coding.

Mayer and Moreno (1998) conducted multimedia-learning research to determine which method of instruction maximizes learning. They tested students' abilities to learn from a figure accompanied by either a verbal narration or written text. Students who received the verbal narrative outperformed the students who received the textual narrative, supporting the argument for distinct verbal and visual channels. Additionally, to maximize learning, Mayer and Moreno (1998) recommend utilizing both channels during instruction, rather than having the image and written text compete for the resources of the visual channel.

2.3 Eye tracking

Since the late 1800s there have been three eras of eye-movement research, the first concerned with reading behaviors, the second interested in behaviorist understanding of eye movements, and the third, involving the processes of recording and monitoring eye movements (Rayner, 1998). Since the 1970s, use of eye-tracking technology has exploded into myriad experiments to determine how humans visually interact with a plethora of settings and in multiple domains including mathematics, numerical reading, problems solving, marketing and advertising, dual-task situations, reading, face perception, brain-damage research (Duchowski, 2002) and recently the geological sciences (e.g. Busch et al., 2009

and 2010; Coyan et al., 2009 and 2010; Maltese and Riggs, 2009; Richardson and Libarkin, 2010).

Eye movements are a result of the perceptual processes that occur while looking at an image (Buswell, 1935). Hoffman and Subramaniam (1995) have shown that humans cannot voluntarily move their eyes to a new location without first shifting attention to the new location. It is important to note, however, that once a fixation has occurred, it is possible to consciously shift our attention outside of our foveal view or to the peripheries of our center of vision (Duchowski, 2002). The shift in attention; however, takes a conscious effort. As a result, when we are looking at a photograph, our conscious attention is typically focused on the item on which we are fixating. Consequently, we can come much closer to approximating where a student's covert attention lies by monitoring their overt attention using instrumentation that detects and records a student's fixations and saccades. Because eye movements are most commonly made without conscious intervention, monitoring them provides us with a window into cognition (Rayner, 1998; Babcock, 2002; Boucheix et al., 2010; Hyönä, 2010; Mayer, 2010).

Eye-tracking devices provide objective and quantitative evidence of a student's overt attentional processes (Duchowski, 2002), as a student scans an image through the combination of saccades and fixations. Fixations are defined as times when the eyes are mostly still and focused on something (Buswell, 1935; Abrams, 1992; Babcock et al., 2002; Hyönä, 2010). There are two types of saccadic eye movements that occur while scanning or searching. One type of eye

movement is used to shift attention; these are large-scale movements (macro saccades). The second type of eye movements are small-scale movements, which are used to correct vision (microsaccades). These small movements are always occurring, even when the eye is fixating on an object, although we are unaware of them. They include a constant tremor of the eye, which is believed to facilitate proper vision and firing of the retinal nerve cells. Another movement, drift, is the slow subtle movement that the eyes make as they wander off target. Drift is usually corrected by microsaccades, which restore our focus to the target (Rayner, 1998). Modern eye-tracking devices are able to record fixation location and length, saccade length (both the amount of time and the distance in degrees), and pupil-size information.

Eye tracking is preferred to a think-aloud protocol or a self-reporting protocol as a method of learning about students' cognitive processes; the latter methods have a high risk of social desirability bias, which is the tendency of participants to respond favorably to others (Arnold and Feldman, 1981; Donker and Markopoulos, 2002). Moreover, Schneider and Shiffrin (1977) have shown that competing stimuli may affect an individual's attention without the individual being aware of or being able to report the shift. Consequently, in cases in which individuals are unconsciously distracted by an object included in a picture for scale, individual may not self report this distraction. Self report of attention and eye movement is also limited by humans commonly being unaware of these movements and unable to describe them accurately (Buswell, 1935).

3. Methods

3.1 Participants

Participants consisted of 170 introductory geology students from a large university in the American Southwest. Participants ranged in age from 18 to 26, were undergraduate students, and were considered novices in geology.

Participants were randomly assigned to one of three groups: a control group (group 1) that listened to a narration about geology and two experimental groups that watched narrated slide shows about geology (groups 2 and 3).

3.2 Materials

3.2.1 Narrated slide show

Participants assigned to the experimental groups were exposed to a 12-minute-long-narrated slide show consisting of 16 images with accompanying audio narration (Appendix C). The slide show presented various geologic topics, including the following: how joints affects weathering, characteristics of sand dunes and the formation of crossbeds, formation of horizontal layers, characteristics of lava flows and volcanic necks, river deposits, unconformities, and layers that had been offset, faulted, and folded. The narration for the slide show was constructed from four introductory geology textbooks (Marshak, 2001; Tarbuck and Lutgens, 2002; Plummer et al., 2003; Reynolds et al., 2008). Common ideas from all four books were combined or altered to create a cohesive narration.

The two narrated slide shows were constructed in advance using Camtasia Studios software. Prerecorded narration was combined with images of landscapes

to make two nearly identical slide shows. Scale objects, or distractors, were either added or removed from the images using Adobe Photoshop. Examples of distractors added to photographs were humans, hot-air balloons, or vehicles (Figure 1.1). Likewise, humans, rafters, kayakers, and animals were removed in some images.

The key difference between the narrated slide shows observed by the treatment groups (groups 2 and 3) was that each image that contained a distractor for one group did not contain a distractor for the other group. For instance, when group 2 viewed an image about joints and the image contained distractors in the form of two climbers on the face of a cliff, group 3 viewed the same image but without the climbers. Conversely, in the next image, group 3 viewed an image with a distractor and group 2 viewed the same image without the distractor. Of the 16 images observed by each group, eight contained distractors and eight did not. The slides were arranged so that every other image contained a distractor (Table 1.1).

3.2.2 Pretest and posttest

All groups were given the same test as a pretest and posttest. The tests consisted of 16 multiple-choice questions about structures or geologic processes, such as how joints and erosion contribute to the formation of a landscape (Appendix A). The test was constructed using a pilot group of 22 participants who were asked the same 16 questions; however, the questions were open-ended and the pilot group was encouraged to produce written, free responses. The responses

from the pilot were then grouped, coded, and used as distractors on the pretest and posttest.

3.3 Procedure

Participants were randomly assigned to one of three groups: the two groups that watched the narrated slide show (group 2 and group 3) and the narration-only group (group 1, the control group). A fourth group was then used to understand the effects of taking the pretest and posttests and to conduct item analyses on the test (Appendix B). This fourth group completed the pretest, watched 20 minutes of a non-related geology video and then took the posttest; there was no significant difference between pretest and posttest scores for this group.

When participants arrived at the testing facility they were asked to review and sign a consent form. Students were told that they were being tested on the amount of information learned from an educational video with the goal of motivating them to pay attention and learn content in a natural way. The instructions presented to the participants omitted information about distractors so as not to overtly draw their attention to the distractors. This approach was taken because it has been shown that a participant will alter his or her behavior based on instructions given to him or her (Buswell, 1935; Yarbush, 1967; Rayner et al., 2001).

Following the instructions, participants were given a pretest and then exposed to the treatment, which involved viewing the narrated slide show (groups 2 and 3) or only listening to the narration (group 1). Participants were seated at a

desk surrounded on three sides by walls, allowing the experimenter to monitor the eye-tracking equipment out of the subjects view. The experimental space was designed to minimize a student's feelings of being monitored. Images were displayed on a 19" flat-screen monitor and narration was delivered through two, 6-inch-tall computer speakers located on each side of the monitor. Participants generally sat 18 to 24 inches from the monitor. Before the slide show began, the eye tracker was calibrated to each participant by having him or her look at a grid of numbered dots. During the treatment, acquisition of gaze data was manually monitored for completeness or loss of calibration. The control group received no visual stimulation through the monitor and was not eye tracked but sat in the experimental space and listened to the narration.

3.4 Eye tracking

3.4.1 Hardware

An Applied Science Laboratories' (ASL) D6 Desktop unit was used to record and calculate a participant's gaze locations. The D6 eye-tracking apparatus is approximately 8 inches wide by 4 inches tall by 6 inches deep, and was located below the 19" monitor. The D6 unit contains 2 cameras, one for heading-tracking purposes and one for monitoring the angle between infrared light bouncing off the participant's cornea and retina-reflected light escaping from the pupil. The D6 eye tracker calculates the angle between the two types of reflected light and then transforms the angle into x, y coordinates. The gaze location is later transposed onto the corresponding image.

3.4.2 Coding of eye fixations

All fixation and gaze analyses were conducted post hoc. Gaze and fixation data were analyzed using Applied Science Laboratories' *Results* software package. Fixation minimums were defined as 1-degree minimum change in fixation location over 0.1 seconds. These values define the minimum expected time required for a human to process visual information meaningfully, while negating the effects of microsaccades (Yarbus, 1967; Alpern, 1969; Young, 1970; Fischer and Ramsperger, 1984; Darrien et al., 2001).

Fixation data were processed and displayed as focus maps. Focus maps, also called heat maps by some researchers, are a qualitative way to look at a participant's fixation data. They take visual activity and determine fixation densities. Areas with the highest fixation densities are the locus of the highest visual activity. To produce a focus map, fixation densities are converted into a range of gray-scale values, where the darker shades of gray represent the most visual activity, the lighter shades of gray represent progressively less visual activity, and areas lacking gray represent no visual activity. To qualitatively explore general search behaviors, focus maps for each image were combined for all participants who viewed that image.

4. Results and discussion

Data for all participants were combined to produce a single focus map for each image. In many cases only 4 of the 16 images were analyzed and compared between the groups largely because of the huge volume of data collected during the research. The video was subdivided by time into four quarters and one image was selected from each quarter. The results of the various analyses conducted with the eye-gaze data are reported and discussed below.

4.1 How much time do participants spend looking at distractors?

Table 1.2 presents the maximum, minimum, and average percentages of time participants spent looking at the distractor for each image. The average percentage of time that participants in each group looked at the distractor ranged from a minimum of 4.5% on image 9, which contained kayakers, to a maximum of 45.7% on image 13, which featured people in a riverbed taking a photograph. The maximum percentage of time any participant spent looking at a distractor was 85.5%, where the distractor was a climber (image 15). The minimum amount of time a participant looked at a distractor was 0.0% and occurred for several images. Average percentage of time participants spent looking at the distractors are presented in Figure 1.2.

The most distracting features were humans actively engaged in an activity and located either in the center or just off center of the image. Although other images contained human distractors (image 5, a kayaker, and image 10, a geologist) the distractors were placed either off to the side or toward the bottom of the photograph. Moreover, the two climbers in image 1 were nearly identical,

both wearing white clothing and having the same dimensions, but on average participants looked at the climber in the center of the photograph 35% of the time and the climber on the bottom of the photograph only 7% of the time. These results demonstrate that human distractors placed in the center of an image were more likely to draw attention than if they were placed on the periphery. Similarly, the distractors in image 7 were a dog, located in the bottom-left-hand corner of the photograph, and graffiti located in the center of the photograph. On average participants spent 15.4% of their time looking at the graffiti in this image and only 6.6% of the 15.4% was spent time looking at the dog. Again, the dominant distractor was the one in the center of the image. From these observations, we can further surmise that when any distractor, not just a human distractor, is placed in the center of an image, participants are more likely to attend to it.

Image 3 was a photograph of sand dunes with a dune buggy located along the top center of the photograph. Although the dune buggy was located on the periphery of the photograph there was still a large amount of visual activity associated with it. In this photograph, however, the high level of visual activity on the distractor may be attributed more to the nature of the geology in the photograph (fairly uniform sand dunes) than to the nature and location of the distractor. The increased percentage of time participants spent looking at the distractor may be a result of low texture variability and less visual stimulation in the photograph, excluding the distractor.

4.2 Is there a difference in test performance among groups?

Questions on the pretest and posttest were subdivided based on whether they corresponded to images that contained distractors for the two slide show groups. An analysis of variance (ANOVA) was conducted on each set of questions to determine if there was a significant difference between the pretest and posttest score difference (gain score) across the three groups. No significant differences were found among groups when analyzing questions that corresponded to images that contained distractors for group 2 ($F(1, 136) = 0.34$, $p = 0.72$); however, the average score for group 2 (mean = 0.90) was less than that of both group 1 (mean = 1.05) and group 3 (mean = 1.10). Similarly, when comparing gain scores for questions that corresponded to images with distractors for group 3, no significant difference was found among groups ($F(1, 136) = 1.31$, $p = 0.27$); however, the average scores for group 2 and group 3 (0.52 and 0.52, respectively) were greater than that of the control group (0.25). We did not expect to, nor did we, find significant differences between groups 2 and 3, which experienced nearly identical treatments. The lack of significance on gain scores between the narration only group and the treatment groups may be largely a result that the pre- and posttest tested information only from the narration rather than testing information from visuals.

4.3 Is there a relationship between time on distractor and score?

To determine if there was a relationship between gain scores and the amount of time spent looking at the distractor for groups 2 and 3, a bivariate correlation was computed and found that these variables were not significantly

correlated; however, because of the previously mentioned design considerations of the pretest and posttest, we also correlated time spent looking at distractors with the final grade participants received in their introductory geology class. There was a significant, inverse correlation found between the student's final-introductory-geology-class grade and total time on distractor $r(62) = -0.26, p < .05$. In general, students who performed better in class generally spent less time looking at the distractors in the narrated slide shows.

4.4 How do distractors affect search behaviors?

Fixation and gaze patterns were analyzed to determine general search behaviors. Search-pattern behaviors were examined for the participants with the maximum, minimum, and average amount of time spent looking at the distractor for four images: images 1, 5, 10, and 15 (Appendix E). These images were exemplary examples of photographs used in classroom teaching.

4.4.1 Image 1

Image 1 was a photograph of horizontal beds and vertical joints on a cliff face (Figure 1.1A). The distractors in this image were two climbers, one in the center of the image and one at the center bottom of the image. All participants who looked at image 1 with the distractors spent some of their time looking at the distractors. The average distractibility was 43.8%, as exemplified by a participant who looked at the distractors 43.2% of the time. For this participant, the first fixations were on the distractor followed by repeated fixations off the distractor followed by fixating again on the distractor. This participant displayed average

distractibility by examining the geology for 3-5 fixations before returning attention back to the distractors.

The minimum percentage of time spent looking at the distractor was 14.2% by a participant who first looked at the center of the image and then looked from the center of the image to the climbers. Her next 8 fixations were back on the center of the image looking at the cliff. The participant's gaze then returned to the climbers for several fixations. For the remainder of time on this image, this participant primarily surveyed the center of the image with occasional fixations on the extremities of the image thereby demonstrating low distractibility.

Another participant spent the largest percentage of time fixating on the distractor (71.5%). This participant also looked at the climbers first, but then looked away from the distractor for 1 fixation and then back to the distractor for several fixations. This behavior of looking at the distractor for several fixations and then away for 1 or 2 fixations was repeated for the remaining time that the image was displayed, and would be considered an example of high distractibility.

4.4.2 Image 5

Image 5 was a photograph of flat-lying layers in the Yampa River Canyon taken from inside the canyon looking up at the canyon walls (Figure 1.1E). The distractor in the image was a kayaker floating on the river. The average percentage of time all participants spent looking at the distractor for image 5 was 12.0%. A participant representative of this average, looked at the distractor 12.4% of the time, looked at the distractor twice in the first 10 fixations and then surveyed the rest of the image for the next 20 fixations. During the following 10

fixations, the participant's gaze returned to the distractor. The remaining time that this participant looked at image 5 was primarily spent looking at features located in the center of the image.

The least distractible participant looked at the distractor in image 5 the least (0.5% of the time) and began by looking at the distractor and then continued to look at the rest of the image. The majority of fixations were in the center of the image. Conversely, the most distractible participant looked at the kayaker in image 5 for the greatest percentage of time (39.8%). This participant looked at the distractor when the image was first displayed and then looked at the surrounding image. He returned attention to the distractor approximately every 8 fixations and although he had few fixations on the distractor, the fixations were long, in some cases as much as 3 consecutive seconds.

4.4.3 Image 10

Image 10 was a photograph of a fault with flat-lying layers above the fault and folded layers below the fault (Figure 1.1J). The distractor in image 10 was a geologist in a yellow jacket located on the right-hand side of the photograph looking at the fault. One participant looked at image 10 for 9.0% of his time on the image, closest to the group average time of 9.0%. This participant looked at the geologist first and then looked at the rest of the photograph, focusing mostly on the fault, for the following 30 fixations. Following the 30 fixations on the fault, the participant's focus then returned to the distractor for several fixations. The participant then spent the remaining time looking at the rest of the image thereby demonstrating average distractibility.

The least distractible participant looked at the distractor in image 10 the least (0.0% of his time). This individual never fixated on the distractor and instead looked primarily at the center of the image, focusing the most on the fault, with some fixations above and below the fault. Another participant, who looked at the distractor in image 10 for the greatest percentage of her time (30.2%), began by looking at the geologist, then looked at the fault, and then returned his or her attention to the geologist every 4-5 fixations demonstrating high distractibility.

4.4.4 Image 15

Image 15 was a photograph of Siccar Point, a classic unconformity that has gentle dipping layers unconformably overlying vertical layers (Figure 1.10). The distractor in the image was a climber scaling the unconformity. The average distractibility was 25.1%, as exemplified by a participant who looked at the climber 25.4% of the time, looking at the distractor when the image first appeared and then returned to the distractor every 4 to 5 fixations for the remaining time spent on the image. The least distracted participant only looked at the climber during their final fixations on the image for a total of 1.4%. The most distractible participant spent nearly 85% of time looking at the distractor. This participant looked at the distractor first and then continued to look at the distractor every 2 fixations. Additionally, this participant's distractor inspections involved multiple, consecutive fixations before looking away.

4.4.5 Discussion of search pattern behaviors

Visual search pattern behaviors observed for participants who spent the maximum, minimum, and average amount of time looking at the distractor for the

four images seemed to be consistent within their category (high distractibility, low distractibility, and average distractibility) across all images. Participants who spent the maximum amount of time looking at the distractor fixated on the distractor during the initial presentation of the image, and nearly all continued to look at the distractor every 2 to 4 fixations. Participants who spent the minimum amount of time looking at the distractor typically fixated on the distractor only during his or her first fixations or his or her final fixations. The remaining time was usually on the geology in the center of the image and rarely on the distractor. Recall that one participant did not look at the distractor as often as the other distractible participants; but had longer fixations. Participants who spent the average amount of time looking at the distractor tended to have tens of fixations on the rest of the image, in some cases as many as 30, between distractor examinations. These participants occasionally looked at the distractor. Overall, participants with a high distractibility factor looked at the distractor every 2 to 4 fixation, whereas participants with a low distractibility factor looked at the distractor during the initial or final survey of the scene.

A learner's tendency to look or not to look at the distractor as well as an individual's ability to disembed may have to do with whether the individual is field dependant or field independent. A field dependent individual processes information globally and tends to rely on external cues. He or she tends to use the perceptual field as a whole. Field independent individuals, in contrast, can break the visual field down into component parts. Field independent individuals rely on internal cues and are minimally influenced by external cues (Witkins et al., 1977).

Field independent learners are expected to disembed pertinent information from a noisy background more readily than field dependant individuals. Although we did not use the hidden figures test (Witkins et al., 1977), a test that can determine if an individual is field dependant or field independent, we would predict that individuals who had high distractibility would be field dependant and individuals who had low distractibility would be field independent.

4.5 Where do students look most?

Fixation data indicates that the highest visual activity occurred at the center of the images (Figure 1.3) or associated with distractors. In many cases the part of the image near the edges was visually neglected unless a distractor was present on or near the edge. Also neglected were areas of photographs that lacked a distractor or lacked visually interesting geology, such as the sky, and areas that lacked texture, like a sand dune.

When a human or animal distractor was present in a photograph and the face of the human or animal was visible, participants looked at the faces of both humans and animals more than any other part of the human or animal. In general, the greatest amounts of visual activity occurred at the center of images and on faces (Figure 1.4).

4.6 Does the presence of a distractor influence the amount of an image viewed?

In order to compare the areal extent of an image surveyed for images with and without distractors, a grid consisting of 23 columns and 15 rows was overlain on each photograph. In total the grid contained 345 grid squares. Each grid square was equal to one half of the average interfixation degree for a participant sitting

18 inches from the computer screen, the minimum distance a student was able to sit from the screen as dictated by our equipment setup. A one-way analysis of variance was conducted to evaluate the relationship between the presence of a distractor and the number of grid squares in which fixations occurred for each image. For each ANOVA, the independent variable, presence of a distractor, included two levels: a distractor present and no distractor present. The dependent variable was the number of grid squares in which a fixation occurred. The grid comparison was conducted on images 1, 5, 10, and 15.

Image 1 was a photograph of a cliff with layers and joints (Figure 1.1A). It was identical for both groups except that distractors were present (two small climbers) in the image viewed by group 2. The ANOVA was significant, $F(1, 62) = 13.65, p < 0.001$. The strength of relationship between the presence of a distractor and the number of grid squares in which a fixation occurred, as assessed by partial eta squared, was strong, with the presence of a distractor accounting for 18.5% of the variance of the dependant variable.

The ANOVA conducted for image 15 (Figure 1.1O) was also significant, $F(1, 62) = 23.68, p < .001$. The strength of the relationship between the presence of a distractor and the number of grid squares in which a fixation occurred, as assessed by partial eta squared, was strong, with the presence of a distractor accounting for 28.3% of the variance of the dependant variable. The analyses of variance conducted for both image 5 (Figure 1.1E) and image 10 (Figure 1.1J) were not significant. For image 5, $F(1, 62) = 0.01, p = .93$ and image 10, $F(1, 62) = .50, p = .48$. In summary, participants who looked at images 1 and 15,

which contained a distractor, looked at significantly less of the image than did students who looked at images without distractors. A different result was obtained for images 5 and 10. Participants, who looked at images 5 and 10, which contained distractors, looked at an equal-sized area of the image compared to participants who looked at versions of images 5 and 10 that did not contain distractors.

Behavioral differences for the 4 images may be a result of the location and type of distractors present in the images or a result of the geology featured in the image itself. The distractors in both images 1 and 15 were climbers either in the center of the image or just off center, whereas the distractors in images 5 and 10, were a kayaker and geologist located on the bottom and right-hand side of the image, respectively. Our previous analyses indicate that when a distractor is located in the middle of an image, there will be more visual activity on the distractor. The location of the distractor may account for the difference in visual search behaviors alone; however, the types of distractors may also account for some of the variability in search area. The distractors that were climbers (image 1 and 15) were potentially facing more danger and may have drawn more attention than the kayaker (image 5) who was in minimal danger or the geologist (image 10) who was in no danger. Previous research has shown that when humans view an emotionally negative stimuli or when they perceive danger, they are prone to attend to the scene for a longer duration (Vuilleumier et al., 2001; Charles et al., 2003; Most et al., 2005; Johnson et al., 2006). Therefore, the lack of fixations on the rest of the photograph for images 1 and 15 may be due to the lack of an

emotional response to the nature of the distractors. The perceived danger may have drawn more focus and as a result learners looked at less of the image.

The geologic nature of each image may also contribute to the discrepancy in fixation area. For example, depending on a participant's prior experience, the geology featured in image 1 (layers and fractures) may be considered obscure. One of the reasons that participants may have spent more time looking at the distractors was because they may not have known where to look for relevant geologic information. As a result, a participant's inability to discern relevant geologic information may have caused the participant to spend more time looking at the distractors. Also, the relatively homogenous character of the geology across the scene may not have provided a single focus point in the scene. Conversely, if a participant was familiar with or could easily identify the joints in the image, they may have focused on the distractor more after quickly taking in the geology. To assess which scenario was more likely, we can examine the other three images.

The geology featured in image 15 might be considered obscure, whereas the geology in images 5 and 10 is more obvious. The flat-lying layers in image 5 should be easy for students to locate as they were the main feature in the photograph. Similarly, the fault in image 10 would also be considered very easy to locate. Conversely, the thin boundary between horizontally-oriented rocks overlying vertically-oriented rocks is a difficult structure to locate and is also a conceptually difficult boundary to understand. Consequently, we infer that obvious geologic features prompt additional visual inspection (Figure 1.1E and

1.1J), whereas, more complex or obscure geologic features cause less visual inspection (Figure 1.1A and 1.1O) due to an inability to disembed or locate salient items. The difficulty in locating relevant content may have caused individuals' attention to default to the distractor.

4.7 Does distractor novelty wane as viewing time increases?

To determine at what point participants looked at the distractor the most (when an image first appeared or after the image had been displayed for a period of time), fixation data for images 1, 5, 10, and 15 were broken up into three equal-length segments based on duration of viewing time. On average for image 1, participants spent the most time looking at the distractor during the first segment (44.2% of their time) and last segment (43.2%). They looked at the distractor for 33.2% of the time during the middle segment. For photograph 5, participants again looked at the distractor the most during the first segment (average of 19.0%). They looked at the distractor an average of 9.6% of the time during the middle segment and 9.1% on average during the last segment. While viewing image 10, on average, participants looked at the image 11.6%, 7.8%, and 9.0% of the time for the first, middle, and last segments, respectively. Finally, for image 15, participants looked at the distractor an average of 23.6%, 26.4%, and 31.7% of their time for the first, middle, and last segment, respectively (Figure 1.5).

The average times participants spent looking at the distractors, in each of the three segments an image was displayed, were similar for images 5 and 10. In general participants looked at the distractor most during the first third of the time the image was presented and then the visual activity on the distractor waned. In

the previous discussion we offered two possible explanations for the lack of significance, either the distractor being on the periphery of both images or the more obvious geology was more likely to hold attention. We suggest that the same explanations are appropriate here. Our research has demonstrated that the primary fixation location, when looking at a photograph, is the center. Additionally, if a distractor is present in the center of a photograph, it receives far more attention than when a distractor is on the periphery; by the same token, if a distractor is located on the periphery, we would expect less visual activity.

Participants looked at the distractors in image 1 the most during the first and last segment. In this case, attention on the distractor waned only during the middle segment. This may be an indication that either students were not interested in the geology featured in the photograph or after first focusing on the distractor, participants began to search for relevant geologic information, but were unable to disembed pertinent geologic information and therefore returned their attention back to the distractor.

Participants spent the highest percentage of time looking at the distractor in image 15 during the final segment. This may again be an indication that individuals unable to disembed relevant geologic information, or disinterested with the geology, eventually turned their gaze to the distractor (a more relatable object).

4.8 How long do participants look at the video control bar?

Along the bottom of both narrated slide shows was a panel, which included several buttons (e.g. a play button) and a display showing the amount of

time that lapsed since the beginning of the slide show as well as the length of time remaining. The amount of time participants fixated on the control bar was analyzed in an effort to determine if it contained information about a participant's attention span. It might have also been an additional distractor. In order to evaluate participant interactions with the control bar, all 16 images were included in the analysis. The average amount of time participants looked at the control bar was less than 3% for all images except 16, in which participants looked at the control bar an average of 5.4% of the time (Figure 1.6). The amount of time a participant looked at the control bar ranged from 34.3% (image 16, hot-air balloons as distractors) to 0.0% on several images for a number of participants. In general, the average percentage of time that participants looked at the control bar increased as the narrated slide show progressed from image 1 to image 15.

A linear regression analysis was conducted to evaluate the prediction of the average percentage of time participants spent looking at the control bar from slide show image number. The scatter plot for the two variables, as shown in figure 1.7, indicates that the two variables are linearly related such that as image number (and therefore time) increases, the amount of time looking at the control bar increases. The regression equation for predicting the time participants spent looking at the control bar is:

$$\text{Predicted time spent looking at the distractor} = 0.105 \text{ Image Number} + 1.41$$

The 95% confidence interval for the slope, 0.01 to 0.20 does not contain the value of zero, and therefore the average percentage of time participants spent looking at the control bar is significantly related to the image number. The correlation

between image number and time on the control bar was 0.54. Approximately 29% of the variance of the time fixating on the control bar was accounted for by its linear relation with the image number.

The significant regression between image number and average percentage of time participants spent looking at the control bar may be an indication that slide show attention gradually decreased (and restlessness increased). Although the average attention span for a college level individual can be as high as 20 or 30 minutes, research by Neuchterlein and others (1983) has shown that when information is obscure or degraded, as in discriminating ambiguous patterns presented against a noisy background (or disembedding), sustained attention may become affected in as quickly as 5 or 10 minutes. Therefore, our data support the conclusions of Neuchterlein and others (1983).

4.9 Do students look where a human distractor is looking?

Research has shown that humans from infancy to adulthood are very accurate at predicting where another individual is looking and have a strong disposition to imitate gaze behaviors, even of a person in a photograph looking in a certain direction (Gibson and Pick, 1963; Cline, 1967; Hood et al., 1998; Ricciardelli et al., 2002; Grosbas et al., 2005; Frischen et al., 2007). In order to evaluate if there was a relationship between the direction in which the geologist was looking in image 10 (Figure 1.1J) and a participant's gaze, each visual interaction with the geologist's face was analyzed. The angle in which participants looked from elsewhere on the image to the geologist's face and the angle in which participants looked from the geologist's face to other areas of the

image were calculated and plotted on rose diagrams (Figure 1.8). In addition, an independent group of students from an introductory geology class (N=49), who did not participate in the eye-tracking study, were asked to draw a line from the geologist face to where they thought the geologist was looking. Figure 1.8A and 1.8B show the angles in which participants looked from other areas of the image to the geologist's face and from the geologist's face to other areas of the image. Additionally, figure 1.8C shows the angle that the geologist in the photograph was looking as estimated by the independent group of participants.

An ANOVA was conducted to evaluate the relationship between interactions with the geologists face and outcrop and the azimuthal gaze angles. The independent variable, interaction between the geologist's face and outcrop, included three levels: 1) gaze-path angles in which participants looked from the rest of the image to the geologist's face, 2) the gaze-path angles in which participants looked from the geologist's face to other parts of the image, and 3) the estimated angle of the geologist's gaze. The dependent variable was the actual gaze-path angles as measured from vertical both collected from the eye tracker and calculated from the independent group of participants. The ANOVA was significant, $F(1, 2) = 3.63$, $p = 0.03$. The strength of relationship between the gaze path angles and the calculated look direction, as assessed by partial eta squared was weak with the gaze path angles accounting for 4% of the variance of the dependant variable.

Follow-up tests were conducted to evaluate pairwise differences among the means. Because the variances among the three groups ranged from 131.82 to

4727.05, we chose not to assume that the variances were homogenous and conducted post hoc comparisons with the use of Dunnett's C test, a test that does not assume equal variances among the three groups. There was a significant difference in the means between the calculated direction the geologist was looking and the fixation angles in which participants looked from the rest of the image to the geologists face, but there was no significant difference between the angles in which participants looked from the geologists face to the rest of the image and the calculated direction the geologist was looking as estimated by the independent group of participants. The 95% confidence intervals for the pairwise differences as well as the means and standard deviation for each gaze path angle are reported in Table 1.3.

The most common azimuthal angles of students' gazes to and from the geologist's face were between 285° and 290° . The calculated azimuthal angle the geologist in the photograph appeared to be looking was approximately 272° . It appears that in this image configuration, (the distractor standing off to the side of the photograph looking toward the center of the photograph) participants were taking cues from the human distractor. One weakness of this analysis, though, is that the geologist was looking toward the center of the image; therefore, it is difficult to discriminate whether students were looking from the geologist's face to the center of the image simply because their natural tendency was to look at the center as previously discussed or because they were cued by the geologist to look at the center. Future research will involve eye-tracking students while they look at an image containing a human distractor who is looking at or pointing to a location

not near the center of the photograph. This methodological refinement may help to evaluate if participants follow the cue produced by the distractor or if participants continue to look mostly at the center of the image.

5. Conclusions and implications

Human-eye movements have similarities to computer-generated, probability-based-optimal-eye movements (Findlay and Gilchrist, 1998; Najemnik and Geisler, 2005). In general, humans use medium-length saccades to search an image for meaningful information; after globally surveying an image, humans use shorter saccades and longer fixations to resolve finer details (Buswell, 1935; Mackworth and Morandi, 1967; Noton and Stark, 1971; Babcock et al., 2002). Although we see the same trends in our research, one difference we have observed is that humans do not optimize search to the extremities of photographs, but instead focus primarily on the center of an image. It is our recommendation that when photographs are used to teach scientific concepts, the object of interest should be in the center of the image, where it will receive the greatest amount of attention.

Geologists typically include humans in photographs for scale. We have shown that the presence of a human in a photograph interferes with a viewer's ability to focus on pertinent geologic information and in many cases a participant's attention will continue to return to the human distractor for the entire duration the image is displayed. Additionally, we surmise that including a human in a photograph that is being used for instruction may draw so much attention that it impedes learning. We recommend not using humans or animals as scale objects in photographs unless the lesson is meant to highlight humans engaging in scientific activities. Moreover, if a human scale is necessary in a teaching

photograph, he or she should be positioned to the sides or edges of the photograph as this should minimize the amount of attention paid to the distractor.

In order to maximize learning and minimize distractions, we further recommend using a simple scale located on the periphery of the photograph. Likewise, when showing a series of teaching photographs, we recommend using the same, simple scale positioned off to the side. Recall, when a distractor is located on the periphery of a photograph, visual attention on the distractor wanes as a function of time; therefore, if the same, simple scale is located on the periphery of each photograph in a series, we predict that the amount of visual attention and cognitive load spent looking at the distractor will become minimal.

Finally, if, during instruction, students are required to disembed pertinent information using photographs, we recommend lecture bursts no longer than 8 to 10 minutes. Recall that sustained attention length may become affected when disembedding is necessary (Neuchterlein et al., 1983). By limiting the lengths of continuous lectures, students will have a chance to reset, thereby increasing their attention span and their learning.

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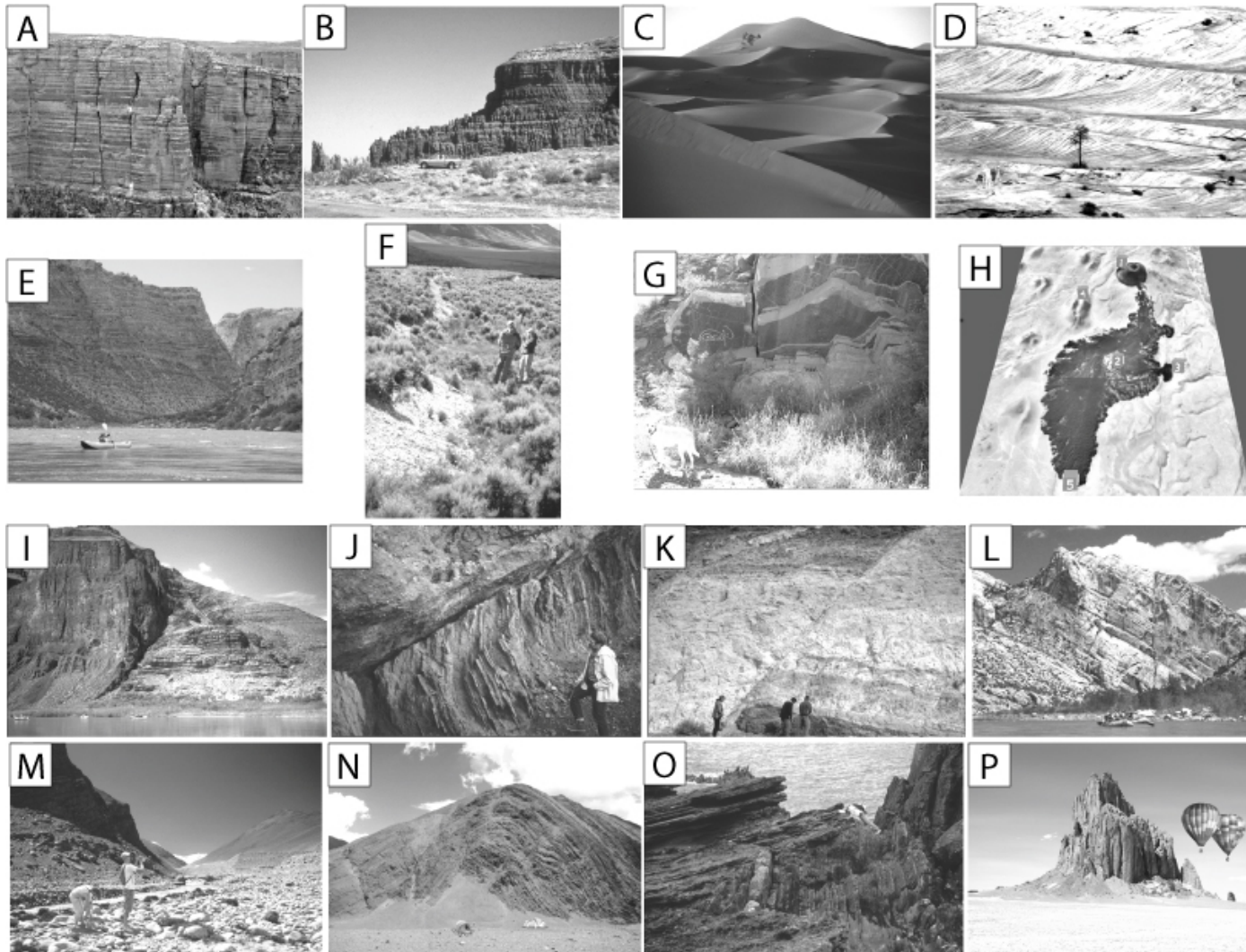


Figure 1.1: Photographs (with distractors) comprising the narrated slide shows. The numbers correspond to sequence of images in the slide shows. Figure 1.1A is a photograph featuring vertical and horizontal joints; 2 climbers are the distractors (one in the center and one near the bottom). Figure 1.1B is a photograph feature the result of weather on joints; a truck is the distractor. Figure 1.1C is a photograph featuring sand dunes; the distractor is a dune buggy. Figure 1.1D is a photograph featuring crossbeds; the distractor is three geology students. Figure 1.1E is a photograph of the Yampa River Canyon featuring horizontal layers; the distractor is a kayaker. Figure 1.1F is a photograph featuring a fault scarp; two people are the distractor. Figure 1.1G is a photograph featuring a rock outcrop with preserved paleomud cracks; the distractor is a dog. Figure 1.1H is a photograph of a 3 dimensional landscape featuring a cinder cone volcano and lava flow; the distractors are cubes with location numbers on them. Figure 1.1I is a photograph is a photograph featuring truncated layers due to a fault; the distractors are three small kayakers. Figure 1.1J is a photograph featuring a fault with folded layers below; the distractor is a geologist. Figure 1.1K is a photograph featuring offset layers; the distractors are three geologists. Figure 1.1L is a photograph featuring tilted layers; the distractor is two rafts filled with people. Figure 1.1M is a photograph of a dry-river channel featuring rounded clasts; the distractors are a person taking a photograph and a girl picking up a rock. Figure 1.1N is a photograph featuring an anticline; the distractors are two tents. Figure 1.1O is a photograph featuring horizontal layers unconformably overlying vertical layers; the distractor is a climber. Figure 1.1P is a photograph featuring a volcanic neck; the distractors are hot-air balloons.

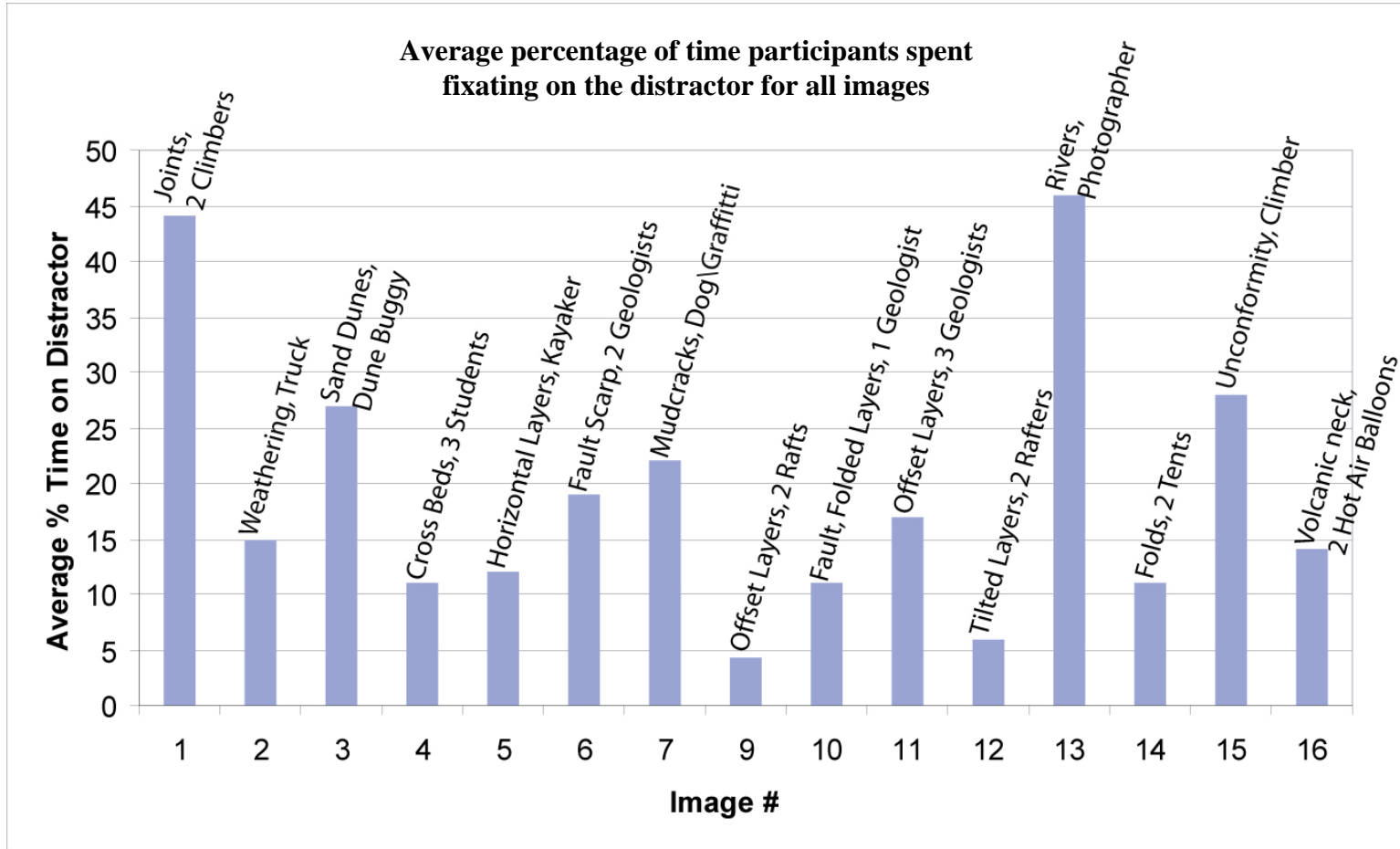


Figure 1.2: Chart showing the average percentage of time participants spent looking at the distractor for each image. Each image is labeled with the topic and the distractor associated with it. The label is in the form: Topic, Distractor(s).

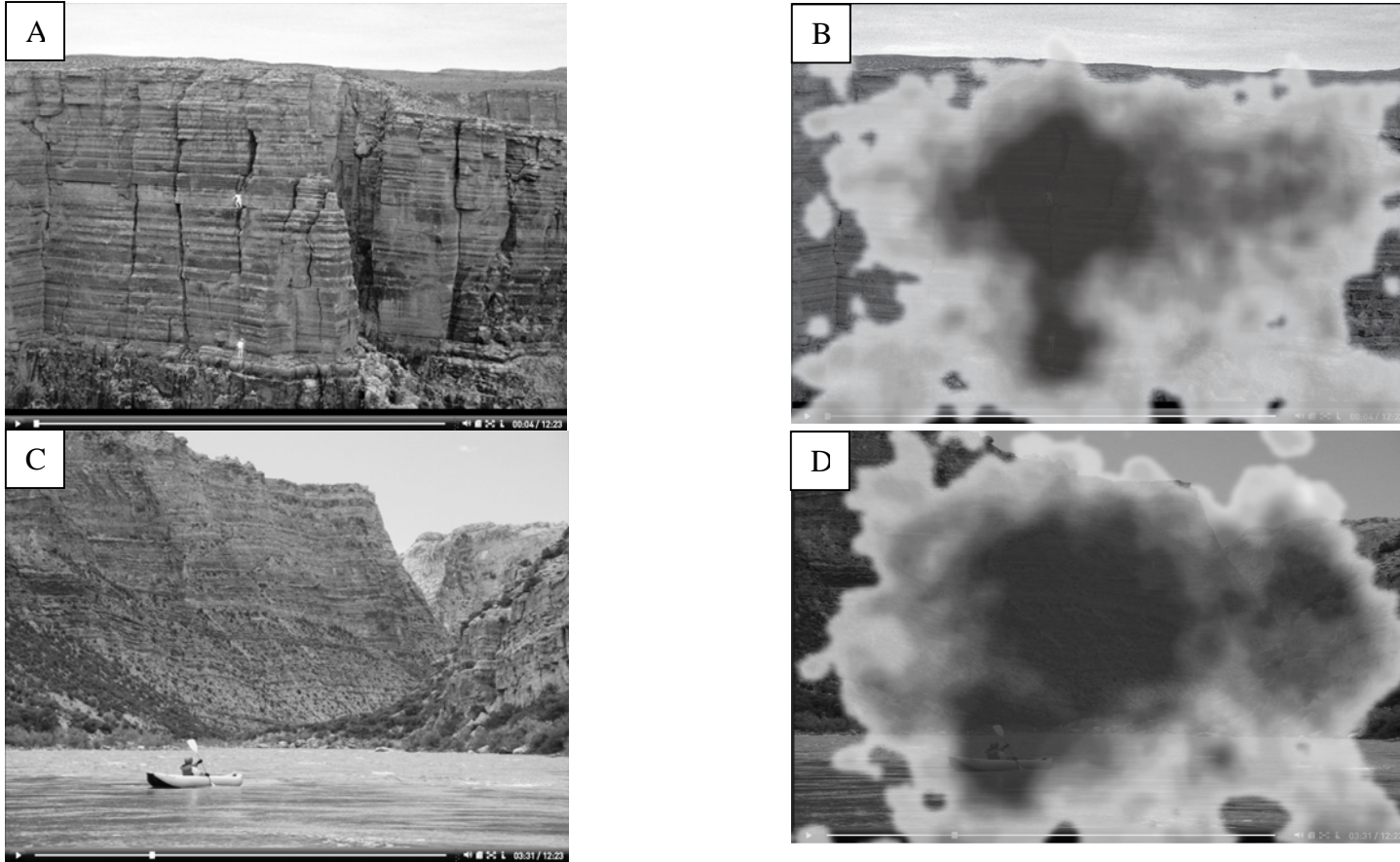


Figure 1.3: Images showing both the original image converted to grayscale (A and C) and the visual activity for all students combined and overlain on the original image (B and D). Darker shades of gray represent the most visual activity, lighter shades of gray represent progressively less visual activity, and areas lacking gray represent no visual activity. Students primarily looked at the center of the image and, in general, neglected the edges of images unless a distractor was present.

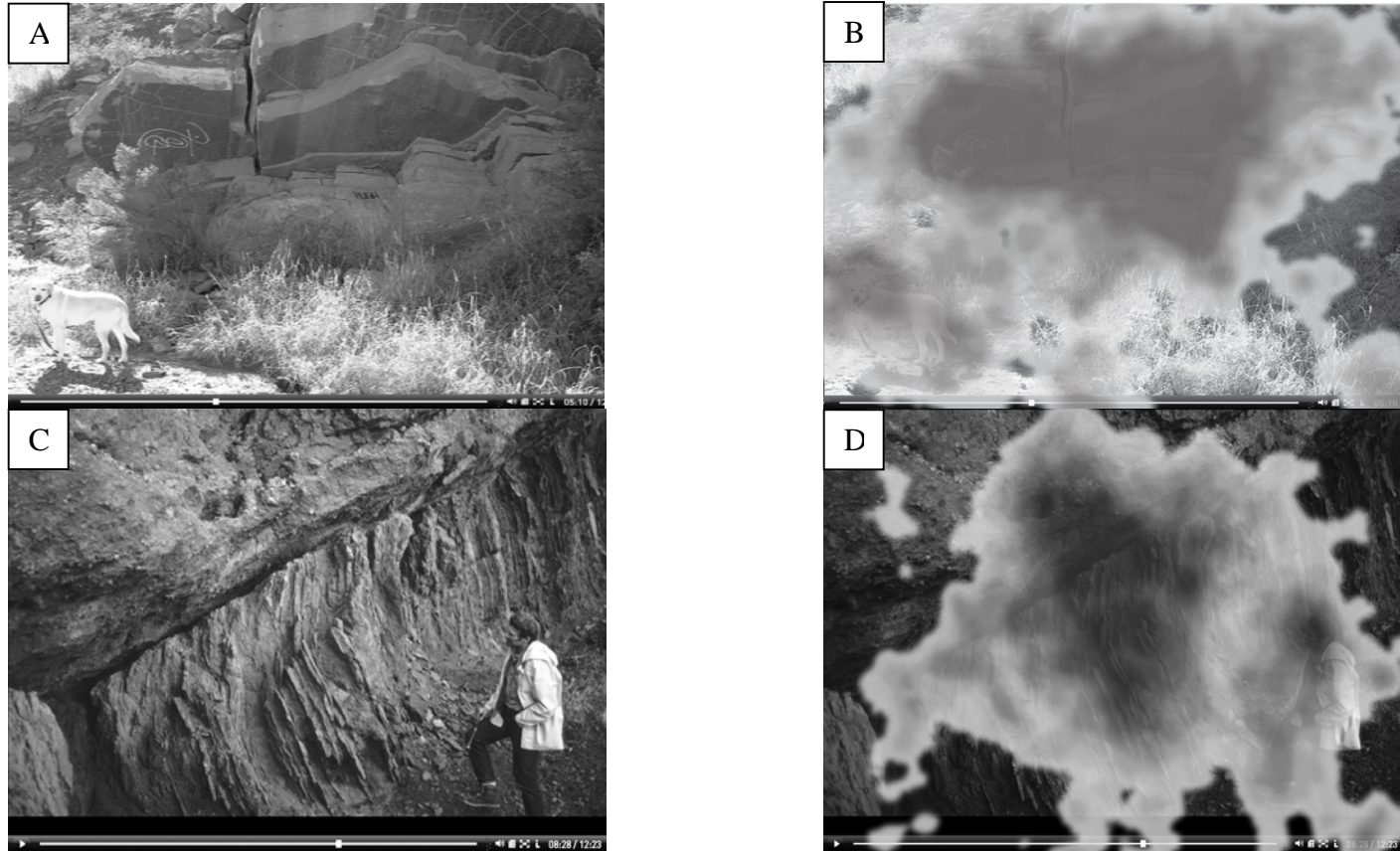


Figure 1.4: Images showing both the original image converted to grayscale (1.1A and 1.1C) and the visual activity for all students combined and overlain on the original image (Figure 1.1G and 1.1J). Darker shades of gray represent the most visual activity, lighter shades of gray represent progressively less visual activity, and areas lacking gray represent no visual activity. Although students looked at the center of the image, the next location that contained the highest amount of visual activity was on the faces of both the human and animal distractors.

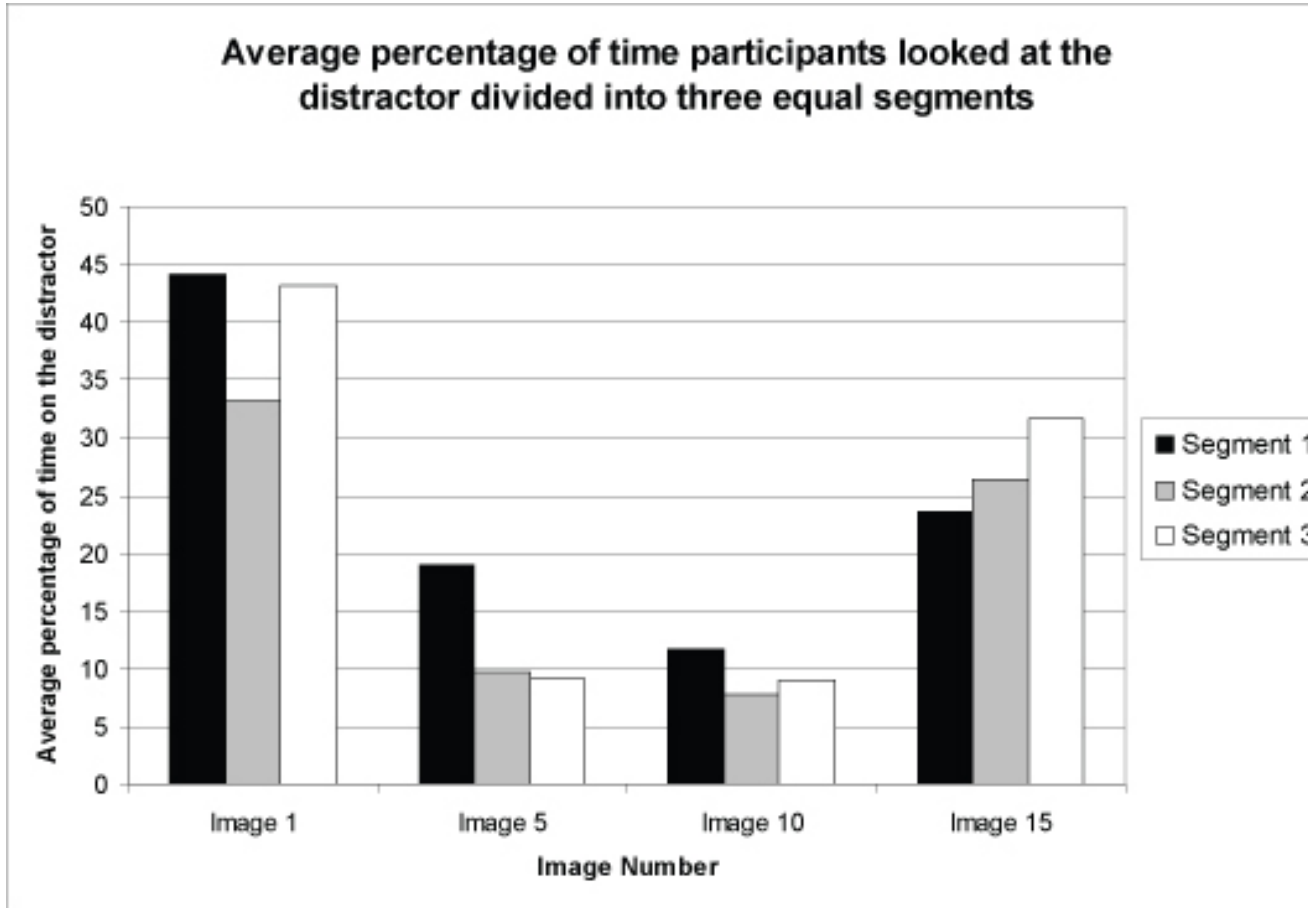


Figure 1.5: Chart showing the average time participants looked at the distractor during each image. Each image has been broken up into three equal segments in order to determine if participants look at the distractor more when the image first appears or after the image has been displayed.

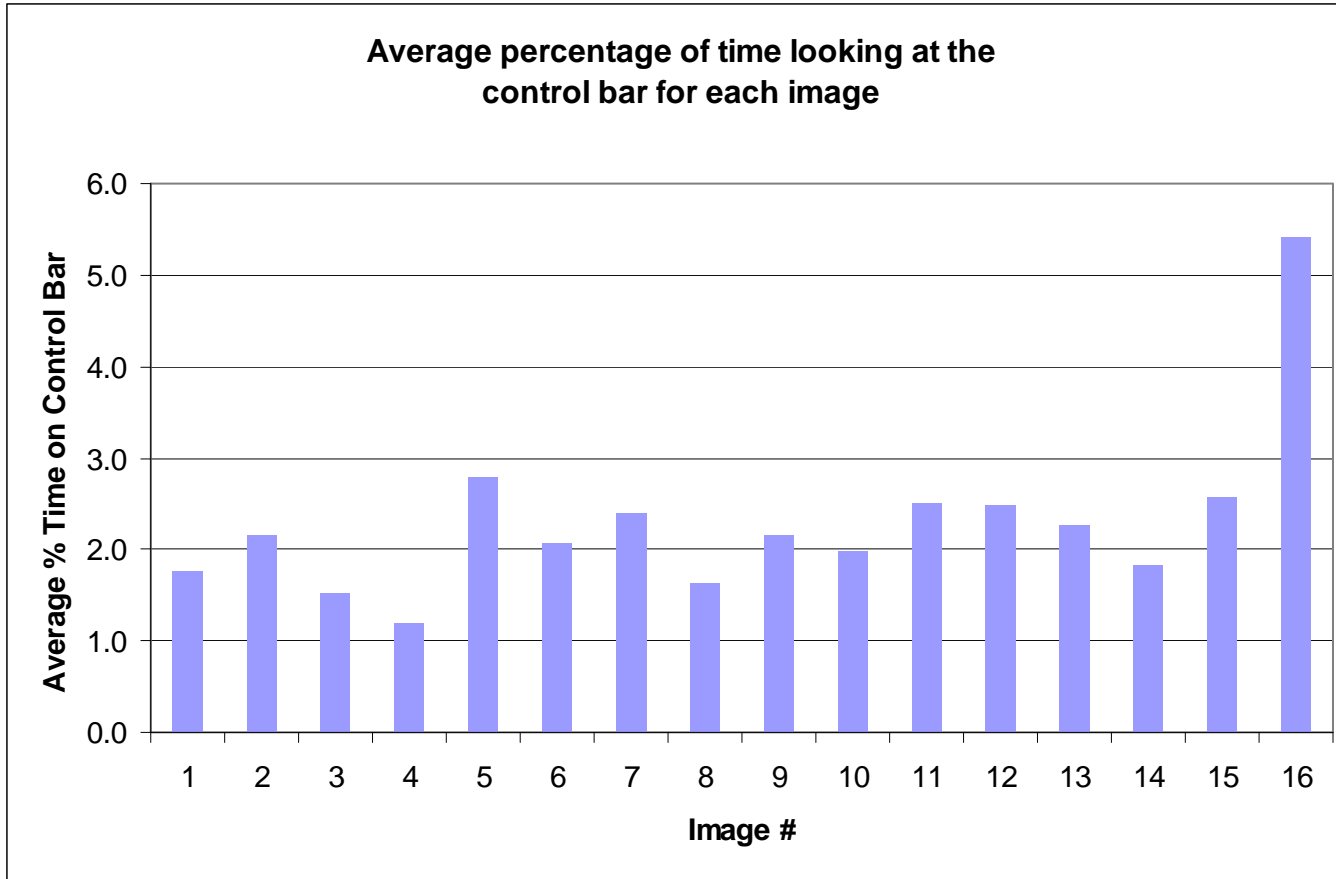


Figure 1.6: Chart showing the amount of time participants looked at the control bar for all images.

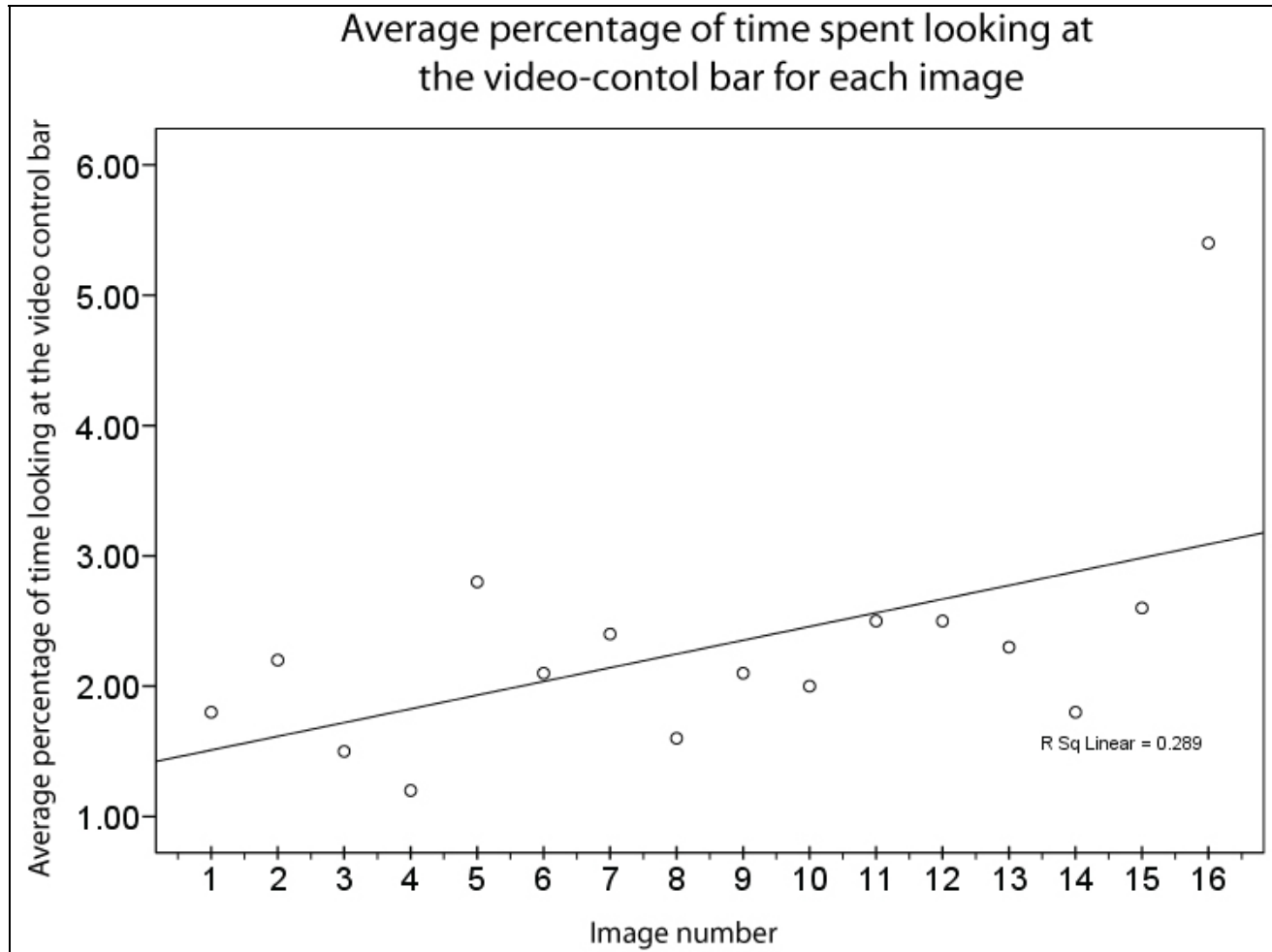


Figure 1.7: Scatterplot showing the relationship between the average percentages of time participants spent looking at the video-control and image number.

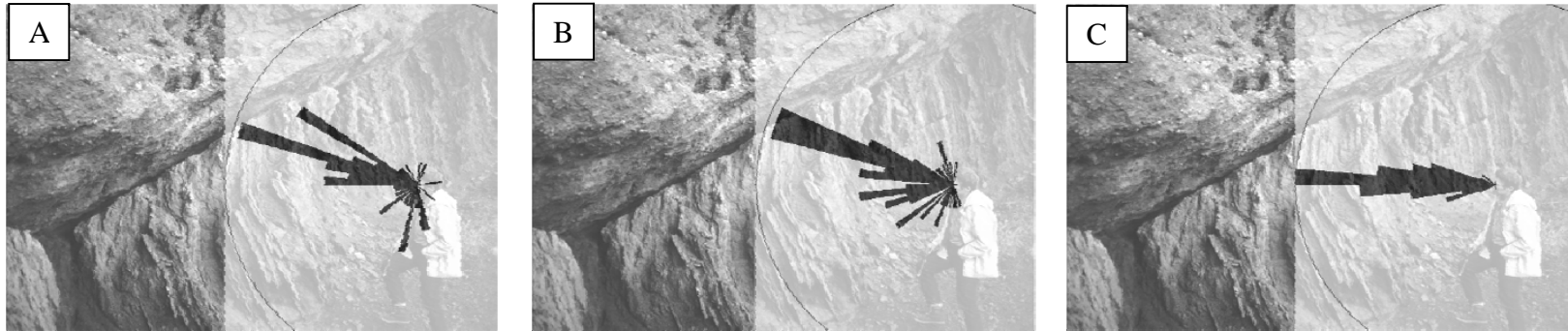


Figure 1.8: Rose diagrams overlain on image 10 that group 2 saw. The rose diagrams show the angles that participants looked from the photograph to the geologists' face (1.10A) and the angle that participants looked from the geologists face to other parts of the photograph (1.10B). Figure 1.10C also shows the estimated angle the geologist was looking in the photograph. Note: the rose diagram is a circular histogram that displays directional data and the frequency of each class.

Table 1.1: Slide show images that contained distractors for each group.

Image number	Group 2 viewed image with a distractor	Group 3 viewed image with a distractor
Image 1	Yes	No
Image 2	No	Yes
Image 3	Yes	No
Image 4	No	Yes
Image 5	Yes	No
Image 6	No	Yes
Image 7	Yes	No
Image 8	Yes	Yes
Image 9	No	Yes
Image 10	Yes	No
Image 11	No	Yes
Image 12	Yes	No
Image 13	No	Yes
Image 14	Yes	No
Image 15	No	Yes
Image 16	Yes	No

Table 1.2: Percentages of time participants spent looking at the distractor in each image.

Image number	Maximum	Minimum	Average	SD
Image 1	71.5	14.2	43.8	17.5
Image 2	52.1	0.0	15.0	14.5
Image 3	69.2	1.0	27.3	18.0
Image 4	50.5	0.0	10.6	10.7
Image 5	39.8	0.5	12.0	7.8
Image 6	52.9	0.0	18.8	14.1
Image 7	45.8	1.5	22.0	12.4
Image 8	25.0	0.0	4.0	5.0
Image 9	24.6	0.0	4.5	5.5
Image 10	30.2	0.0	10.7	6.4
Image 11	51.1	0.0	17.3	14.8
Image 12	33.5	0.0	5.9	6.9
Image 13	81.6	13.3	45.7	19.2
Image 14	27.3	0.0	11.0	8.2
Image 15	85.5	1.4	28.1	24.7
Image 16	40.9	0.0	14.1	11.0

Table 1.3: 95% Confidence interval of pairwise differences in mean angle changes.

Visual Interaction Angles	M	SD	Incoming Angles	Outgoing Angles
Incoming Angles	245.75	68.75		
Outgoing Angles	263.11	52.39	-44.02 to 9.29	
True Calculated Angle	271.88	11.48	-48.02 to -4.24*	-24.98 to 7.44

Note: An asterisk indicated that the 95% confidence interval does not contain zero, and therefore the difference in means is significant at the .05 significance using the Dunnett's C procedure.

Chapter 2

THE IMPACT OF EXPLICIT VISUAL SIGNALING ON STUDENT ABILITY TO DISEMBED RELEVANT FEATURES FROM GEOLOGIC PHOTOGRAPHS

Abstract

Introductory geology learners have a difficult time disembedding relevant geologic features from photographs. In an effort to counteract the effects of distractors in geologic photographs and to aid in disembedding ability, two groups of learners were exposed to photographs that were annotated to highlight the relevant geologic features. Each group was exposed to the same photographs, but the annotation, or signaling, technique was different. The two types of signaling involved either 1) replacing the photograph with a schematic drawing that displayed only pertinent geologic features or 2) including lines and text as callouts on the photograph to directly point out pertinent geologic items. In general, learners in the two signaling conditions exhibited the same learning behaviors. When compared to learners who did not receive signaling, however, there was a marked difference. Learners who received signaling tended to look at the distractor less, look at the geology more, and surveyed more of the photograph than learners who did not receive signaling.

1. Introduction

Scientists rely heavily on visual representations and inscriptions for the purpose of scientific communication (Pozzer-Ardenghi and Roth, 2005). In general, figures (charts, maps, photographs, etc.) are the vehicle for communicating data, interpretations, and conceptual models (Baigrie, 1996). Specifically, photographs are critical to illustrating concepts in the geosciences in classrooms and professional settings. Although scientists are typically concerned with increasing their topical knowledge, science students in introductory science classes are engaged in the understanding of and construction of the core concepts of science. Visualizations appropriate for use by experts may, therefore, be inappropriate for use by novices due to the inferred knowledge required to understand them (Edelson, 1998).

In teaching geological sciences, static images, including photographs, are the primary instructional method used today (Libarkin, 2002). Although photographs are one of the primary methods used for teaching geosciences, little is known about how students make sense of and learn from photographs (Pozzer-Ardenghi and Roth, 2005). A key issue when teaching with photographs is their inherent visual complexity. Visual scenes contain an overwhelming number of items that compete for the viewer's attention and may lead to information overload or multiple interpretations. In general, humans are very adept at prioritizing and recognizing critical aspects of a visual scene (Chun, 2000; Pozzer-Ardenghi and Roth, 2005); however, if students are unaware of what the

critical aspect is, they will be unable or unlikely to recognize it. Therefore our goal in teaching is to take resources experts use to extend their knowledge and find ways in which learners can access and develop some of the same knowledge (Edelson, 1998).

Instructors can employ numerous methods in an attempt to increase a student's ability to understand visual displays; Seufert (2003) suggests simply highlighting pertinent items with visual cues such as arrows. When symbols and text are used to label objects in pictures, the image may be transformed into a more efficient educational tool (Baigrie, 1996). Numerous studies have shown that attention-directing cues, or *signaling*, successfully improves learners understanding of visualizations and reduces cognitive load (e.g. Mayer and Moreno, 1998 and 2003; Mayer, 2001; Grant and Spivey, 2003; Boucheix and Lowe, 2010; De Koning et al., 2007 and 2010). For example, De Koning et al. (2010) showed that when learners were visually cued to specific areas of an image, they attended to cued areas longer than non-cued areas. Additionally, there is evidence that visual cues not only affect perceptual processing (Kriz and Hegarty, 2007) but can also improve understanding of concepts (Grant and Spivey, 2003; De Koning et al., 2010).

In order to determine the effectiveness of signaling as an instructional tool, we use eye-tracking technology to answer several questions. Does signaling affect the amount of time students spend looking at potentially distracting objects included in an image for scale? Does signaling promote extended focus on

pertinent items? Does signaling affect how much of an image students examine at and where in the image they look? Do different signaling methods affect students' learning behavior differently?

Our research shows that during the eight seconds immediately following signaling, students look at the distractor less and they look at relevant portions of the photograph more. Additionally, during the entire time an image was displayed after signaling, participants who received signaling looked at more of the image, looked at the distractor less, and had higher visual activity on relevant items. In general, students who received signaling fixated on pertinent geology longer than students who did not receive signaling.

2. Background

2.1 *How we look at photographs*

The process of learning from photographs includes searching photographs for meaningful information, creating mental models, interpreting information, and integrating information from short-term to long-term memory. Searching photographs for meaningful information is the most fundamental process and is very complex. Due to the limited field of vision of the central portion of the human eye, the portion of the eye with the highest ability to focus, rapid eye movements or *saccades*, are necessary to move the central portion of the eye, across images in order to obtain information (Rayner, 1998). Between saccades are *fixations*, which are periods of time when the eye is not moving or when attention is fixed on a single location (Buswell, 1935; Abrams, 1992; Babcock et al., 2002; Hyönä, 2010). During fixations, meaningful information about objects in an image, including size, color, relative location, or inferred motion, may be obtained (Doll, 1993; Wolfe, 1993). Information obtained from multiple fixations provides viewers with a comprehensive view of a photograph.

The saccadic and fixation patterns used to search an image are not random; instead, each eye movement is very efficient and is similar to computer-modeled ideal search patterns based on the probability of a target's location (Findlay and Gilchrist, 1998; Najemnik and Geisler, 2005). Additionally, fixation time and saccade length have been shown to change the longer an image is displayed. While searching a photograph, fixation times are shorter and saccades

lengths are longer during initial search; however, saccade lengths decrease and fixation times increase when an image has been displayed for longer periods of time. The change in fixation time and saccade length corresponds to global-scene survey followed by the collection of finer details (Buswell, 1935; Mackworth and Morandi, 1967; Noton and Stark, 1971; Babcock et al., 2002).

In general, a viewer's attention lies at the location of his or her fixation (Hoffman and Subramaniam, 1995; Duchowski, 2002). Using eye-tracking technology to study the location of and length of fixations and the length of saccades gives us an opportunity to determine where an individual's overt attention lies and may provide us with a window into cognition (Rayner, 1998; Babcock, 2002; Hyönä, 2010; Mayer, 2010).

2.2 How we teach from photographs

Although humans are very efficient at searching an image for a specific target, searching a photograph for scientific, contextual targets is much more difficult. Learners are commonly deficient in searching for information in static, scientific displays due to the inability to identify salient regions of the display. Accurate selection of pertinent information from a static, scientific visualization relies on background knowledge that novices generally do not possess (Mayer and Gallini, 1990; Lowe, 2002; Lewalter, 2003). Additionally, students may have difficulty creating referential connections between different elements of a photograph (Libarkin, 2002; Seufert, 2003). A possible result of not distinguishing the important scientific information to be learned is a lack of

understanding of content. Lack of understanding may lead students to feel confused or frustrated (Mayer and Gallini, 1990).

One way to combat a learner's inability to distinguish salient items from background noise in a photograph is through the presence of a guiding lecturer. Take for instance the geologic picture in Figure 2.1 and the corresponding text. In a lecture-type setting an instructor would have the ability to use gestures to illustrate what the term "juxtapose" means, for example, to point out the rocks as they are discussed, and to demonstrate the relative motion required to place the two different rock units next to one another (Pozzer-Ardenghi and Roth, 2005). Although the presence of a lecturer can aid learners in discerning important information in a photograph, students may still not be able to reconcile the information delivered by a lecturer with the relevant material in a photograph.

The lack of reconciliation between instructor content and photograph content may be a function of poor lecturing etiquette including "talking to the picture", using poor highlighting practices, or general lack of understanding of student inability. If a lecturer begins to explain a photograph before the learner has had a chance to internalize the photograph, the learner may miss valuable verbal content while they are studying the image (Reynolds and Peacock, 1998). Similarly, when gesturing or pointing to a photograph using either a laser pointer or a pointing stick, learners may miss valuable relationships due to the limited ability of pointers to reference only a single location at a time. Furthermore, outlining using pointing devices may be inefficient due to the sometimes maniacal

nature instructors exhibit when using laser pointers or pointing sticks (Pozzer-Ardenghi and Roth, 2005). In many cases, instructor may be unaware that students are having problems. For example, Hamel (2003) conducted research in literature classes and found that teachers were commonly unaware of their student's inability to understand content. Additionally, Hamel found that there was very little attention paid to discovering the teacher/student discrepancy.

In general, textual descriptions alone are not adequate to convey meaning in photographs. Pozzner-Ardenghi and Roth (2004 and 2005) suggest that additional methods are needed to instruct students to select relevant details in photographs. Although the presence of lecturers can assist learners in understanding content, an additional step may be required to help learners discover important aspects in photograph. The proper use of visualizations can give students a means to participate in the practice of science (Edelson, 1998).

2.3 Signaling

Image comprehension is a process in which learners must first identify relevant information in the image and then identify relationships among elements in the image, also known as inter-representational coherence formations (Seufert, 2003). To obtain a deeper understanding of an image, students need to reconcile verbal instruction with visual information. By mapping textual or narrative elements onto an image, learners are able to fully understand the processes depicted.

Techniques designed to increase a learner's scientific visualization ability can have an enormous impact because they exploit the human visual system to identify relevant scientific patterns (Edelson, 1998). Directive help, which directly points to relevant content, has been shown to increase an individual's ability to identify salient items and is ideal for individuals with low prior knowledge (Seufert, 2003). Grant and Spivey (2003) have been successful at assisting learners to make correct inferences in problem solving and reasoning using pulsing pixels in a digital display that direct student gaze. They suggest that although attention and eye movement are the results of cognitive processes, it may be that cognitive processes are the result of attention and eye movement and, therefore, fixating on salient regions of an image is paramount. Past cueing research has involved assisting learners in processing information from static images (Mautone and Mayer, 2007; Tversky et al., 2008) as well as animations (Lowe, 2004; Boucheix, 2008; Fischer et al., 2008; Boucheix et al., 2010; Lowe and Schnotz, 2008; Meyer et al., 2010). Mayer and Moreno (2003) were the first to investigate the effects of signaling during a narrated animation and found that when learners were cued to relevant items, comprehension increased.

Research has shown that the presence of distractors in a photograph can be detrimental to a learner's ability to successfully search photographs for valuable content (Coyan, Chapter 1). Photographs used as visual teaching materials in the geosciences classically contain images with people or objects for scale. Although these scale objects are necessary to indicate relative size relations, they also tend

to distract learners from being able to disembed relevant structures in landscape photographs, therefore preventing students from reaching a deep understanding. Eye-tracking data (Coyan, Chapter 1) revealed students look at less of an image when a distractor is present and focus on faces when human distractors are present over relevant geologic features. Additionally, learners focus primarily in the center of a photograph. In general, students who perform better in introductory geology classes looked at more of an image. It is for these reasons that we strive to increase a student's ability to identify salient items in a visual display as well as increase the area of an image that students looks. By increasing both of these factors, we may be able to train poorer students to exhibit behaviors similar to better performing students.

3. Methods

Our methods predominantly followed the methods of Cohan (Chapter 1); however, notable differences between the two studies include the number of participants involved and the length and nature of the narrated slide shows. Similar to participants in Cohan (Chapter 1), students participating in this research were unaware that they were being eye tracked. The participant demographics, procedures, eye-tracking space, eye-tracking apparatus, and the methods for coding eye fixation data followed that of Cohan (Chapter 1).

3.1 Participants

Fifty introductory geology students from a large university in the American Southwest were included in this study, 23 males and 27 females. Due to poor calibration or incomplete data only 34 students' data were analyzed. Participants ranged in age from 18 to 27 years old. All participants were recruited from and enrolled in an introductory geology course.

3.2 Materials

3.2.1 Narrated slide show

In this experiment, participants were exposed to a 10-minute-long-narrated slide show consisting of 8 images with accompanying audio narration (Appendix D). The slide show was constructed in advance using Camtasia Studios software; combining prerecorded narration with images of landscapes. The slide show contained explicit instruction in the form of signaling.

Our slide show design incorporated a three-stage learning cycle, which included signaling. Reynolds and Peacock (1998) had success with a 3-stage learning cycle that first, allowed the learner to observe and explore an image on their own, second, introduced terms and concepts, and finally, allowed the learner to apply his or her new knowledge. This approach gave learners the opportunity to survey an image without bias. They were then introduced to relevant content they could apply to the image with which they were already familiar. Musheno and Lawson (1999) found that scientific text presented in learning-cycle formats, in which examples were presented before term and concept introduction, lead to higher comprehension. Our investigation, therefore, employed this same type of learning-cycle approach. First learners viewed the image without interruption. Second, attention-directing cues appeared on the image. Finally, the image returned to its unannotated form. Once the image had returned to its original form, instructive narration began in an attempt to approximate content delivery from a lecturer. It was, therefore, our goal to test the effects of attention-directive cueing in a learning-cycle setting. We anticipate that by combining a learning-cycle approach and attention-directive cues, students would spend less time looking at distractors and more time looking at salient items in the photograph. Additionally, we intended to promote an increase in the area of the photograph that learners searched.

Our design employed two types of signaling: 1) signaling elements incorporated into the photograph and 2) signaling elements in place of the

photograph. Lowe (2008) points out that cueing must occur in exactly the correct location to be effective. Lowe further suggests that although realism is a common goal in teaching, it is counterintuitive to the long-established practice of simplicity and reduction of realism to assist the learner. He states that it is important to remove irrelevant material in order to make salient features more apparent. This practice of reduction evolved because real-world situations were often too difficult to learn from directly (Lowe, 2002). We were interested in determining which type of signaling is the most successful form of instruction – simplicity achieved with line drawings or by applying cues directly to a photograph – our signaling design, in which signaling elements were incorporated into the photograph, included arrows and text boxes (callouts) overlain directly on the photograph. Our second form of signaling consisted of fading out the image after the exploration phase and replacing the image with a schematic drawing, which contained the same line drawings and textual callouts. Problems with adding visual cues to an already rich display include disruption of overall appearance of the display and the impositions of an additional graphic layer overlain on the photograph (Lowe, 2002). Furthermore, Mayer (1998 and 2001) demonstrated that adding text to a visual display while narration was occurring was detrimental to learning; for these reasons, instruction only remained on the image for 8 seconds and was then removed (Figure 2.2).

The first two images and accompanying narration did not include signaling and were included in the narrated slide show in order to introduce

participants to the image-narration format and give participants a chance to become accustomed to the viewing space. The fixation data corresponding to the first two images were not analyzed. Following the first two images, the subsequent images viewed by the overlay group and the schematic-replacement groups were broken up into 3 segments corresponding to our learning-cycle approach. The first segment lasted 8 seconds and did not contain narration.

The slide show presented the following geologic topics: the formation of horizontal and folded layers, how weathering affects joints, the surface expression and offset of faults, and unconformities (Appendix D). The narration for the slide show was constructed from four introductory geology textbooks (Marshak, 2001; Tarbuck and Lutgens, 2002; Plummer et al., 2003; Reynolds et al., 2008). Textual explanations from each book were combined to form a single coherent narration.

3.3 Coding of eye fixations

As in Coyan (Chapter 1), an Applied Science Laboratories' (ASL) D6 Desktop unit was used to record and calculate a participant's fixation locations and gaze paths. All fixation and gaze analyses were conducted post hoc. Gaze and fixation data were analyzed using ASL's *Results* software package. Fixation minimums were defined as 1-degree minimum change in fixation location over 0.1 seconds. These values define the minimum expected time required for a human to process visual information meaningfully (Alpern, 1969; Young 1970; Yarbus, 1967; Darrien et al., 2001; Fischer and Ramsperger, 1984).

Fixation data were processed and displayed as focus maps (also called “heat maps”). Focus maps are a qualitative way to look at a participant’s fixation data. To create a focus map, fixation densities are converted into a range of colors or gray-scale values, where the darker shades of gray represent the most visual activity, the lighter shades of gray represent progressively less visual activity, and areas lacking gray represent no visual activity. To qualitatively explore general search behaviors, focus maps were combined for all participants in a group.

3.4 Analyses

Eye-tracking data for the two signaling groups (overlay and replacement) were gathered for 1) the eight seconds prior to signaling, 2) the eight seconds during which signaling occurred (in the form of an overlay or a schematic replacement), and 3) the period of time following signaling. Post-signaling-fixation data were analyzed twice; one analysis considered only the first eight seconds following signaling. The second analysis includes the entire time the image was available following signaling. The entire post-signaling period of time for each image was unique and is presented in Table 2.1. By analyzing these data separately, both the immediate and the lingering effects of signaling were investigated.

Our analyses of eye-tracking data also involved comparing visual behaviors of participants who received signaling to those (from a previous experiment) who did not receive signaling but looked at the same images (Coyan, Chapter 1). The no-signaling group, used as a comparison group, watched a

narrated slide show with the same images and narration; however, the first two stages of the leaning cycle were not present. Instead, the narration started immediately when the image was displayed.

We compared data between the signaling groups and no-signaling group in two ways. First, we compare eye-tracking data from the 8 seconds following signaling to the equivalent time looking at the image for the no-signaling group (16-24 seconds). In short, when comparing the signaling groups with the no signaling groups, we are comparing 1) two groups that looked at the image for 8 seconds uninterrupted and that received signaling for 8 seconds with 2) a group that had already listened to 16 seconds of narration (Figure 2.3).

The second comparison between the signaling groups and the no-signal group is for data collected during the entire post-signaling period (Figure 2.3). Content delivered during this period of time was identical to content viewed by the no-signal group. In this comparison, the images, narration, and duration for all three groups were identical. A shortcoming of this comparison; however, is that the two signaling groups were exposed to the image for 8 seconds longer than the no-signaling group and received 8 seconds of explicit instruction in the form of signaling. Although the comparisons between the signaling groups and the no-signal group were not ideal, we feel that they are still valid and may provide insight into the effects of signaling.

To determine how much area of an image participants examined, a grid consisting of 23 columns and 15 rows was overlain on each photograph as in

Coyan (Chapter 1). In total, the grid contained 345 grid squares. Each grid square was equal to one half of the average interfixation degree for a participant sitting 18 inches from the computer screen, the minimum distance a student was able to sit from the screen as dictated by our equipment setup. We used the grid-style comparison to analyze fixation data that only corresponded to the first eight seconds that the image was displayed, the first eight seconds following signaling, and the entire time following signaling. The 345-square grid was used for both comparisons between signaling groups and for comparisons between the signaling and no-signaling groups.

4. Results and discussion

4.1 How much time do participants spend looking at distractors before signaling?

To determine where participants fixated during the pre-signaling segment of each image, we analyzed only the fixation data corresponding to the first eight seconds that the image was displayed. The average percentages of time participants spent looking at the distractor in each image are presented in Table 2.2.

A between-subjects analysis of variance (ANOVA) was conducted for each image to determine if there was a significant difference between the two signaling groups for the amount of spent time looking at the distractor prior to signaling. For each ANOVA, the independent variable, type of signaling, included two levels: overlay and replacement. The dependent variable was the total time participants spent looking at the distractor. There were no significant differences between groups for any of the images.

Generally, participants spent between 9% and 38% of their time fixating on the distractor before signaling. Previous research has shown that when an image is first presented, individuals will globally survey a scene followed by the collection of finer details (Buswell et al., 1935; Coyan, Chapter 1). During the first eight seconds the images were presented, participants were most likely globally surveying the image.

Group focus maps reveal that the visual activity during the pre-signaling portion of the narrated slide show is almost indistinguishable between groups. In

all cases, during the pre-signaling segment, the highest density of visual activity is on the distractors followed by various locations on the rest of the photographs (Column 1 in Figures 2.4 through 2.9).

4.2 How much area of an image do participants inspect prior to signaling?

To determine how much area of an image participants looked at prior to signaling, we used the 345-square grid and analyzed fixation data that only corresponded to the first eight seconds that the image was displayed. The average number of grid squares a fixation occurred in for each image is presented in Table 2.2.

A one-way ANOVA was conducted for each image to determine if there was a significant difference between the two signaling groups and the number of inspected squares. The independent variable, type of signaling, included two levels: overlay and replacement. The dependent variable was the number of inspected squares. The grid comparison was conducted on images 3 through 8. There was no statistical significance between groups. Furthermore, group focus maps again reveal that there is little difference in the amount of an image participants looked at before signaling (Figures 2.4 through 2.9). On average, a fixation occurred in 16 to 23 grid squares during the pre-signaling condition, which roughly equates to 5% to 7% of the image.

4.3 Where do participants look during signaling?

Eye-tracking data collected during the 8-second-signaling phase were analyzed for both the overlay group and the schematic-replacement group. There

were no distractors present during the signaling segment for the schematic-replacement group and, therefore, time on distractor was only analyzed for the overlay group.

4.3.1 Where do participants in the schematic-replacement group look during signaling?

In all cases, participants in the schematic-replacement group fixated on both the text and parts of the schematic drawing that replaced the photograph. During signaling for images 3, 4, 5, and 7, the participants' main focus (the highest density of visual activity) was the text (row 4, column 2 for Figures 2.4, 2.5, 2.6, and 2.8, respectively). The textual components most likely drew the most attention because the text contained the most information, especially for novices who would be unlikely to understand the line drawing or be able to see the sketch as a representation of the real world without additional information (Baigrie, 1996). Participants' main focus during signaling for image 6 and 8 was again on the text box; however, there was an equal amount of visual activity on the schematic drawing (row 4, column 3 for Figures 2.7 and 2.9). The increase in visual activity on the schematic drawing for images 6 and 8 was most likely the result that the diagram displayed complex spatial relationships between rock units and therefore required the learner to look at the drawings more in an effort to reconcile the relationships and processes depicted.

4.3.2 Where do participants in the overlay group look during signaling?

Similar to the schematic-replacement group, participants in the overlay group, focused on both the text and the line drawings during signaling; however, visual activity on the image, which included line drawing callouts, was higher than on that of the textual callouts. Additionally, the overlay group examined more area of the image, surpassing that of the schematic-overlay group (column 2 for Figures 2.4 through 2.9). The higher density of visual activity on the photograph rather than the text was most likely the result that the photograph overlain with line drawings contained the most information and therefore drew the most attention. In general, participants in the overlay group were likely trying to reconcile information in the photograph with information presented by the signaling.

Due to the nature of the signaling format for the overlay group, the amount of time participants spent looking at the distractor was also analyzed as the distractors remained on screen while the callouts were present. Table 2.4 presents the average percentage of time participants spent looking at the distractor during signaling. The average percentage of time participants spent looking at the distractors ranges from 2.0% to 17.0%. The effects of participants focusing on the distractor for this amount of time are most likely a latent effect of looking from textual callouts to line drawing callouts.

4.3 Is there a difference in the amount of time participants spent fixating on the distractor prior to signaling and during the first 8 seconds following signaling?

To determine if there was a difference in the amount of time participants fixated on the distractor prior to and after signaling, fixation data corresponding to the initial eight seconds directly following signaling were analyzed and compared to the pre-signaling 8 seconds. A one-way within-subjects (repeated measures) ANOVA was conducted for each image (images 3 through 8). The independent variable was pre- and post signaling and the dependant variable was the total time fixating on the distractor. Table 2.5 presents the results of the ANOVAs and means and standard deviations for total time fixated on the distractor for each image before and after signaling. As there were only two levels of the within-subjects factor, follow up tests were not necessary.

In all six cases, participants, on average, spent less time fixating on the distractor after signaling than before signaling. In two out of the six cases these differences were statistically significant. The reduction in time spent fixating on the distractor after signaling indicates that participants' initial, immediate reaction to signaling was to look at the distractor less, therefore examining more of the geology. Qualitative observations of focus maps also reflect this trend (column 3, Figures 2.4 through 2.9). Our previous research showed that without signaling cues, students continue looking at the distractor unchanged as time progresses (Coyan, Chapter 1); we assume that the decrease in the time fixating on the distractor is a direct effect of signaling.

4.4 Is there a difference in the area of an image participants fixated on prior to signaling and during the first 8 seconds following signaling?

To determine if there was a difference in the amount of an image participants looked at prior to and during the 8 seconds following signaling, we used the 345-square grid. A one-way within-subject ANOVA was conducted for each image. The independent variable was pre- and post signaling and the dependant variable was number of inspected squares. Table 2.6 presents the results of the ANOVAs and means and standard deviations for total time fixating on the distractor for each image pre- and post signaling. Because there were only two levels of the within-subjects factor, no follow up tests were conducted.

In all six cases, participants looked at fewer grid squares after signaling than before signaling. Furthermore, in 2 out of the 6 cases (images 2.7 and 2.8) this difference was statistically significant. On average, a fixation occurred in 16 to 20 grid squares following signaling. The reduction in area participants fixated on during the 8 seconds following signaling indicates that the participant's initial, immediate reaction to signaling was to look at less of the image. This may be an indication that participants were no longer searching the image, but instead focusing on salient areas in order to reconcile signaling content within content from the photograph. Additionally, observations from focus maps reveal that participants' fixations were more highly concentrated in cued areas that contained more relevant geology (Figures 2.4 through 2.9).

4.5 Are there differences among groups in the amount of time spent looking at the distractor during the first 8 seconds following signaling?

We conducted an analysis to determine if participants who received signaling looked at the distractor less during the 8 seconds following signaling than participants who did not receive signaling for the equivalent time period (16-24 seconds). Table 2.2 presents the average percentages of time participants spent looking at the distractor during the post signaling and equivalent time periods. Participants who did not receive signaling looked at the distractor the most while viewing images 3, 5, and 6; however, participants in the overlay group looked at the distractor the most while viewing images 4, 7, and 8. We hypothesize that for all images, the no-signaling group would have fixated on the distractor the most; however, this was not the case probably because textual callouts were placed near distractors. We propose that as a result of callouts being placed near or over distractors in images 4, 7, and 8, participants' eyes remained in the vicinity of the distractors after the removal of the callouts, thereby inflating the time spent looking at the distractor.

A between-subjects ANOVA was conducted for each image to determine if there were differences among groups on the amount of time spent fixating on the distractor during the 8 seconds following signaling for the signaling groups and equivalent time for the no-signaling group. For each ANOVA, the independent variable, type of signaling, included three levels, no signaling, overlay, or replacement. The dependant variable was the total time participants

fixated on the distractor. The omnibus hypothesis for the ANOVAs corresponding to images 3, 4, 5, and 8 were statistically significant. Follow-up tests were conducted to evaluate pairwise differences. For all follow-up tests, the Dunnett's C test, was used when variances were not assumed to be homogenous among the three groups. The Bonferroni method was used when variances were assumed to be homogenous. The omnibus results and 95% confidence intervals for the pairwise differences, as well as the means and standard deviations for the three groups for images 3, 4, 5, and 8 are reported in Table 2.7.

The ANOVAs for images 4 and 5 were marginally significant. Follow-up tests, however, revealed no significant differences. Post hoc analysis for image 3 revealed that there was a significant difference between the no signaling group and the groups that received signaling. The no-signal group fixated on the distractor 3 times longer than the overlay or schematic-replacement groups. Similarly, there was a significant difference between the no signaling group and the overlay group for image 8. There was no significant difference; however, between the two signaling groups.

4.6 Are there differences among groups in the amount of area participants surveyed during the 8 seconds following signaling?

We conducted an analysis using the 345-square grid to determine if participants who received signaling looked at more or less of the image during the 8 seconds following signaling than participants who did not receive signaling for the equivalent time period. Average percentages of time participants spent

looking at the distractor during the post-signaling period and equivalent time periods for the no-signaling group are presented in Table 2.3.

A between-subjects ANOVA was conducted for each image to determine if there were differences among groups for the number of inspected squares during the 8 seconds following signaling for the signaling groups and equivalent time for the no-signaling group. For each between subjects ANOVA, the independent variable, type of signaling, included three levels, no signaling, overlay, and replacement. The dependant variable was the number of grid squares inspected.

The between-subjects omnibus ANOVAs for each image were significant. The results of the between-subjects ANOVAs are presented in Table 2.8. Pairwise comparisons for image 4, 5, and 8 revealed significant differences between the no-signaling group and schematic-replacement group. Additionally, pairwise comparisons for image 6 revealed that there was a significant difference between the no-signaling group and the overlay group and between the overlay group and the schematic-replacement group. For all other images there was no significant difference between the groups that received signaling. In all cases, the replacement group looked at more of the image after signaling, followed by the overlay group, followed by the no-signaling group. The replacement group most likely looked at more of the image following signaling because this group needed to reconcile the newly obtained signaling information with information from the original image. Although the overlay group also needed to reconcile this new

information, this process would likely have been faster and require fewer fixations following signaling because the callouts were displayed directly over the image. Furthermore, because the callouts were presented over the existing image, participants in the overlay group did not need to re-establish spatial relationships between the photograph and the callouts. Finally, because there was nothing to prompt change for participants in the no-signaling group, this group was expected to have no change in area surveyed and was expected to look at less of the image.

4.7 How much time do participants spend looking at distractors following signaling?

We conducted an analysis to determine how much time participants spent fixating on the distractor during the entire post-signaling period. The duration of the post-signaling segment for the overlay and replacement groups was identical to that of the no-signaling group. The average percentage of time participants spent looking at the distractor during the entire time an image was displayed following signaling is presented in Table 2.9.

A between-subjects ANOVA was conducted to determine if the three groups had significant differences in the amount of time spent fixating on the distractor during the entire post-signaling period. For each analysis of variance, the independent variable, signaling type, included three levels: no signaling, overlay, and replacement. The dependent variable was the total time participants fixated on the distractor. Follow up tests were conducted to evaluate pairwise differences. Once again, the Dunnett's C test was used when variances were not

assumed to be homogenous and the Bonferroni method was used when variances were assumed to be homogenous. The omnibus ANOVA results and the 95% confidence intervals for the pairwise differences, as well as the means and standard deviations for the three groups for images 3 through 8 are reported in Table 2.10.

The ANOVAs revealed significant differences for all images. Post-hoc analyses revealed a significant difference in the amount of time fixating on the distractor for the participants that received signaling compared to those from a previous study who did not receive signaling for all images except image 7. For all images, on average, participants who did not receive signaling fixated on distractors longer than those who did receive signaling. There were no significant differences between the overlay group and the replacement group.

The differences in time spent between groups cannot definitively be attributed to signaling. By comparing participants from a previous experiment who did not receive signaling and subsequently viewed 16 seconds less of each image, we are unable to determine if significance was solely due to signaling or simply time on task or some combination of the two. There is however, a strong indication that the signaling played a role in the decrease in time that participants spent fixating on the distractor. Our previous research has shown that the amount of time participants look at the distractor does not decrease as a function of time (Coyan, Chapter 1); therefore, we infer that the significant decrease in time looking at the distractor and the cause of group differences was due to signaling.

Observations from focus maps additionally revealed that participants who received signaling spent more time looking at relevant geology than the group that did not receive signaling (Figures 2.4 through 2.9).

4.8 How much area of an image do participants spend looking at following signaling?

To determine how much area of an image participants fixated on during the entire time an image was displayed after signaling, the fixation data corresponding to the entire time after signaling and equivalent was again analyzed using the 345-square grid. Table 2.11 presents the average number of grid squares a fixation occurred in.

A between-subjects ANOVA was conducted to determine if there was a significant difference between the 3 groups and the number of inspected squares. For each ANOVA, the independent variable, type of signaling, included three levels: no signaling, overlay, and replacement. The dependent variable was the number of grid squares in which a fixation occurred. The grid comparison was conducted on images 3 through 8. The omnibus ANOVAs were found to be significant for all images. The results of the between-subjects ANOVAs are presented in Table 2.12. Pairwise comparisons for all images revealed significant differences between the no-signaling group and both the schematic-replacement group and the overlay group. For all images there was no significant difference between the groups that received signaling.

While viewing each image, participants in the groups that received signaling looked at significantly more of the image than the group that received no signaling. Although it is again difficult to determine if the presence of signaling was the factor that caused the differences between groups or if the difference was simply due to time on task, observations from group focus maps reveal that participants who received signaling looked at more salient portions of each image. Additionally, based on observations from focus maps, participants who did not receive signaling had the highest density of visual activity on the distractors, and participants who received signaling had the highest visual activity occurring on various locations of the photograph (Figure 2.4 through 2.9). In many cases, high density visual-attention patterns of participants in the signaling groups were not restricted to just the center of the image, as seen in non-signaling cases in previous research (Coyan, Chapter 1), but stretched from edge to edge. We, therefore, assert that signaling was the main reason for the difference between groups.

5. General discussion

Multimedia research has shown that when learners build referential connections between visual and verbal material their learning is enhanced (Mayer, 1994). Visual materials; however, need to be appropriate for novice learners. If visual materials are too complex, students may have problems selecting pertinent information and have trouble disembedding relevant features (Neuchterlein et al., 1983; Mayer and Gallini, 1990; Lowe, 2002; Lewalter, 2003). Participants in the no-signaling group and participants in the signaling groups prior to signaling tended to fixate on the distractors and areas of the photograph that did not contain relevant geology. Once signaling occurred; however, the behaviors of individuals who received signaling diverged from those who did not receive signaling.

De Koning et al. (2010) found that learners cued to look at a specific location of an animation of the circulatory system not only made more fixations on cued items, but spent longer fixating on cued items compared to learners who were not cued. We found a similar result in that participants who did not receive signaling continued to look at non-relevant items, whereas participants who did receive signaling focused on cued locations more than those who did not receive signaling. Additionally, participants in the signaling conditions spent significantly less time fixating on the distractors.

De Koning et al. (2007) also found that cueing learners to look at the valve of a heart in an animation of a circulatory system not only increased a learners' comprehension of the cued content, but also improved comprehension of uncued

content. Although our test did not provide an adequate assessment of comprehension, we found that participants who received signaling examined significantly more of the photograph than participants who did not receive signaling. This increase in search behavior may account for the increase in comprehension of uncued items observed by De Koning et al. (2007). De Koning (2007) went on to infer that the process of cueing possibly segmented the visualization into cued and uncued areas. Once the image was segmented into cued and uncued areas, inspection of each segment could occur independently (and more systematically) of other segments, which would free up working memory. Similar to De Koning et al. (2007), we surmise that the increase in search behavior may be a function of segmenting the photograph through signaling. We surmise that the process of signaling, using both an overlay and the schematic replacement, may have divided the geologically-rich photographs into new segments. The segments were defined as an expert would define them, irrelevant of the presence of a distractor. Once a participant saw the expert segmentation, which was not defined by the distractor, he or she searched the photograph differently causing him or her to focus less on the distractor.

We found our cueing results are consistent with and generalizable to other signaling investigations (eg. De Koning et al., 2007 and 2010; Kriz and Hegarty, 2007) in that directive cueing did influence perceptual processing; however, it was not possible to determine its influence on cognitive processing. Using a short intervention and a test that only tested content delivered via narration limited our

ability to determine if there were learning comprehension differences between the no-signaling and signaling groups. We have incorporated observation about the physical area of a photograph to which individuals attended and found the area increased after signaling. We suggest that further research using a better assessment is needed to evaluate the benefit of looking at more of an image. Our assumption is that by attending to more of an image, learners may gain a more holistic view of the content and therefore exhibit increased learning gains.

6. Conclusions

We have shown that signaling or cueing has a significant affect on how learners search for salient items while looking at information rich photographs. In general, participants in both signaling groups fixated on the distractor the same amount of time and looked at the same amount of each image before signaling. During signaling, participants in the schematic-replacement group primarily focused on the textual callouts whereas participants in the overlay group focused on both the textual and line drawn callouts.

Participants in the signaling groups not only looked at the distractor less but also looked at more relevant geology during the 8 seconds following signaling. During the entire post-signaling time, participants who received signaling, looked at the distractor less and looked at more of the image than participants who did not receive signaling. Furthermore, the schematic-replacement group looked at the image the most, followed by the overlay group, followed by the no-signaling group. Finally, observations from focus maps revealed that participants who received signaling looked at more relevant geology following signaling.

Overall, in this study, both types of signaling coupled with a learning cycle approach resulted in the same outcome. In nearly all analyses there were no statistically significant differences between the two signaling groups. Although we saw no effect on cognitive processing, due to the positive effects observed on perceptual processing, we recommend that when teaching with photographs and

complex graphics, a learning cycle approach coupled with directive cueing be used.

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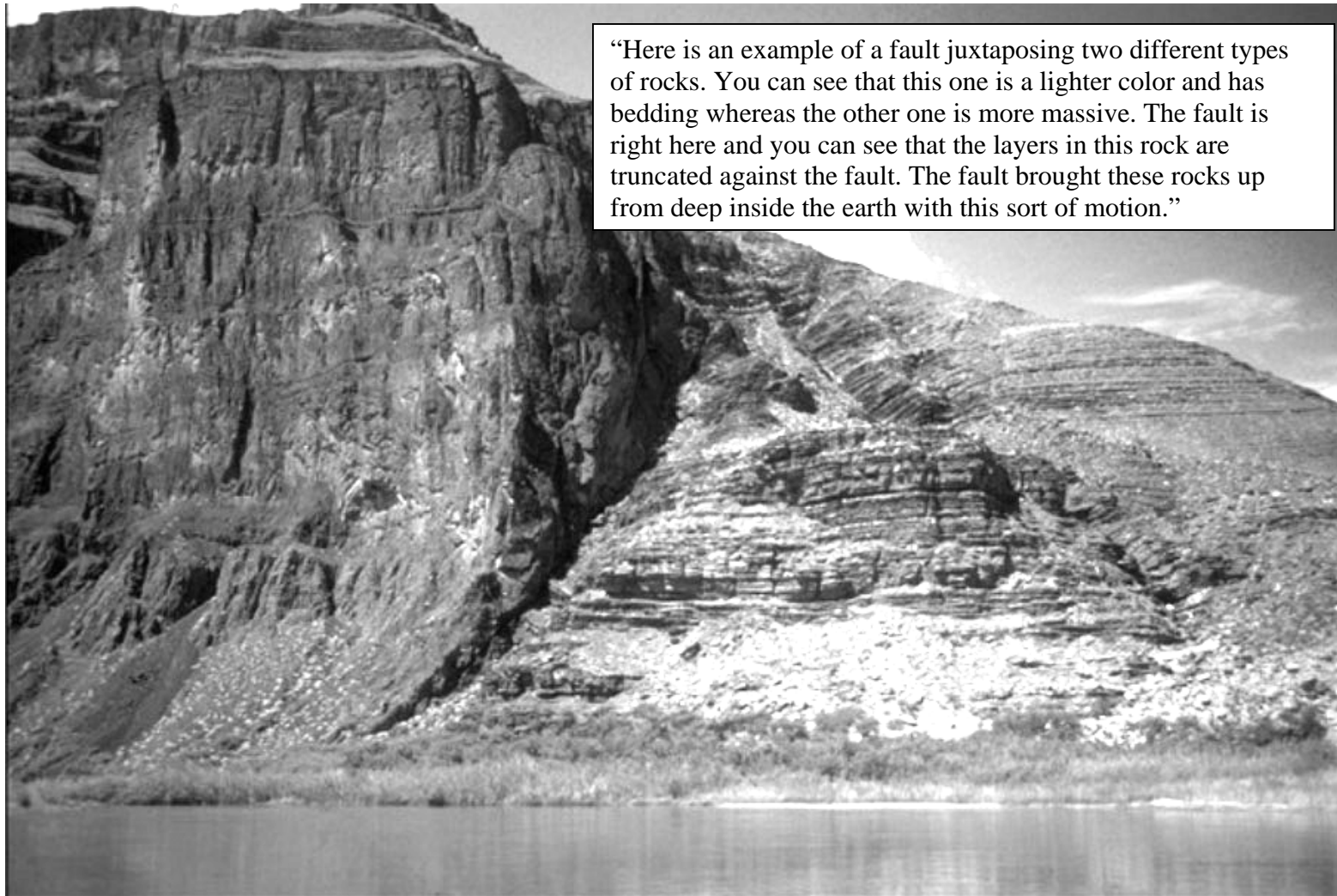


Figure 2.1: Fault photograph with accompanying text. This is a typical photograph that could be used to teach students to recognize faults and the processes involved in faulting. Inset into the photograph is a script an instructor could use in a lecture-type setting to explain aspects of the photograph. The script would be accompanied by gestures.

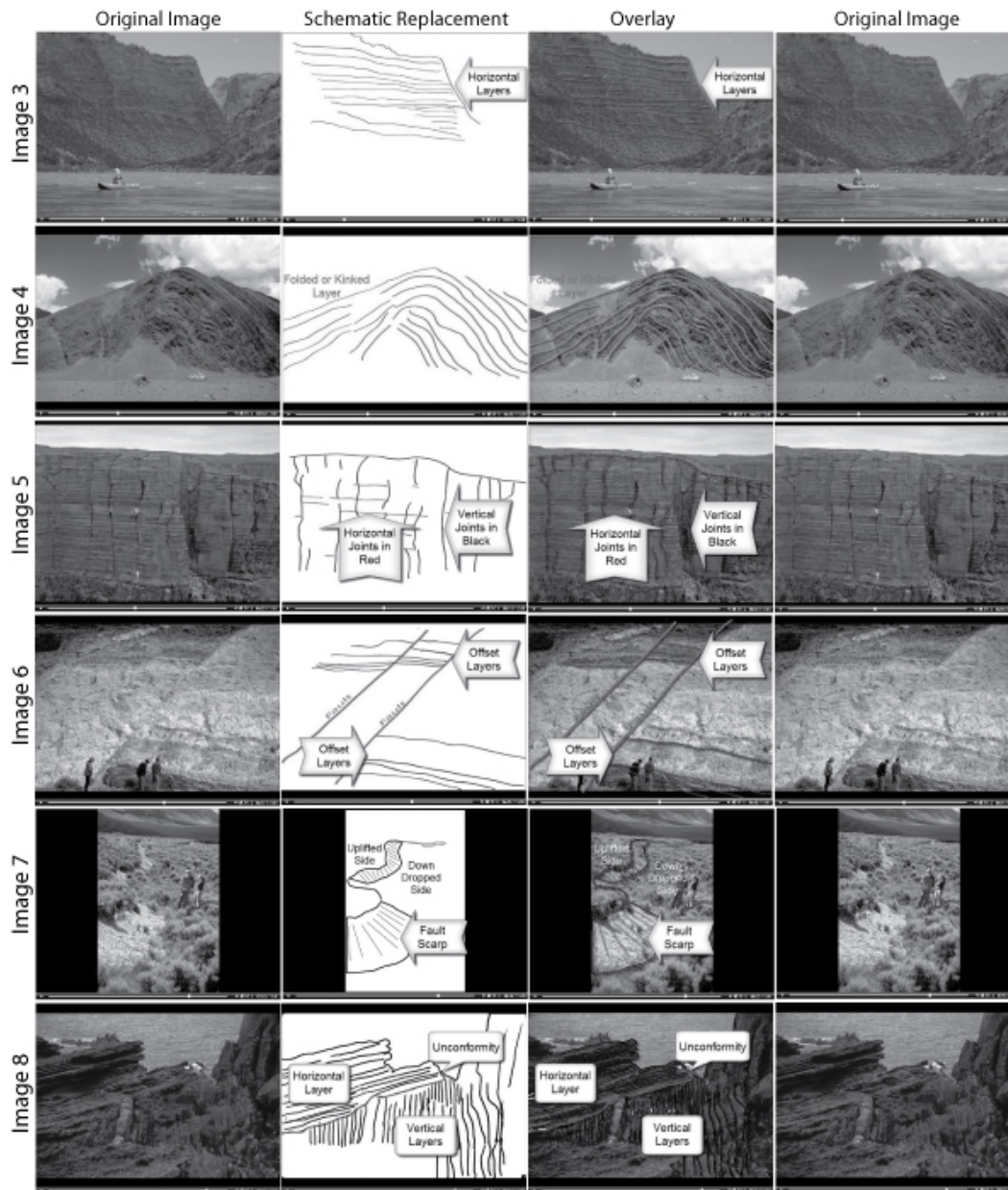


Figure 2.2: Photographs that comprised the two narrated slide shows. The image number is listed on the left side of each row. Column 1 contains the pre-signaling images or the images in their original state. Participants viewed this image for ~8 seconds. Column 2 contains the signaling state for the schematic-replacement group. Column 3 contains the signaling state for the overlay group. Participants viewed either the schematic-replacement condition or the overlay condition for ~8 seconds. Note that the callouts are the exact same line drawings and text as the schematic-replacement group. Image 3 was a photograph of the Yampa River Canyon featuring horizontal layers; the distractor was a kayaker. Image 4 was a photograph featuring an anticline; the distractors were two tents. Image 5 was a photograph featuring vertical and horizontal joints; 2 climbers were the distractors

(one in the center and one near the bottom). Image 6 was a photograph featuring offset layers; the distractors were three geologists. Image 7 was a photograph featuring a fault scarp; two people were the distractor. Image 8 was a photograph featuring horizontal layers unconformably overlying vertical layers; the distractor was a climber in the center of the image.

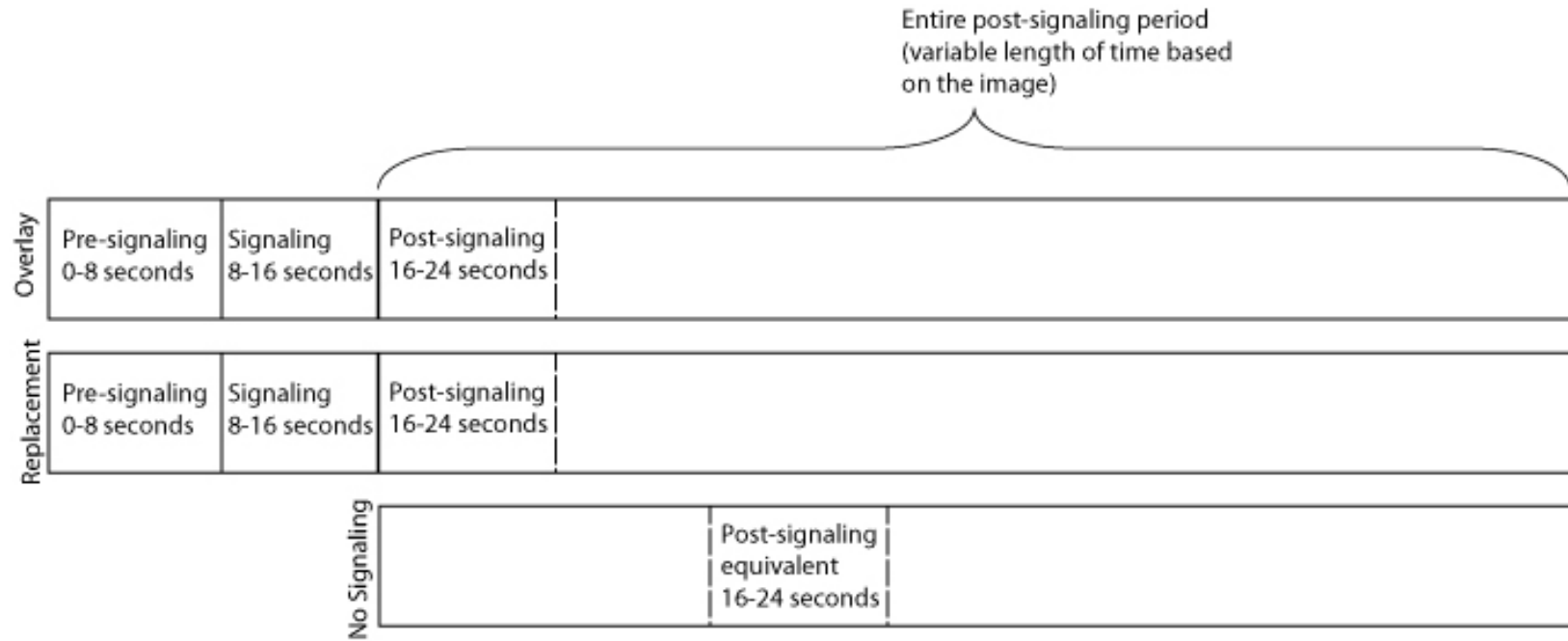


Figure 2.3: Schematic illustration of the video timelines for the overlay group, the schematic-replacement group, and the no-signaling group. The data for the signaling and no-signaling groups were compared in two ways. First, we compared eye-tracking data from the 8 seconds following signaling to the equivalent time looking at the image for the no-signaling group. The second comparison between the signaling groups and the no-signal group is for data collected during the entire post-signaling period. Content delivered during this period of time was identical to content viewed by the no-signal group. In this comparison, the images, narration, and duration for all three groups were identical.

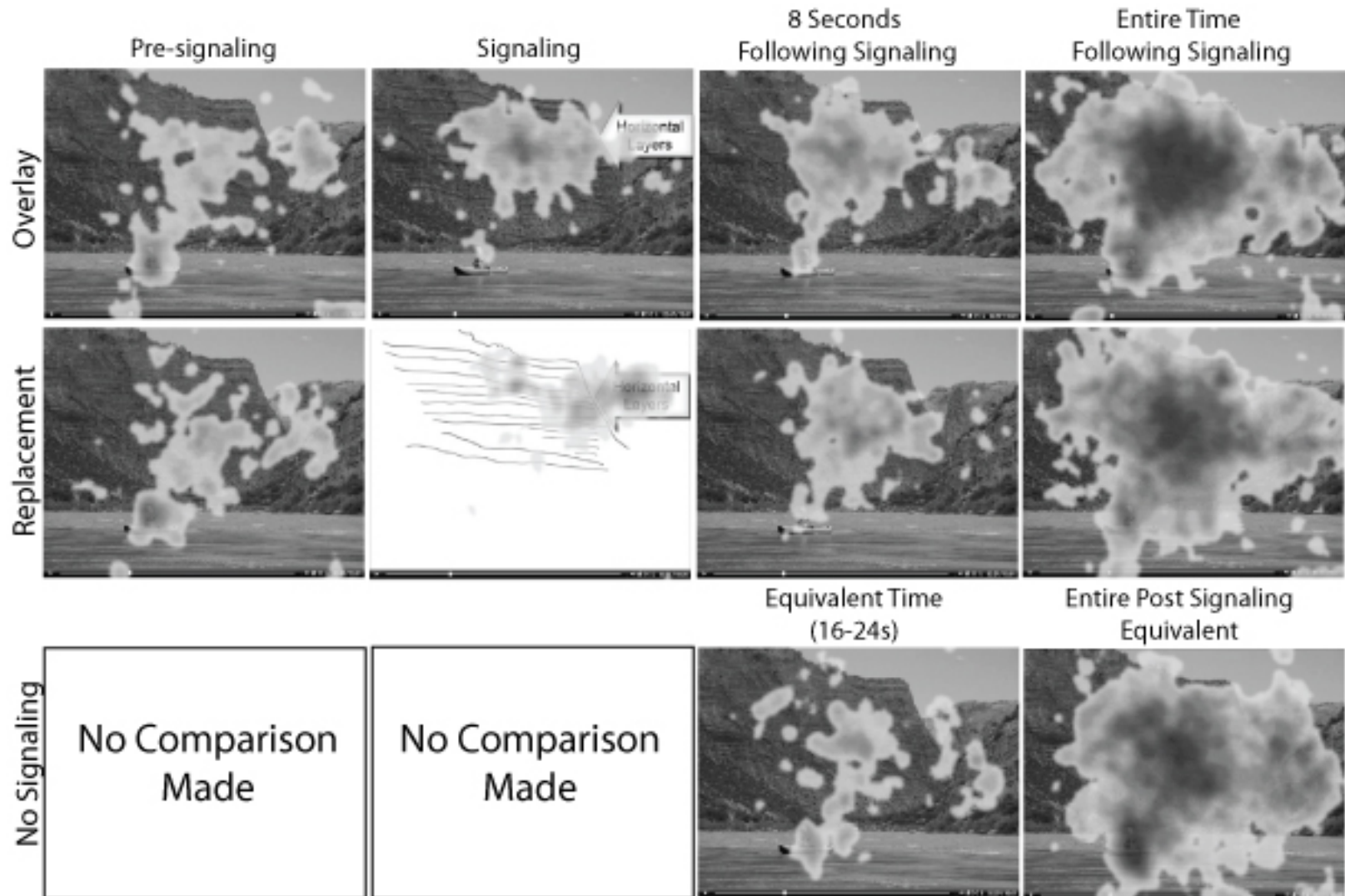


Figure 2.4: Group focus maps for image 3. Focus maps display the relative visual activity for all participants in each group overlain on the original image. Darker shades of gray represent the most visual activity, lighter shades of gray represent progressively less visual

activity, and areas lacking gray represent no visual activity. The top row contains the focus maps for the overlay group. The second row contains the focus maps for the schematic-replacement group. The third row contains the focus maps for the no-signaling group. Column 1 contains the pre-signaling focus maps for each group. Column 2 contains the signaling focus maps for each group. Column 3 contains the focus maps for each group for the first 8 seconds following signaling. Column 4 contains the focus maps for each group for the entire time the image was displayed following signaling. Note, the narrated slide show that the no-signaling group viewed did not contain a pre-signaling or signaling condition, instead the narration for this group started right away.

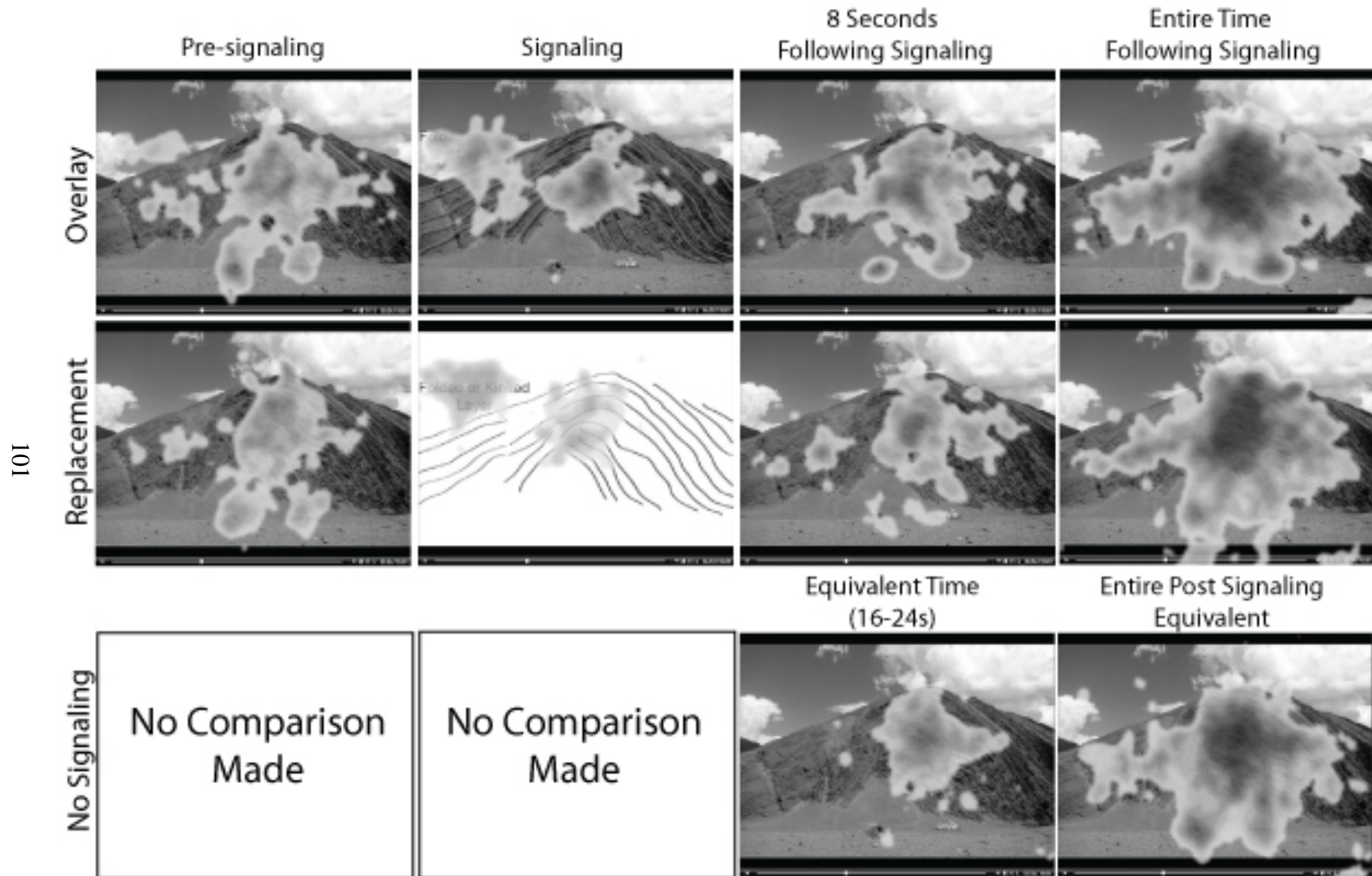


Figure 2.5: Group focus maps for image 4. Layout and conventions are the same as for figure 2.3.

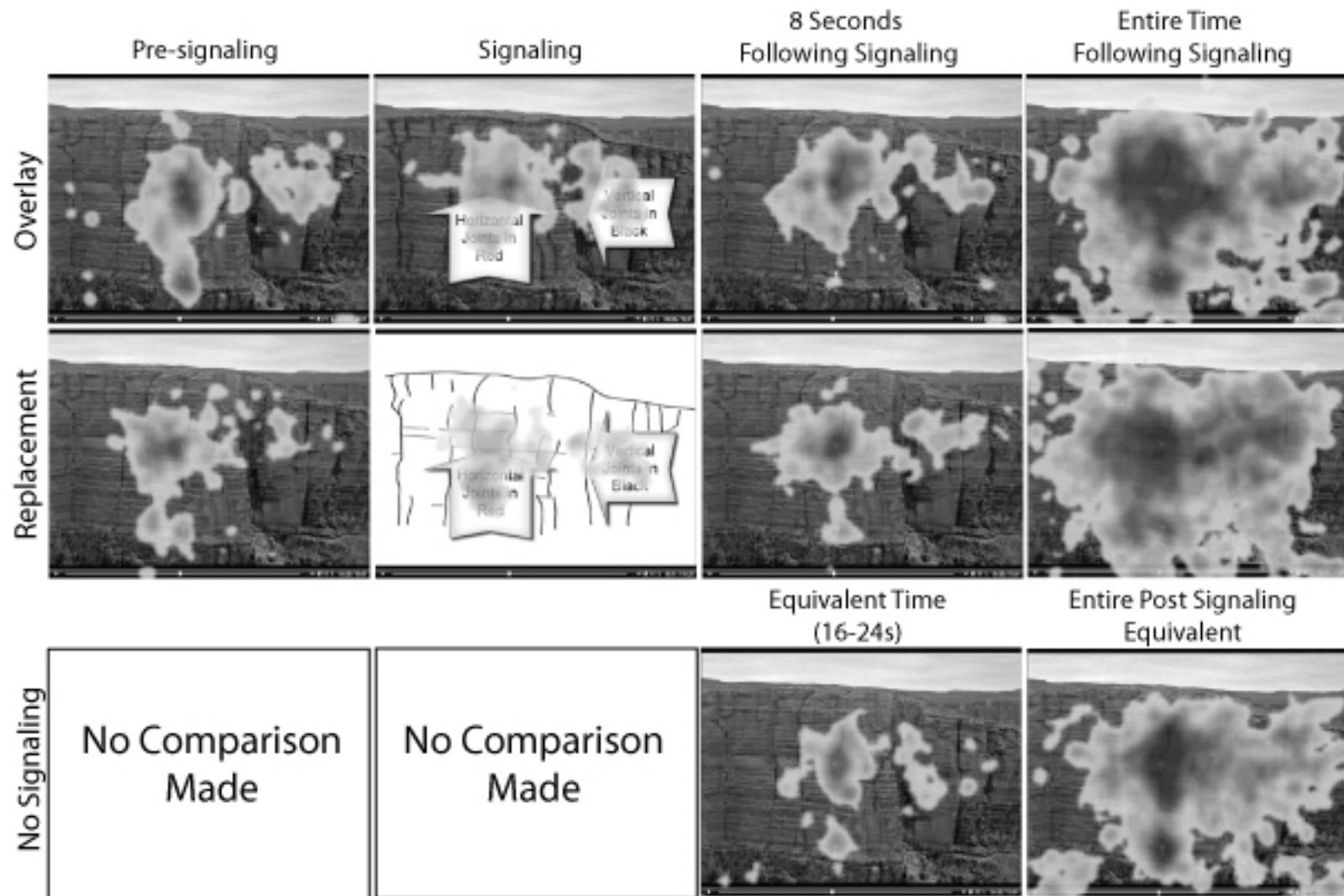


Figure 2.6: Group focus maps for image 5. Layout and conventions are the same as for figure 2.3.

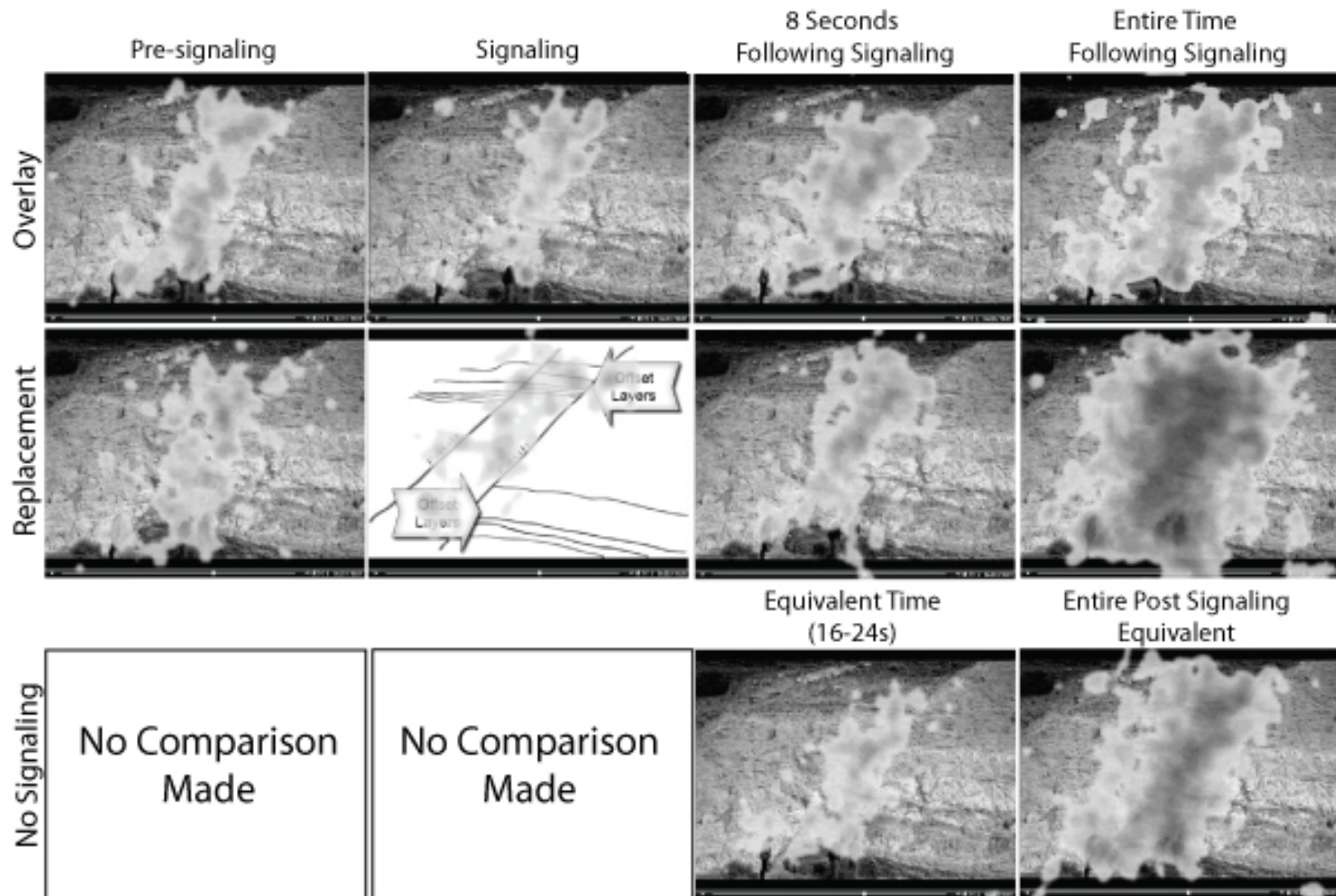


Figure 2.7: Group focus maps for image 6. Layout and conventions are the same as for figure 2.3.

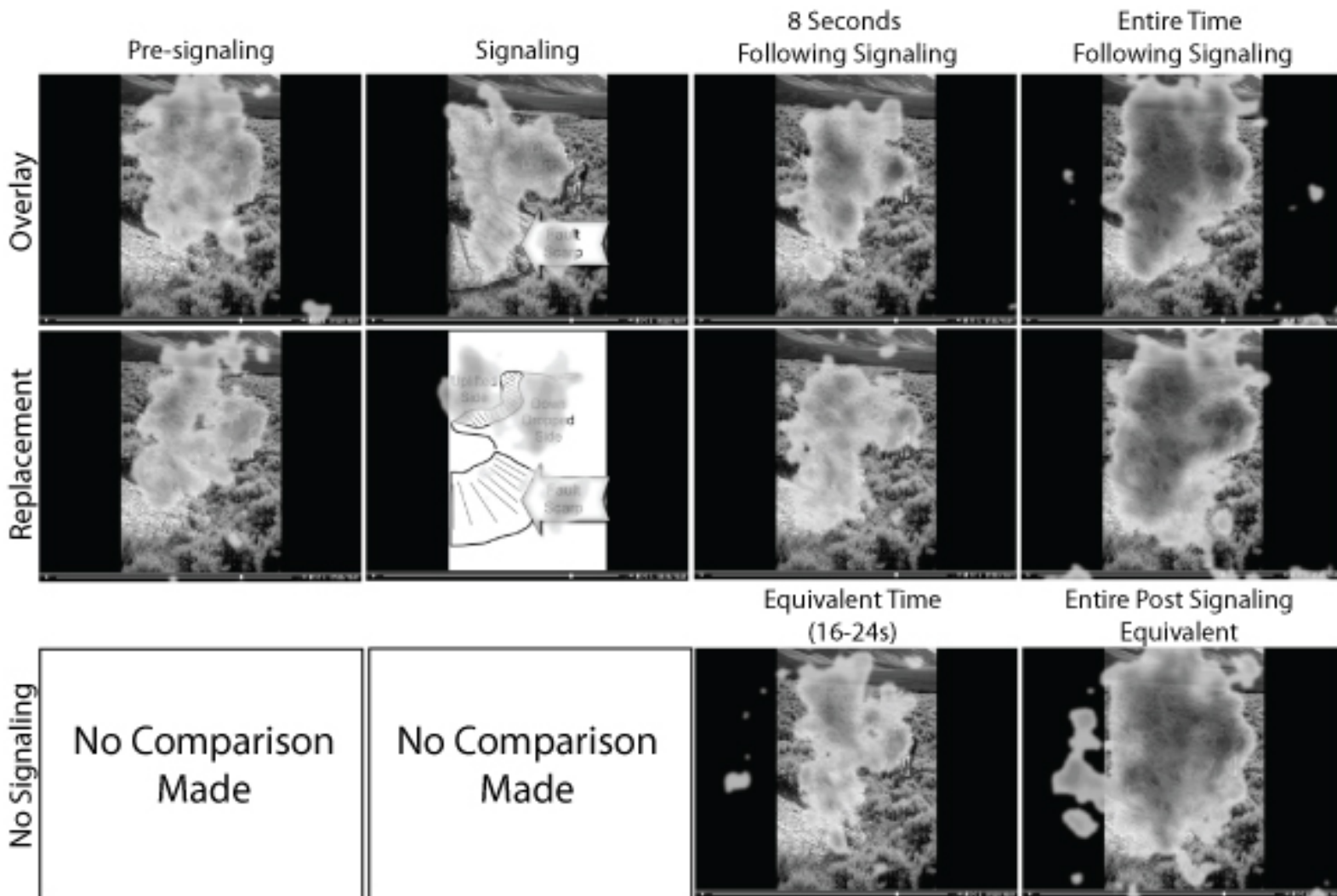


Figure 2.8: Group focus maps for image 7. Layout and conventions are the same as for figure 2.3.

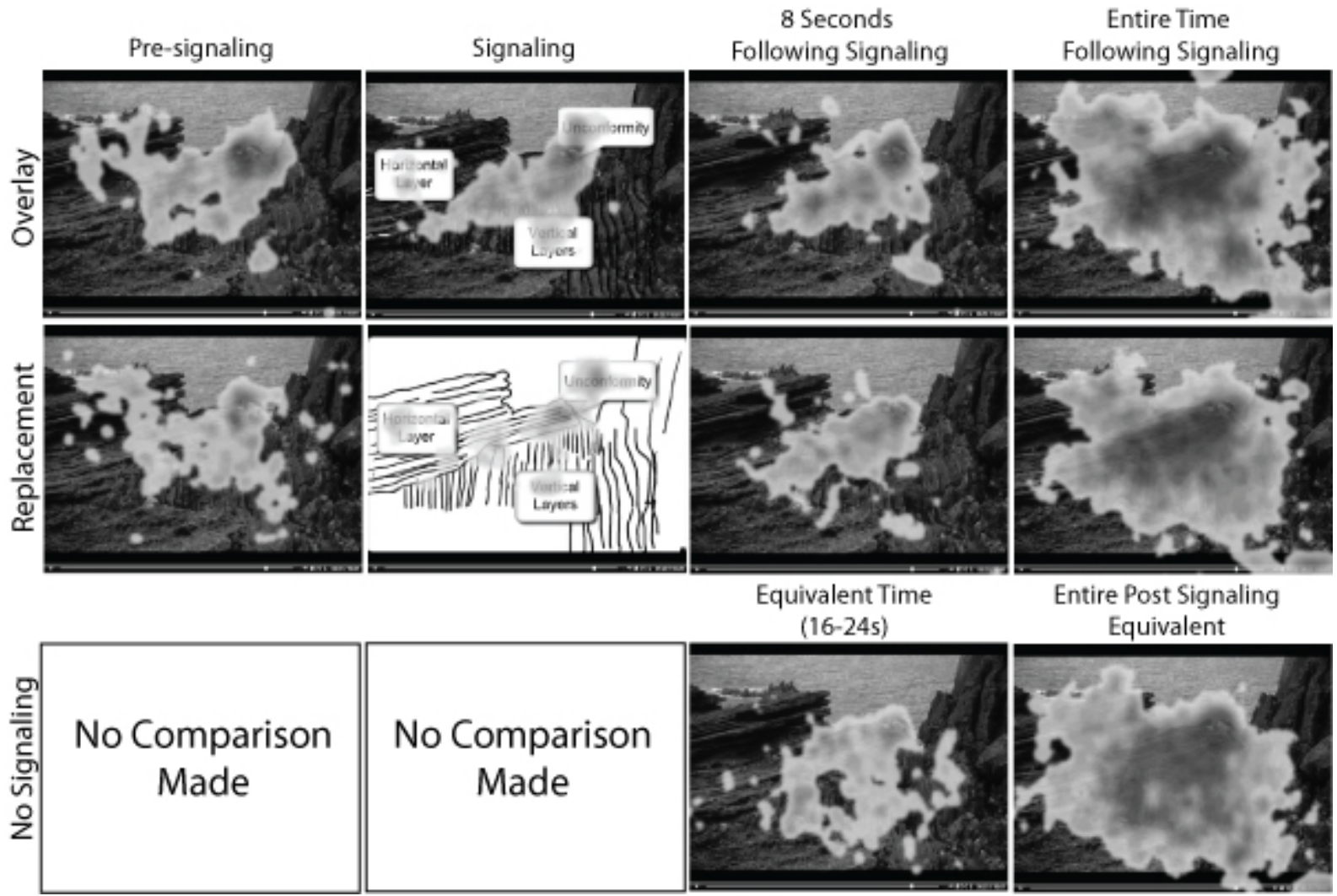


Figure 2.9: Group focus maps for image 8. Layout and conventions are the same as for figure 2.3.

Table 2.1: Time in seconds each image was displayed post signaling.

Image #	Time (s)
3	60.5
4	43.0
5	82.0
6	66.4
7	45.5
8	57.8

Table 2.2: Average percentage of time participants fixated on the distractor pre- and 8-seconds post-signaling.

Image #	Pre-signaling		8-seconds post-signaling		
	Overlay group	Replacement group	Overlay group	Replacement group	No-signaling group
3	15.86	19.88	3.65	3.33	14.87
4	11.79	9.48	10.85	1.72	5.47
5	20.47	23.29	12.54	21.40	34.76
6	13.57	14.24	4.79	7.43	10.16
7	15.61	13.32	14.51	10.34	11.13
8	38.11	24.40	29.36	18.69	16.10

Table 2.3: Average number of grid squares a fixation occurred in pre- and 8-seconds post-signaling.

Image #	Pre-signaling		8-seconds post-signaling		
	Overlay group	Replacement group	Overlay group	Replacement group	No-signaling group
3	19.33	21.86	19.47	19.86	14.47
4	19.25	19.71	17.4	18.36	12.58
5	16.33	19.00	14.47	18.50	12.84
6	21.73	22.82	17.13	23.14	11.32
7	17.19	19.79	16.00	16.43	12.31
8	18.13	21.48	15.25	19.46	14.28

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Table 2.4: Average percentage of time participants in the overlay group spent fixated on the distractor during signaling. Image 7 was not analyzed because the callouts covered more than 50% of the distractor; therefore, it would be difficult to determine if fixations were occurring on the callout or on the distractor.

Image #	Overlay group
3	5.0
4	2.0
5	7.0
6	2.5
7	--
8	17.0

Table 2.5: One-way within subjects ANOVA results for total time participants fixated on the distractor prior to signaling and during the 8 seconds following signaling.

Image number	N	Pre-signaling	Post signaling	ANOVA statistics		
		M (SD)	M (SD)	F	Wilk's Λ	Partial η^2
3	27	1.34 (.84)	.24 (.28)	39.84***	.40	.61
4	29	.69 (.66)	.52 (1.30)	.50	.98	.02
5	29	1.60 (1.28)	1.25 (1.52)	1.10	.962	.04
6	29	.82 (.74)	.42 (.48)	6.40*	.81	.19
7	29	1.12 (.86)	.96 (1.54)	.40	.99	.01
8	28	2.31 (1.70)	1.83 (1.58)	1.91	.93	.07

*p < .05. **p < .01. ***p < .001.

Table 2.6: One-way within subjects ANOVA results for average number of grid squares a fixation occurred in pre signaling and the immediate 8 seconds following signaling.

Image number	N	Pre-signaling	Post signaling	ANOVA statistics			
		M (SD)	M (SD)	F	Wilk's Λ	Partial η^2	95% CI
3	28	21.25 (4.65)	19.82 (5.24)	3.701	.88	.12	18.77 to 22.30
4	29	20.03 (5.02)	17.86 (5.85)	3.73	.88	.12	17.22 to 20.67
5	29	17.66 (5.37)	16.41 (5.75)	1.53	.95	.05	15.18 to 18.89
6	29	22.21 (6.55)	20.03 (6.07)	2.89	.91	.09	19.11 to 23.14
7	30	18.47 (4.33)	16.20 (4.53)	7.45**	.80	.20	15.91 to 18.75
8	29	20.00 (6.19)	17.14 (4.77)	5.72*	.83	.17	16.86 to 20.28

*p < .05. **p < .01. ***p < .001.

Table 2.7: 95% confidence intervals for pairwise differences in mean amount of time looking at the distractor 8 seconds following signaling for images 3, 4, 5, and 8.

Image number	Group	Pairwise differences				Omnibus		
		M	SD	No signaling	Overlays	F	p	Partial η^2
3	No signaling	.84	1.0			F (2, 54) = 4.40	< .05*	.14
	Overlay	.27	.37	.04 to 1.10*				
	Replacement	.24	.16	.13 to 1.07*	-.26 to .32			
4	No signaling	.22	.50			F (2, 55) = 3.10	= .05*	.10
	Overlay	.89	1.74	-1.87 to .53				
	Replacement	.11	.21	-.17 to .37	-.41 to 1.96			
5	No signaling	2.26	1.78			F(2, 54) = 3.16	< .05*	.11
	Overlay	.96	1.29	-.001 to 2.61				
	Replacement	1.56	1.73	-.64 to 2.03	-2.12 to .91			
8	No signaling	.87	1.33			F (2, 44) = 3.49	< .05*	.14
	Overlay	2.21	1.81	-2.61 to -.06*				
	Replacement	1.29	1.19	-1.71 to .88	-.44 to 2.27			

Note: An asterisk indicates that the 95% confidence interval does not contain zero and therefore the difference in means is significant at the 0.05 significance using the Dunnett's C procedure or at the 0.0167 significance controlling for Type I error using the Bonferroni Method.

Table 2.8: 95% confidence intervals for pairwise differences in mean number of grid squares a fixation occurred in during the immediate 8 seconds following signaling for images 3 through 8.

Image number	Group	Pairwise differences				Omnibus		
		M	SD	No signaling	Overlays	F	p	Partial η^2
3	No signaling	14.47	5.66			F (2, 45) = 5.20	< .01	.19
	Overlay	19.47	4.50	-9.68 to -.31				
	Replacement	19.86	6.06	-10.16 to -.61	-5.43 to 4.65			
4	No signaling	12.58	4.30			F (2, 45) = 5.73	< .01	.20
	Overlay	17.40	5.29	-9.41 to -.23				
	Replacement	18.36	6.56	-10.46 to -1.10*	-5.89 to 3.98			
5	No signaling	12.84	4.52			F (2, 45) = 5.06	< .01	.18
	Overlay	14.47	4.81	-6.02 to 2.77				
	Replacement	18.50	6.10	-10.14 to -1.18*	-8.75 to .69			
6	No signaling	11.32	5.10			F (2, 51) = 23.42	< .001	.48
	Overlay	17.13	5.78	-10.04 to -1.59*				
	Replacement	23.14	4.83	-16.14 to -7.50*	-10.82 to -1.20*			
7	No signaling	12.31	4.67			F (2, 53) = 4.94	< .05	.16
	Overlay	16.00	3.56	-7.33 to -.05				
	Replacement	16.43	5.57	-7.92 to -.32	-4.62 to 3.77			
8	No signaling	14.28	5.39			F (2, 51) = 5.00	< .01	.16
	Overlay	15.25	3.89	-4.83 to 2.87				
	Replacement	19.46	4.86	-9.30 to -1.06*	-8.71 to .29			

Note: An asterisk indicates that the 95% confidence interval does not contain zero and therefore the difference in means is significant at the 0.05 significance using the Dunnett's C procedure or at the 0.0167 significance controlling for Type I error using the Bonferroni Method.

Table 2.9: Average percentage of time participants spent looking at the distractor during the post signaling segment.

Image #	Overlay group	Replacement group	No-signaling group
3	4.48	4.90	13.19
4	6.84	3.01	12.84
5	20.29	20.96	42.48
6	5.58	8.38	19.85
7	13.01	12.35	22.48
8	21.94	13.75	30.81

Table 2.10: 95% confidence intervals for pairwise differences in mean percentage of time looking at the distractor during the entire post signaling period for images 3 through 8.

Image number	Group	Pairwise differences				Omnibus		
		M	SD	No signaling	Overlay	F	p	Partial η^2
3	No signaling	13.19	11.12			F (2, 54) = 7.53	< .001	.22
	Overlay	4.48	3.89	2.87 to 14.54*				
	Replacement	4.90	3.38	2.56 to 14.02*	-3.97 to 3.14			
4	No signaling	12.84	7.31			F (2, 50) = 8.49	< .001	.25
	Overlay	6.84	10.06	-1.76 to 13.75				
	Replacement	3.01	1.94	5.85 to 13.81*	-3.10 to 10.77			
5	No signaling	42.48	18.83			F (2, 59) = 14.36	< .001	.33
	Overlay	20.29	11.71	9.89 to 34.50*				
	Replacement	20.96	12.11	8.92 to 34.13*	-15.35 to 14.01			
6	No signaling	19.85	14.57			F (2, 49) = 9.96	< .001	.29
	Overlay	5.58	4.38	6.08 to 22.45*				
	Replacement	8.38	5.97	2.76 to 20.19*	-7.95 to 2.35			
7	No signaling	22.48	12.69			F (2, 50) = 3.71	< .05	.13
	Overlay	13.01	12.61	-1.16 to 20.09				
	Replacement	12.35	14.02	-.72 to 20.98	-11.33 to 12.65			
8	No signaling	30.81	25.74			F (2, 53) = 3.29	< .05	.11
	Overlay	21.94	16.39	-7.69 to 25.42				
	Replacement	13.75	10.51	2.69 to 31.42*	-5.14 to 21.52			

Note: An asterisk indicates that the 95% confidence interval does not contain zero and therefore the difference in means is significant at the 0.05 significance using the Dunnett's C procedure or at the 0.0167 significance controlling for Type I error using the Bonferroni Method.

Table 2.11: Average number of grid squares a fixation occurred in following signaling.

Image #	Overlay group	Replacement group	No-signal group
3	68.00	69.14	49.26
4	48.60	48.71	18.74
5	67.33	82.14	38.26
6	69.00	77.79	11.4
7	42.75	43.50	23.69
8	63.25	59.14	33.77

Table 2.12: 95% confidence intervals for pairwise differences in mean number of grid squares a fixation occurred in following signaling for images 3 through 8.

Image number	Group	Pairwise differences				Omnibus		
		M	SD	No signaling	Overlay	F	p	Partial η^2
3	No signaling	49.26	15.88			F (2, 46) = 8.42	< .001	.27
	Overlay	68.00	16.48	-34.56 to -2.91*				
	Replacement	69.14	15.71	-36.31 to -3.45*	-18.21 to 15.93			
4	No signaling	18.74	5.57			F (2, 45) = 48.22	< .001	.68
	Overlay	48.60	10.95	-39.72 to -20.01*				
	Replacement	48.71	14.03	-42.73 to -17.22*	-15.24 to 15.01			
5	No signaling	38.26	10.78			F (2, 45) = 20.61	< .001	.48
	Overlay	67.33	21.50	-48.38 to -9.76*				
	Replacement	82.14	27.19	-68.60 to -19.16*	-44.26 to 14.64			
6	No signaling	11.40	5.20			F (2, 52) = 140.81	< .001	.84
	Overlay	69.00	15.79	-70.47 to -44.73*				
	Replacement	77.79	20.19	-84.12 to -48.65*	-30.25 to 12.68			
7	No signaling	23.69	6.33			F (2, 53) = 25.40	< .001	.49
	Overlay	42.75	11.17	-28.63 to -9.49*				
	Replacement	43.50	14.16	-32.59 to -7.02*	-15.84 to 14.34			
8	No signaling	33.77	15.62			F (2, 53) = 19.08	< .001	.42
	Overlay	63.25	16.17	-44.87 to -14.09*				
	Replacement	59.14	19.32	-41.43 to -9.32*	-13.61 to 21.83			

Note: An asterisk indicates that the 95% confidence interval does not contain zero and therefore the difference in means is significant at the 0.05 significance using the Dunnett's C procedure or at the 0.0167 significance controlling for Type I error using the Bonferroni Method.

Chapter 3

THE STRUCTURAL SETTING OF HYDROTHERMAL GOLD DEPOSITS IN THE SAN ANTONIO AREA, B.C.S., MX.

Abstract

The San Antonio area in the southern part of the Baja California Peninsula is host to hydrothermal gold deposits. A structural study including drill-core analysis and detailed geologic mapping was conducted to determine the types of mineralization present, the types of structures present, and the relationship between the two. This investigation revealed that two phases of mineralization have occurred in the area; the first is hydrothermal deposition of gold mineralization associated with sulfide deposits and the second is oxidation of sulfides to hematite, goethite, and jarosite. Mineralization varies as a function of depth, with sulfides, including pyrite, pyrrhotite, and chalcopyrite, occurring at depth, while minerals indicative of oxidation are limited to shallow depths. A structural analysis revealed that the oldest structures in the study area include low-grade to medium-grade metamorphic foliation and ductile mylonitic shear zones. Ductile deformational structures were overprinted by brittle-ductile mylonitic fabrics, which were later overprinted by brittle deformation. Both primary and secondary mineralization in the area are restricted to the later brittle features. Brittle features that contain alteration have an average NNW strike consistent with northeast-southwest-directed extension, whereas brittle features that do not contain alteration have an average NNE strike consistent with northwest-

southeast-directed extension. Comparing these inferred stress orientations to regional stress patterns implies that ore deposition probably occurred during early to middle Cenozoic extension, prior to the rifting of the Baja Peninsula from mainland Mexico.

1. Introduction

Precious metals can be emplaced in a variety of ways, and in various types of deposits. Many are formed by hydrothermal deposits, where mineral-rich fluids flow through and interact with country rock. The mineral-rich fluids require conduits and space to transport precious metals, commonly along fractures and joints. Therefore, to understand and predict the location of hydrothermal ore deposits, it is paramount to evaluate the structures that once controlled fluid flow and that now host the mineral deposit (Evans, 1993). We conducted an analysis of mineralized structures in the southern part of the Baja California Peninsula to assess the relationship between bedrock structures and mineralization of a hydrothermal gold deposit.

The southern part of the Baja California Peninsula, Mexico contains gold prospects and mines that have been known since the 1500's, including the Las Colinas Mining District (Figures 1 and 2) (Ashley, 1991). Since this early time, native people have mined precious metals in the area. According to one estimate 115,000 ounces of gold were removed from 1862 to 1915 (Derry et al., 2007). Recent prospecting in the area began in the 1990s when Echo Bay Exploration Inc. conducted detailed studies of the gold deposit, including geologic mapping, soil-chemical analyses, ground geophysics, drilling, and assay analyses. In 2005 Pediment Exploration Inc. acquired the property rights and began conducting studies of their own, which included a drilling program, a soil-chemical analysis, and an induced polarization (IP) survey (Derry et al, 2008; Brown et al, 1998;

Hanson, 2010). In 2007 we began to evaluate the structural controls of mineralization in the Las Colinas Mining District to understand the origin of the deposit and to determine prime locations for exploration.

The zone of gold mineralization passes through the Las Colinas Mining District located north of the historic mining town of San Antonio (Figure 3.1). The Las Colinas Mining District is located approximately 40 kilometers southeast of La Paz in the southwest end of the San Juan de los Planes Basin and is composed of three mining concessions, which are currently controlled by Pediment Exploration. The mining concessions are Cirio, Emily, and Trincheras (Figure 3.2). The main focus of our investigation was the Cirio concession. The Cirio concession is approximately 4500 meters in length in a north/south direction and 3300 meters wide in an east/west direction. Local geographic landmarks in the area include the town of San Antonio, which is located approximately 5 kilometers to the south and Fandango Wash, which is one of the primary drainages in the area carrying floodwaters eastward from the Sierra Las Calabazas located to the west. (Figure 3.2). The concession contains several hills surrounded by a soil- and gravel-covered pediment. Although the concession mostly lies north of the eastern extent of Fandango Wash, the lack of outcrops and thick sediment cover in that portion of the concession caused us to focus our investigation primarily to a section south of Fandango Wash (Figure 3.2). A portion of our field area does include the southern extent of the Cirio Concession (Hanson, 2010).

In order to determine the nature of the gold deposit, we collected observations about the types of minerals present in the area and the relationship between mineralization and structures. We also compiled data from geologic mapping, borehole logs, and structural measurements.

This chapter will present detailed mapping south of the Cirio Concession, featuring the main rock types and structures that are present in the area. Additionally, we present borehole logs that reach to a maximum depth of 183 meters. We combined surface mapping, structural measurements, and borehole data to create cross sections. Finally, we present the results of a structural analysis that characterizes structures based on the presence or absence of alteration mineralization. The structural analysis provides information that contributes to the understanding of the structural evolution of the area and of the origin of the mineral deposit. Our research shows that gold mineralization in the Cirio concession primarily occurs along steeply dipping brittle faults and fractures, interpreted to have formed in a shallow setting and relatively late in the structural sequence, probably during Cenozoic extension.

2. Background

2.1 Tectonic setting

Baja California Sur has a complex geologic history, including the early Cretaceous accretion of suspect terranes (Coney, 1989; Dickinson and Lawton, 2001; Sedlock, 2003; Umhoefer, 2003). In addition to terrane accretion, the Baja Peninsula has undergone extensive plutonism and volcanism, and currently is rifting from mainland Mexico in an oblique divergent setting (Stock and Hodges, 1989).

The peninsula is composed of a series of exotic terranes that began to accrete at approximately 125 Ma (Coney, 1989; Dickinson and Lawton, 2001). During the Early Cretaceous, eastern North America continued pulling away from Africa and South America due to seafloor spreading along the Mid-Atlantic Ridge. At this time, there was an active convergent margin on the western coast of North America, and several island arcs were in transit to be accreted to this margin (Baldrige, 2004). On Mexico's western margin, there existed either a northeast-facing intraoceanic island arc approaching a southwest-facing continental-margin magmatic arc (Dickinson and Lawton, 2001) or simply a northeast-facing island arc (Sedlock, 2003). In either case, exotic terranes (the Guerrero Superterrane or the Alisitos Arc) were accreted during this interval. Following accretion of the Early Cretaceous terranes, at about 100 Ma, arc magmatism created the Peninsular Range Batholith (PRB) (Normark and Curray, 1968). The PRB served to stitch together accreted arcs (Sedlock, 2003) and

formed the host rocks for most gold mineralization in the study area (Brown, 2003).

In the Late Cretaceous, the subducted slab beneath southwestern North America shallowed in dip, causing volcanism to migrate inland and magmatism in the PRB to shut off. During and after this time, the batholith was exhumed. (Sedlock, 2003). By 90 to 80 Ma magmatism had migrated eastward, out of the Baja region, into present-day mainland Mexico. This inward migration of magmatism can be correlated to the Laramide Orogeny in Arizona and adjacent areas. Due to the uplift of the eastern Peninsular Range, sediments were shed westward and then eastward (Sedlock, 2003).

Approximately 28 Ma, an important plate reorganization occurred as the Pacific-Farallon ridge-transform system encountered the North American plate around what is now San Diego, California (Stock and Hodges, 1989; Sedlock, 2003; Umhoefer, 2001, 2003; Dickinson and Lawton, 2003). As the spreading center encountered the margin of North America, subduction ended along the region of contact and the Farallon plate became segmented into the Juan de Fuca and Cocos Plates. Two triple junctions (the Mendocino and the Rivera) formed and began to migrate in opposite directions, lengthening the Pacific-North American Transform Boundary (Stock and Lee, 1994). During this time detachment-dominated extension commenced and continued until 12 Ma, at which time basin-and-range faulting became the dominant mode of extension, first in a northeast-southwest direction and later an east-west to northwest-

southeast direction (Angelier et al., 1981; Axen, 1995; Henry and Aranda-Gomez, 1998). These extensional styles are thought to be precursors to continental rifting and, eventually, to a divergent plate margin in the present-day Gulf of California.

Protogulf extension began ca. 12 Ma to 6 Ma followed by marine incursions (Martinez-Gutiérrez and Sethi, 1997; Sedlock, 2003). These transgressive events began in the southern Gulf of California first (9 to 8 Ma) and migrated northward. By 6.5 Ma, the northern gulf was fully inundated by the sea. Before 3 Ma, full-scale rifting and seafloor spreading was underway in the southern Gulf of California (De Mets, 1995; Fletcher and Munguia, 2000), moving the Baja Peninsula further northwestward with respect to mainland Mexico.

The Gulf of California is currently marked by an oblique-divergent boundary that has extensive transform faults linked by short, widely spaced spreading centers. It is estimated that since 6 Ma, a total of 250 ± 10 km of total displacement has occurred (Sedlock, 2003). In addition to oblique divergence within the Gulf of California (e.g., Munguia et al., 2006), onshore normal faults along the southwestern margin of the gulf accommodate east-west extension (Fletcher and Munguía, 2000).

Structural analyses conducted by Henry (1989), Umhoefer et al. (2002), and Angelier (1981) have also shown consistently that prior to 34 Ma, the maximum horizontal stress direction (σ_1) was directed in a northeast-southwest direction, most likely a result of northeasterly directed subduction of the Pacific

Plate under the North American Plate. Henry (1989) also demonstrated a clear shift in the stress directions at 34 Ma from northwest-southeast-directed extension to a northeast-southwest-directed extension. Umhoefer et al. (2002) and Angelier et al. (1981) also have recorded measurements that are consistent with Henry and show that from 12 to 6 Ma extension was directed in a northeast-southwest direction. A final change in the orientation of extension, shown by all three researchers, occurred when northeast-southwest extension gave way to northwest-southeast extension in the late Miocene in northern areas of the Baja Peninsula and during the Pliocene in southern portion of the Baja Peninsula.

2.2 Influence of depth on deformation

Geologic structures that form at depths greater than 10 to 15 km (below the brittle ductile transition) are typically ductile in nature and include foliation, lineation, folds, and shear zones, accompanied by metamorphism (Higgins, 1971; Kerrich and Allison, 1978). Ductile shear zones formed at depth are typically planar to gently curving and are commonly arranged in sets that remain subparallel or eventually link up (Sibson, 1977; Davis and Reynolds, 1996).

As rocks are uplifted to the surface, and quartz is no longer warm enough to flow, ductile deformation gives way to brittle deformation, which occurs at shallow levels in the crust (less than 10 km), where temperatures are cooler and confining pressure is relatively low. Consequently, in this environment strain rates are much faster in nature and strain is typically more concentrated (Sibson, 1990). Brittle structures include fractures, joints, and faults that offset the rock by

crushing and breaking it (Higgins, 1971; Sibson, 1977 and 1990; Kerrich and Allison, 1978).

Intermediate structures are structures that exhibit both brittle and ductile deformation styles and are therefore referred to as brittle-ductile (Davis and Reynolds, 1996). Brittle-ductile deformation commonly occurs at a depth of 10 to 15 km (Sibson, 1977 and 1990). One style of brittle-ductile deformation occurs at depth where moderately high temperatures and pressures cause select minerals such as quartz to flow rather than break; whereas other minerals at the same temperature and pressure, such as feldspar, will remain brittle (Higgins, 1971). When deformation occurs in this type of environment, quartz minerals will flow into elongate ribbons. Feldspar crystals that are adjacent to each other can impinge against one another, causing one of the crystals to shatter and break into angular fragments. The result is fragmented feldspar clasts in a matrix of smooth elongate quartz ribbons (Kerrich and Allison, 1978; Sibson, 1980; Evans, 1988). In order to determine relative offset of ductile and brittle-ductile structures, sense-of-shear indicators include the orientation of deflected markers, foliation patterns, shear bands, S-C fabrics, mica fish, pressure shadows, folds, boudins, porphyroclasts, and veins (Lister and Snoke, 1984; Davis and Reynolds, 1996).

2.3 Mineralization

Hydrothermal solutions are capable of carrying and depositing a wide variety of materials, such as gold (Guilbert and Park, 1986; Evans, 1993). Typical hydrothermal ore deposits are usually on the scale of a few cubic kilometers in

size. Certain minerals, such as sulphides and oxides, characterize hydrothermal deposits (Skinner, 1979). Hydrothermal water sources are restricted to surface and groundwater (meteoric waters), seawater, formation fluids and deeply penetrating meteoric waters, metamorphic fluids, and magmatic waters (Guilbert and Park, 1986; Evans, 1993). One hypothesis holds that cooling magmas may be the source of most hydrothermal solutions (Fyfe and Kerrich, 1985). In the case that fluids are derived from cooling magmas, solutions are considered to be residual and left over after crystallization (Hodgson et al., 1993; Fan, 2003). For example, research by Burnham (1979) showed that felsic magmas typically contain 2.5 to 6.5 wt % water, which may be as much as 100×10^{11} liters for 1 km^3 of felsic magma with 3% water (Brimhall and Crerar, 1987). It has also been shown that intrusive magmas typically do not exsolve fluids at depths greater than 4.5 km. Below these depths, water will remain in solution due to high confining pressures (Whitney, 1975; Skinner, 1979). Above depths of 4.5 km water will readily come out of solution and may be a source of both alteration and mineralization. Furthermore, magmatic fluids may contain a high concentration of metals released from water-saturated magmas that are located at high levels in the crust (Evans, 1993).

Due to their corrosive nature, ligands, such as sulfide, hydrogen sulfide, chloride, and hydroxide, may be the root means of gold transportation in solution (Barnes, 1979; Henley et al., 1984; Kishida and Kerrich, 1987; Ashley, 1991; Evans, 1993). Acidic fluids exsolved from a pluton have not been found to be robust enough to maintain a low pH state for periods of time required to dissolve

enough metals to form large ore bodies; therefore, another means of transport is required. In contrast, hydrogen sulfides in solution are extremely corrosive and found to be stable up to temperatures of 300° c. In hydrothermal systems, it is most likely the combination of acidic fluids and the presence of ligands such as hydrogen sulfide that facilitates transport (Skinner, 1979; Seward, 1991). The corrosive nature of hydrogen sulfide in solution is also likely to dissolve gold into solution, thereby assisting in mobilization. As a result, precious metal deposits, such as gold, are commonly accompanied by sulfide minerals including galena, pyrite, arsenopyrite, chalcopyrite, and pyrrhotite (Rose and Burt, 1979; Ashley, 1991; Evans, 1993; Cail and Cline, 2001; Fan et al., 2003).

Once metals and sulfides have been transported in a hydrothermal system, they are commonly deposited as disseminated or stockwork deposits (Ashley, 1991; Mine Development Assoc., 2005). Disseminated deposits are characterized by metals and accompanying alteration of host rock being restricted to small concentrated pods and veinlets scattered throughout the rock (Kerrick and Watson, 1984; Guilbert and Park, 1986). Stockwork systems are characterized by mineralization and accompanying alteration that is wholly, or largely, limited to veins and open-pore spaces (Evans, 1993; Fan, 2003). As a result of this style of deposition, areas of exploration for both types of deposits are commonly brittle structures and locations with open pore spaces that provide space into which minerals can be deposited (Rose and Burt, 1979; Guilbert and Park, 1986; Sibson, 1986; Sibson, 1990; Ashley, 1991).

In addition to primary hypogene mineralization in veins and disseminations, secondary mineralization may occur as a result of interaction with meteoric waters. As sulfides associated with precious metal deposits (pyrite, chalcopyrite, and galena) are uplifted and react with meteoric waters they are easily oxidized and form new minerals such as hematite, goethite, jarosite, or a combination of these iron-bearing minerals (limonite) (Rose and Burt, 1979). As meteoric waters progress deeper from the surface, the oxygen content is rapidly diminished. As a result, secondary minerals are commonly only found in the upper portion of veins. In addition to oxidizing sulfides and other minerals, meteoric waters can transport valuable metals downward in the vein and concentrate them, as a supergene enrichment (Kerrick and Watson, 1984). In many cases, the presence of oxidation minerals may be an indicator that secondary enrichment of precious metals has occurred (Guilbert and Park, 1986). Consequently, brittle deformation that enhances the presence and migration of meteoric water through an ore system may be favorable for exploration, as an enriching feature.

3. Methods

A structural survey was conducted between January and April 2007 to evaluate the character and origin of the Las Colinas gold deposit. In addition to collecting structural observations, measurements, and rock samples, we also examined the location of gold mineralization and the structural controls of macroscopic aspects of alteration.

Due to the nature of the landscape (small hills protruding through Quaternary cover), outcrops in the area were sparse. Accordingly, local exposures including incised drainages and road cuts were exploited to collect measurements and make observations about rock types and mineralization. Specifically, we focused our efforts along road cuts along the La Paz-San Jose del Cabo/Mexico 1 highway, a 4.2-km-long section of road that stretches from San Antonio eastward over the Los Chiles Mountains toward San Bartolo. Additionally, we collected data from exposed bedrock within Fandango Wash (Figure 3.2), and in trenches and cuts dug as part of mineral exploration.

3.1 Data acquisition

We collected structural data from three settings: bedrock exposures, trenches, and drill cores. Observations from bedrock exposures involved measuring the orientation of joints, veins, shear bands, and faults in the Las Colinas Mining District and in adjacent areas with better bedrock exposures.

To collect structural data within the concession itself, trenches that ranged from 0.5-m deep to 2-m deep and up to 60-m long were excavated by Pediment

Exploration and prior companies through the soil and into bedrock. We compiled detailed structural data from the trenches into trench logs. Trench logs were created for trenches that were two meters deep or greater. PhotoStitch 3.0 software was used to merge photographs of the trench walls to create a continuous panorama (Figures 3.4, 3.5, and 3.6).

In addition to our compilation of surface and near-surface data, core and drill logs were examined. We were granted access to borehole core that was collected by Pediment Exploration from January to June of 2007. During this period of time, thirteen boreholes were drilled by two different drilling machines, a smaller drill rig, or “winky” (denoted in core logs by LCW), which sampled to depths of 82 meters or less, and a larger, reverse-circulation drilling sled (denoted in drill logs by LCDD), which sampled to depths ranging from 117 to 182 meters (Figure 3.7). Drilling to depths greater than 100 meters (deep drilling) was only conducted on the northwestern portion of the concession. To intersect a hypothesized, west-dipping mineralized zone, all deep-sample boreholes were drilled with an inclination angle of either 50-degree or 70-degree to the east. Drilling to depths less than 100 meters (shallow drilling) was conducted on the eastern portion of the concession. These boreholes were drilled with either a 90-degree or 70-degree inclination toward the west (e.g. Figure 3.10). Boreholes were drilled with the sole purpose of obtaining bedrock samples for lithologic, structural, and geochemical analyses.

Drill core was packed in boxes and shipped to the nearby town of San Antonio where it was logged, cut lengthwise for the purposes of assay, and stored. A geologist from Compañía Minera Pitalla, the Mexican sister company to Pediment Exploration, logged all drill core in Spanish. For this investigation, drill-core logs were translated from Spanish to English and then schematic representations were constructed using Adobe Illustrator. We made our own observations of cores, where possible.

While examining exposed outcrops, trenches, and drill cores, we noted, crosscutting relationships and sense-of-shear indicators, including S-C fabrics, sigmoidal foliation, and shear bands. Structures were characterized as ductile features, brittle-ductile features, or brittle features. Measurements of ductile features included the orientation of mylonitic shear zones and foliation. Measurement of brittle-ductile features included orientations of brittle-ductile shear zones that contain angular crushed porphyroclasts floating in a mylonitic matrix of flattened quartz ribbons. Measurements of brittle features include joints and fractures, as well as faults and cataclasites. Additionally, the general orientation of dikes was also recorded.

Ductile, brittle-ductile, and brittle structures were further divided into groups based on whether they contained mineralization as indicated by any associated alteration. Structural measurements were plotted on an equal-area stereonet (Schmidt net) using the GEORient (Holcombe, 2011) and StereoWin (Allmendinger, 2002) software programs. Dip/dip direction trend and plunge

vectors were contoured to create a dip-density diagram for each structure group. Dip density diagrams were merged with rose diagrams to illustrate strike and dip directions for different types of structures.

3.2 Geologic map

Although outcrop exposures are rare in the Cirio concession, a 1:4600-scale geologic map was constructed by doing new geologic mapping and compiling data from outcrops maps, trench logs, drill core, and soil observations. During the 1990s when Echo Bay Minerals occupied the Cirio concession, an outcrop map was constructed to distinguish where bedrock assay samples could easily be obtained. The original outcrop map included information such as rock type, and bedrock structures. Outcrops in the concession were primarily limited to drainages and topographic highs. Each outcrop location designated on Echo Bay's map was reexamined and scrutinized in the field and remapped or reinterpreted, where necessary, to assess the accuracy of previous classifications as well as define our own classification. This led to our construction of a reinterpreted outcrop map. Our detailed map delineates rock types, the presence and type of mineralization or alteration, and the orientation of bedrock structures. Additionally, we examined soil and Quaternary cover for possible locations of faults. Our studies of these young deposits and faults included geomorphic mapping, cosmogenic dating, gravity studies, and scarp-profile modeling (Busch et al., 2010).

3.3 Cross-section construction

Drill-core data were combined with trench logs, surface mapping, and other field observations, to construct geologic cross sections. Structures observed at depth were extrapolated to the surface and denoted as inferences on the cross section to indicate our uncertainty in the orientation of structures observed in the core and the uncertainty of structures noted by core loggers.

4. Results

4.1 Map units

The dominant rocks in the Las Colinas Mining Concession are medium- to coarse-grained intrusive batholithic rocks. The broader area contains five main rock types; gneissic granite and banded gneiss, gabbro, quartz diorite, granite, and dacite. In addition to the five rock types, cataclasite and mylonitic rocks are also denoted as map units and described below.

4.1.1 Gneissic granite and banded gneiss (KJgr)

The gneissic granite is the oldest rock and is present as screens and xenoliths in other rocks, such as the quartz diorite. On fresh surfaces, the gneissic granite is black and white but tanish white on weathered surfaces. The gneissic granite is composed of approximately 35% lenticular plagioclase crystals (<2cm in length), 45-50% elongated and equant quartz crystals, and 15 - 20% biotite. The gneissic granite is homogenous over single outcrops and friable. Foliation in the gneissic granite varies from weakly to strongly developed. This rock would be considered transitional between a gneiss and a strongly foliated granite. The banded gneissic rocks on the other hand, are present in road cuts east and west of San Antonio, but are not abundant in the Las Colinas Mining District. The banded gneiss has a similar composition to the gneissic granite and is marked by compositional banding. The gneissic granite has previously been dated as Cretaceous in age (Hausback, 1977); however, other researchers (Hanson et al.,

2010) designate it as Jurassic in age. We have therefore designated this unit as Jurassic-Cretaceous in age (KJ).

4.1.2 Gabbro (Kga)

The gabbro forms dark, weathered outcrops that range from light gray to light brown in color and in some cases forms steep resistant hills. On fresh surfaces, the gabbro is either a mixed black and white or mostly black and commonly has a green sheen. The gabbro is composed of approximately 30% plagioclase, 30% hornblende, 30% biotite, and 10% quartz. The gabbro in the area is heterogeneous and varies from finely crystalline to coarsely crystalline. There are four or more textural variations of gabbro in the area. One type of gabbro contains hornblende crystals up to 10 cm long and 3 cm wide within a matrix of white feldspar. This variety of gabbro forms bouldery rounded outcrops. Another variation of gabbro forms blocky outcrops, featuring interlocking hornblende crystals arranged in a spherical pattern. The third gabbro appears to be composed almost entirely of hornblende and is black in color and has a blocky expression. The fourth variation displays a porphyritic texture and forms chloritized, fine-grained mounds that exhibit a slight foliation. The gabbro has previously been dated as Cretaceous in age (Hausback, 1977).

4.1.3 Quartz diorite (Kqd)

The quartz diorite is black, white, and cream colored on fresh surfaces and greenish gray with creamy brown patches and localized green or red staining on weathered surfaces. The quartz diorite on average is composed of 20-30% biotite

(1 to 5 mm in diameter), at least 25 to 35% quartz (1 to 5 mm in diameter), 10-40% milky-white feldspar (1 to 5 mm in diameter), and less than 3% potassium feldspar (1 mm in diameter). The quartz diorite forms blocky outcrops and contains numerous fuzzy green mylonitic shear zones that range from tens of centimeters wide to well-defined zones approximately 1-cm wide. Locally, there are variations within the unit, in which the quartz diorite appears more tonalitic, dioritic, or granodioritic in composition. The quartz diorite varies from poorly to well foliated and in some cases exhibits a bronze sheen due to the alignment of biotite. The quartz diorite has previously been dated as Cretaceous in age (Hausback, 1977).

The contact between the gabbro and quartz diorite is a fault contact in some areas and an intrusive contact in others. The quartz diorite commonly contains xenoliths of the gabbro and gneissic granite, and locally exhibits interfingering with the gabbro. In locations where the contact between the quartz diorite and gabbro is an intrusive contact, it appears that the quartz diorite intruded the gabbro.

4.1.4 Granite (Kgr)

The granite is whitish with bronze flecks on fresh surfaces and has a creamy tan to orange color on weathered surfaces. It is composed of approximately: 1) 40-50% quartz in 2-3 mm in diameter, equant to elongated grains; 2) 40-60% plagioclase feldspar in 4-5 mm in diameter grains, and 3) 5-10% biotite in sheets up to 1 mm in diameter. The granite is homogenous and

forms blocky outcrops, which produce blocky float. The light-colored, nearly leucocratic granite dikes crosscut the gneiss, gabbro, and quartz diorite and related rocks. The contact between the granite and the quartz diorite or the gabbro is both an intrusive contact and a fault contact. The granite is mostly unfoliated, but contains a weak foliation in some locations. It is less deformed than the quartz diorite where the two rocks are in contact. Triton Mining Corporation (1992) and Hanson et al. (2010) characterized the granite as an upper Cretaceous intrusive.

4.1.5 Dacite dikes (Td)

A distinctly younger and more finely crystalline series of dacite dikes crosscut all rocks. In most cases, the dacite dikes appear to be unaltered; however, locally the dacite contains iron oxides limited to brittle fractures probably due to remobilization of alteration minerals. Dikes range in thickness from 1m to several meters in width. The dacite is brownish gray with black patina on weathered surfaces and brownish gray to light gray on fresh surfaces. The aphanitic rock is composed of a matrix of minerals too fine to see with a hand lens, surrounding sparse 1mm in diameter quartz and feldspar crystals. The dacite forms blocky, resistant outcrops. The dacite dikes contain no shearing or foliation. Hanson et al. (2010) described the dacite/andesite as a Cenozoic rock.

4.1.6 Sheared rocks

The mylonitic rocks in the area are derived from other rock types, such as the older metamorphic and intrusive rocks. They can, in some cases, be characterized as either mostly ductile or brittle-ductile. They have a well-

developed mylonitic foliation that crosscuts other metamorphic features, and commonly contain a streaky lineation. The mylonite appears fuzzy green in hand samples. Mylonites nearly everywhere display a down-dip sense of shear as revealed by asymmetric feldspars and S-C fabrics.

4.1.7 Cataclasites

Cataclasite rocks are present near the city of San Antonio, but are not present in the Cirio Concession. These rocks are distinct from the mylonitic rocks in that they consist mostly of finely pulverized fragments that range from <1mm to 4cm in diameter and generally lack any foliation or lineations. They are gray tan to bright orange in color. These rocks are difficult to characterize in the field as a result of their fine-grained character. The cataclasite contains secondary quartz veins and goethite, hematite, limonite, and to a lesser extent jarosite veins. Secondary quartz growth exhibits open-pore filling characteristics, with some deposits of drusy quartz. Due to its pulverized nature, it is not possible to obtain a fresh surface of the cataclasite. Cataclasite is younger than the mylonitic fabrics, but there may be a gradation from mylonitic rocks to brittle-ductile mylonites to cataclasite.

4.2 Orientation of structures

Measurements obtained in Fandango Wash were combined with measurements obtained in road cuts and outcrops along highway La Paz-San Jose del Cabo/Mexico 1 as well as rare outcrops in the San Antonio concession to assess general trends in the orientations of structures within the Las Colinas

Mining District. Dikes that contain iron oxides and other alteration have an average strike of N5E and on average dip of either 64° to the west (n=9) or 64° to the east (n=7), displaying conjugate orientations. Unaltered dikes (mostly dacite) have an average strike of N43E and an average dip of either 54° to the northwest (n=6) or 51° to the southeast (n=6) (Figure 3.8).

Conjugate alteration-bearing faults in the area have an average strike of N6W and an average dip of either 60° to the west (n=36) or 59° to the east (n=19). Conjugate faults that do not contain alteration have an average strike of N9W and an average dip of either 63° to the east (n=14) or 56° to the west (n=15) (Figure 3.8).

Altered joints and veins on average strike N48W and have either a vertical dip, an average dip of either 74° to the northeast (n=22), or 81° to the southwest (n=21). Unaltered joints and veins have an average strike of N43E and an average dip of either 73° to the northwest (n=19) or 70° to the southeast (n=27) (Figure 3.8).

Shear bands and discrete shear zones, had an average strike of N25E with average dips of either 47° to the northwest or 38° to the southeast (Figure 3.8). The primary direction of older metamorphic foliation was N69W, with an average dip toward the northeast of 36° and an average dip toward the southwest of 44° (Figure 3.8). Overall, most altered structures strike in a north to northwesterly direction and most unaltered structures generally strike in a north to northeasterly direction.

Indicators used to determine the sense-of-shear of ductile and brittle-ductile deformation include S-C fabrics, sigma-type winged porphyroclasts, and sigmoidal foliation (Figure 3.9). The S foliation planes in S-C fabrics lean in the direction of shear, and depending on the extent of shearing, may deflect and become parallel to the C-surface, shear planes. In the Cirio Concession and surrounding locations, the foliation planes (S foliation) leaned in such a way to reflect a top down-dip sense of shear. Sigma-type winged porphyroclasts feature shearing of the porphyroclasts on the top and bottom displaying “stair-stepping” asymmetry. In the field area, the top of all porphyroclasts were sheared in a down-dip direction whereas the bottom wing was sheared toward the up-dip direction. Sigmoidal foliation occurs as a result of the rotation of foliation parallel to the shear zone (Davis and Reynolds, 1996). Foliation in the field area typically deflected in a downward direction. Due to the fine-grained nature of ductile and brittle-ductile deformation, S-C fabrics and sigmoidal foliation were the most common sense-of-shear indicators observed in the area. Overall, sense-of-shear indicators indicate a down-dip sense of shear, or that of an evolving extensional environment.

4.3 Mineralization and alteration

Alteration associated with gold mineralization varies as a function of depth, primarily due to the effects of weathering after hypogene mineralization or mineralization occurring at depth. Near-surface mineralization and alteration is commonly associated with oxidation, whereas mineralization and alteration at

depth includes sulfides. Surface alteration minerals observed in exposed bedrock are primarily jarosite, hematite, goethite, and in some cases, iridescent limonite. In most cases, carbonate is closely associated with the alteration and appears whitish to orangish in color and fills brittle structures and open pore spaces. The iron oxides and other alteration minerals are widespread across the area, reflecting the extent of secondary mineralization.

In addition to observing alteration minerals in outcrop, the presence of alteration has also been noted in soils. A thin cover of soil, typically less than a meter thick, commonly mantles near-surface bedrock. Some areas are covered by brownish red to deep red, deflated soils, which are interpreted to be locations of presumed faults and fractures. Although alteration from weathering is most intense near the surface, minor amounts of oxidation are present at depths in the core.

At depth, sulfides are present in brittle structures including cracks, faults, joints, and microfractures. Pyrite lines the walls of many fractures and joints in core samples and locally in outcrop. Quartz and pyrite generally occur together in addition to, but less common, arsenopyrite. Many quartz veins have small, terminated crystals and other evidence for open-space filling. This requires that mineralization occurred at fairly shallow depths; consistent with the inference that mineralization occurred late in the structural evolution.

Primary and secondary mineralization is confined to brittle structures in the area including faults, fault breccias, joints, fractures, and microfractures. The

largest amount of alteration occurs on faults that strike approximately N10E to N5W and dip between 35 and 65 degrees to the west. Mineralization was evidently introduced along these extensional structures across a variety of rock types.

The mylonitic rocks and shear bands contain alteration, but the alteration is restricted to brittle fractures and microfractures within these rocks. In many cases, the mylonitic zones and rocks contain less alteration than adjacent rocks, possibly due to a “sealing” of the rock due to ductile flow of quartz and to an overall fine crystal size of the mylonite, both of which would limit permeability.

4.4 Geologic map

A detailed geologic map south of the Cirio Concession was constructed by examination of outcrops in the area, coupled with drill core data (Figure 3.10). Outcrops are shown on the geologic map with a darker color than the inferred extent of mapped units. Outcrops were included to display control points.

Gabbro and quartz diorite are the dominant rock types in the concession. Quartz diorite is the dominant rock in the northern and eastern portion of the concession and gabbro is the dominant rock in the western and southern portion of the concession. Screens of gneiss are present in the northwest portion of the concession and granite is present as dikes and small hills in the north-central portion of the concession.

The quartz diorite exhibits zones of both highly-sheared ductile and brittle-ductile deformation as well as brittle deformation. The sheared rocks are

generally present as anastomosing structures that trend north-south and dip moderately to the west. A zone of brittle deformation, 120-meters wide, trends in a north to northeast direction and presumably offsets the zone of older sheared rocks. Another prominent structure present in this area is a roughly north-striking normal fault located on the eastern side of the concession. This normal fault is an active, scarp-forming basin-bounding structure that juxtaposes Cretaceous quartz diorite and gabbro with Quaternary alluvial deposits (Busch et al., 2011).

4.5 Geologic cross sections

Geologic cross sections were constructed in the northern part of the geologic map, where there was more control from borehole data. The cross sections are oriented in an east-west direction, perpendicular to the main mineralized trend, and are ~800 m in length. Cross sections were constructed to a depth of 225 m below the surface. Cross section A-A' is the southernmost cross section. Cross section B-B' and C-C' are located north of A-A'.

Geologic cross section A-A' was constructed with the use of surface observations and core from 7 boreholes (LCDD-22, LCDD-12, LCDD-11, LCW-08, LCW-07, LCW-6b, and LCW-05) (Appendix F). The cross section shows a number of brittle faults dipping toward the west (Figure 3.11). Also present in the cross section is a zone of highly sheared rock, or cataclasite that dips at a moderate to shallow angle (15 to 30 degrees) to the west. The west side of the cross section shows numerous west-dipping faults but no east-dipping faults. This lack of east-dipping faults in the western portion of the concession may be largely

due to the orientation of the boreholes, which would be unlikely to intercept east-dipping faults. Steeply-dipping faults may have intercepted the drill core, but are not well constrained on the cross section. Accordingly, on the right side of the cross section are numerous east-dipping faults. Although we predict the presence of both types of faults in the area, core data that were collected from boreholes drilled with a west inclination, which would most easily intersect east-dipping faults and therefore minimize the number of west-dipping faults featured. The cross section illustrates the presence of primarily quartz diorite at the surface with diorite at depths.

Cross-section B-B' is located approximately 150 meters north of cross section A-A' and was constructed from surface observations and core data from 6 boreholes (LCDD-09, LCW-21, LCW-01, LCW-02, LCW-03, and LCW-04) (Appendix F). This cross section features primarily quartz diorite close to the surface and diorite at depth (Figure 3.12). Similar to A to A', this cross section features a zone of ductile and brittle-ductile deformation that is cut by a zone of brittle deformation.

Cross section C-C' is the northernmost cross section in the concession and is located approximately 100 meters north of B to B'. This cross section was constructed by combining surface observations and core data from a single borehole (LCDD-13) (Appendix F). This cross section features a zone of ductile and brittle-ductile deformation that was present in surface outcrops but not in core data (Figure 3.13). The zone of brittle deformation is only hypothesized in this

cross section from its presence in core data and surface observations south of cross section C-C'.

Faults that offset the ductile and brittle-ductile sheared rock were inferred in all cross sections as a means to accommodate the presence of the sheared unit in some locations and not others. The sheared rock is present in some borehole logs but is absent in nearby borehole logs. In order to satisfy this condition, our cross sections required faults that offset the sheared rock in such a way that the sheared rock was not intersected in core. Such geometries are permissive, but clearly very interpretive and poorly constrained. Faults were inferred from borehole logs and surface outcrops.

5. Discussion

5.1 Structural interpretation

Most deformation in the area reflects that of an evolving extensional environment. Only the older higher-grade metamorphic features, such as gneissic bands, are interpreted to be related to metamorphic and deformational events (probably including regional contraction) that accompanied or followed emplacement of the batholith. The older rocks in the area have a poorly to well-defined foliation that was probably due to metamorphic conditions associated with intrusion and concurrent or subsequent high-temperature deformation of the batholith. Some fabrics may be syn-intrusive, but others are clearly post-solidification. Although foliation direction is not well constrained (Figure 3.8), it strikes on average N69W. This northwesterly strike may reflect northeasterly-directed subduction during the Late Cretaceous (Figure 3.3) (Henry, 1989). Locally this early, metamorphic-style foliation has a mylonitic overprint related to later events.

All other structures have a clear down-dip sense of shear or an extensional character (Figure 3.8). During extension, structures evolved from ductile to brittle-ductile to brittle in character. The most ductile mylonitic fabric is consistent with deformation that initially occurred deep in the crust where temperatures were hot and the rock flowed rather than fractured (Sibson, 1990). Sense-of-shear indicators, such as S-C fabrics in mylonitic rocks, consistently demonstrate a down-dip component, whether the mylonitic foliation dips

northwest, southeast, or some other direction. All rocks in the area, except the dacite, contain thin mylonitic shear bands.

Brittle-ductile deformation overprints the ductile deformation and is manifested by discrete, thin shear zones that have an anastomosing foliation. This brittle-ductile deformation occurs at shallower depths in the crust, close to the brittle-ductile transition (Sibson, 1990 and 1993). These structures also demonstrate a down-dip sense of shear. Average strike of brittle-ductile features is N25E with moderate to steep dips (Figure 3.8). These structures more than likely formed in a stress regime consistent with northwest directed extension and probably while northeast-directed subduction was occurring until the mid-Cenozoic (Figure 3.3) (Henry, 1989).

Brittle structures include faults, fractures, and brecciated zones. The oldest brittlely deformed structure is likely the zone of cataclasis, because this deformation occurred under conditions where fluids and pressures could consolidate the rock. In general, thin sections of cataclasite commonly appear as fine-grained breccias that have angular, broken rock fragments at nearly all scales of observation. The cataclasites in this area range from 10-m thick to less than 1-m thick. The cataclasite is not clearly associated with a discrete fault surface, but instead probably represents a distributed west-dipping zone of brittle or locally brittle-ductile shearing. The sense of shear along this west-dipping zone could not be determined at Las Colinas, but reflects down-dip (normal) motion in nearby road cuts and mine workings. The cataclasite is commonly cut by younger, brittle

faults that are not associated with significant gouge or breccia; such faults presumably do not facilitate a large magnitude of offset.

The younger, brittle faults that host secondary alteration strike, on average, north to northwest whereas young brittle faults that do not host secondary alteration strike on average north to northeast (Figure 3.8). These orientations may reflect the changing primary stress directions (Umhoefer et al., 2002; Angelier et al., 1981) in which northeast-southwest extension in the late Miocene gave way to northwest-southeast extension in the Pliocene (Figure 3.3).

The most abundant structures in many roadcuts, natural exposures, and drill cores are fractures and joints. These range from simple cracks to centimeter-wide veins filled with quartz, carbonate, iron oxides, and fine-grained material. At depth in drill holes, many fractures contain sulfides in addition to these minerals.

Altered joints and fractures display an average strike of N48W and a near-vertical dip. Unaltered joints display an average strike of N43E (Figure 3.8). Again, these measurements reflect a change in stress, assuming that the structures containing alteration are older than those that do not. The minimum compressive stress (σ_3) would have initially been oriented in a northeast-southwest direction and has rotated to a northwest-southeast orientation (Figure 3.3). This stress rotation has been observed throughout the American southwest (Menges and Pearthree, 1989; Spencer and Reynolds, 1989). We surmise that altered, brittle structures most likely formed after northeast-directed subduction ended but before the rotation to northwest-southeast-directed extension. The altered, brittle

structures most likely formed sometime during Cenozoic extension, which was in a southwest-northeast direction. Alternatively, they are related to a Late Cretaceous, post-batholithic extension event observed further north (Jacobson and Dawson, 1995). Unaltered structures formed later in the sequence, most likely after the Pliocene extension direction changed, hence the reflection of a northwest-southeast-directed extensional character (Figure 3.3). These fractures crosscut all other features, including mylonite and cataclasite, and so represent some of the youngest structures, except for modern active faults. In all settings, most mineralization occurs within late-stage brittle fractures, and, therefore, late in the sequence, and such fractures are the most important control of mineralization.

The most recent stage of faulting that has occurred in the area is late Quaternary in age. These young faults do not contain iron oxide or other alteration, but they crosscut older faults that do contain alteration. The young, brittle faults flank the field area on the eastern and northern sides. Surface expression of these faults is in the form of a low scarp, with east-side-down displacement (Busch et al., 2011). These faults affected mineralization by down dropping mineralized blocks, thereby preserving them from erosion. Also they fractured the rocks, allowing oxidation and possible enrichment to occur at greater depths than in less fractured rocks.

In summary, structures in the area reflect the past tectonic settings of the region. The older foliation is reflecting a stress regime that probably was

compressive in a northeast-southwestern direction, most likely related to northeastward-directed subduction of the Farallon Plate under the North American Plate (Henry, 1989). Brittle-ductile structures have a north-northeast strike reflecting extension in a northwest-southeast direction (Figure 3.8). The northwesterly orientation of almost all altered structures is consistent with the Cenozoic extensional environment that occurred in the Gulf of California region (Figure 3.3). Conversely, the northeasterly orientation of almost all unaltered structures probably reflects Pliocene extension (Umhoefer et al., 2002; Angliers, 1981; Henry, 1989). We infer that structures that contained alteration formed during Cenozoic extension and that younger faults that do not contain alteration formed after the rotation in stress orientation, which occurred at approximately 5 Ma (Figure 3.8). Any alteration that does exist in the latest structures would most likely be a result of remobilization of secondary mineralization.

5.2 Mineralization

The gold deposits of the Las Colinas Mining District are inferred to be middle to late Cenozoic in age and mineralization probably occurred in a shallow setting. From this study, the orientation of altered faults, fractures, and veins is the most important control on mineralization. Brittle structures that host mineralization generally trend north to northwest, and the main mineralized zone also trends northerly (Hanson, 2010). The gold evidently occurs as intergrowths with pyrrhotite, and to a lesser extent, as inclusions in pyrite (Technical report Paredones Amarillos, 1998). Main-stage gold mineralization is hosted almost

entirely in the brittle structures and in rocks adjacent to such fractures.

Additionally, some gold likely occurs in interstitial zones where biotite has weathered. The alteration associated with gold mineralization varies as a function of depth, primarily due to the effects of weathering. Iron oxides and other alteration are widespread across the area, as seen in surface deposits and outcrops.

The zone of sheared rock hosts little alteration. Any alteration present is restricted to brittle structures that cross-cut the main shear zones, probably because the sheared rock has a much finer grain size than neighboring rocks. Additionally, in many cases the quartz flowed during ductile deformation in the shear zones. Both the fine-grained nature of the sheared rock and the smeared nature of the quartz decreased permeability and created an unfavorable environment for fluid flow. As a result, alteration and mineralization are restricted to brittle structures. Primary mineral deposits most likely resulted from hydrothermal sources. Based on the fact that all mineralization and alteration exhibits open-space filling behaviors and is mostly confined to brittle, extensional structures, we surmise that deposition occurred at a shallow level.

5.3 Geologic map and cross sections

Our geologic map and cross sections reveal a zone of brittle deformation that cuts a zone of highly sheared rock. The highly sheared rock is present as a thick zone of brittle-ductile deformation that dips at a shallow angle (~15 to 30 degrees) to the west and is denoted by past core loggers as cataclasite. It has a down-dip sense of shear, and is extensional in origin. The zone of brittle

deformation denoted in cross sections was inferred from the presence of faults in drill core, the presence of highly-altered, deflated soil on the surface, and the presence of faults in outcrops on the surface. Results of previous workers do not differentiate the moderately west-dipping sheared brittle-ductile rocks from the steeply-dipping, brittle structures, most likely due to their proximity to one another. This distinction between the brittle-ductile and the brittle rocks is critical to understanding the location of mineralization because the ductile structures contain little or no alteration, but the brittle structures contain extensive amounts of sulfides at depth and oxides near the surface. The brittle structures are the main host of mineralization in this area. The zone of brittle deformation and the main axis of mineralization trends in a north-south direction (Hanson, 2010).

Figure 3.14 presents a schematic cross section through the southern portion of the Cirio Concession. The schematic cross section was constructed by compiling all data from geologic mapping, structural measurements, drill-core analyses, and observations of mineralization. It provides a simplified illustration of the relationships between the structures and mineralization. As foliation is variable throughout the field area, the schematic cross section presents a generalized orientation for simplification. Notable features of the cross section include the relationship between brittle structures and alteration and the relationships of the rock types.

The main zone of mineralization is not confined to the study area, but likely extends to the north. Data from previous workers provides evidence that the

mineralized zone extends north of Fandango Wash and farther into the Cirio Concession. Brown and others (1998) used geophysics and soil-chemical analyses to define a zone of mineralization. This zone overlaps with and is as wide as our study area (~1800-m wide), but it also extends north of Fandango Wash, where it narrows (~200 m). Additionally, induced polarization data revealed a similar 1000-m wide mineralized zone in our study area. The mineralized zone continues north of Fandango Wash due north of our mapped zone (John R. Reynolds, personal communication, March, 2007). Furthermore, a recent comprehensive drilling program conducted by Pediment Exploration has refined the zone of mineralization and location of the main ore body. Hanson et al. (2010) define the main ore body as a north-south trending deposit located in the same area as our zone of brittle deformation. In their model, the ore body extends north of Fandango Wash where it widens. The model that Hanson et al. (2010) proposed with the zone widening north of Fandango Wash is the most likely as it was constrained with the most reliable methods for the sediment-covered area, drilling.

The zone of brittle deformation and main zone of mineralization are, therefore, presumed to extend north where they are offset by a young northeast-dipping normal fault. Busch et al. (2011) conducted gravity studies across the San Juan de Los Planes Basin and inferred that offset along this portion of the fault was on the order of hundreds of meters.

6. Conclusions

The Las Colinas Mining District is composed of plutonic rocks of quartz diorite and gabbro, which contain screens of gneissic rocks and smaller intrusions of granite and dacite. The plutonic and metamorphic rocks host ductile structures and fabrics, brittle-ductile structures, and brittle structures.

Mineralization varies as a function of depth in which mineralization at depth is associated with sulfides accompanying gold and shallow mineralization is associated with alteration from weathering. Minerals present at depth are pyrite, arsenopyrite, pyrrhotite, and microscopic gold. Shallow minerals include hematite, jarosite, goethite, and the combination of minerals in the form of limonite and iridescent limonite. Nearly all mineralization is restricted to brittle structures that include joints, fractures, and open pore spaces.

The main axis of mineralization in the Cirio Concession trends north-south and extends north of Fandango Wash. The main zone of mineralization is associated with a zone of brittle deformation that has offset a moderately to shallowly dipping zone of ductile and brittle ductile deformation. The main zone of mineralization has been down-faulted to the north by a late Quaternary normal fault, which is associated with rifting in the Gulf of California. The zone has most likely been down dropped into the basin as much as 500 meters.

Mineral exploration in the area should focus on steeply-dipping, brittle structures. An exploration plan consisting of shallow drilling and exploration pits should focus in an area north of Fandango Wash but south of the active fault

trace, in a northerly trend following the zone of brittle deformation. Furthermore, the exploration plan should also focus on drilling deep boreholes (500 meters or more) north of the active fault trace in an effort to determine the location of the highly mineralized zone of brittle deformation that has presumably been offset and down-dropped by the active, Quaternary fault (Figure 3.15).

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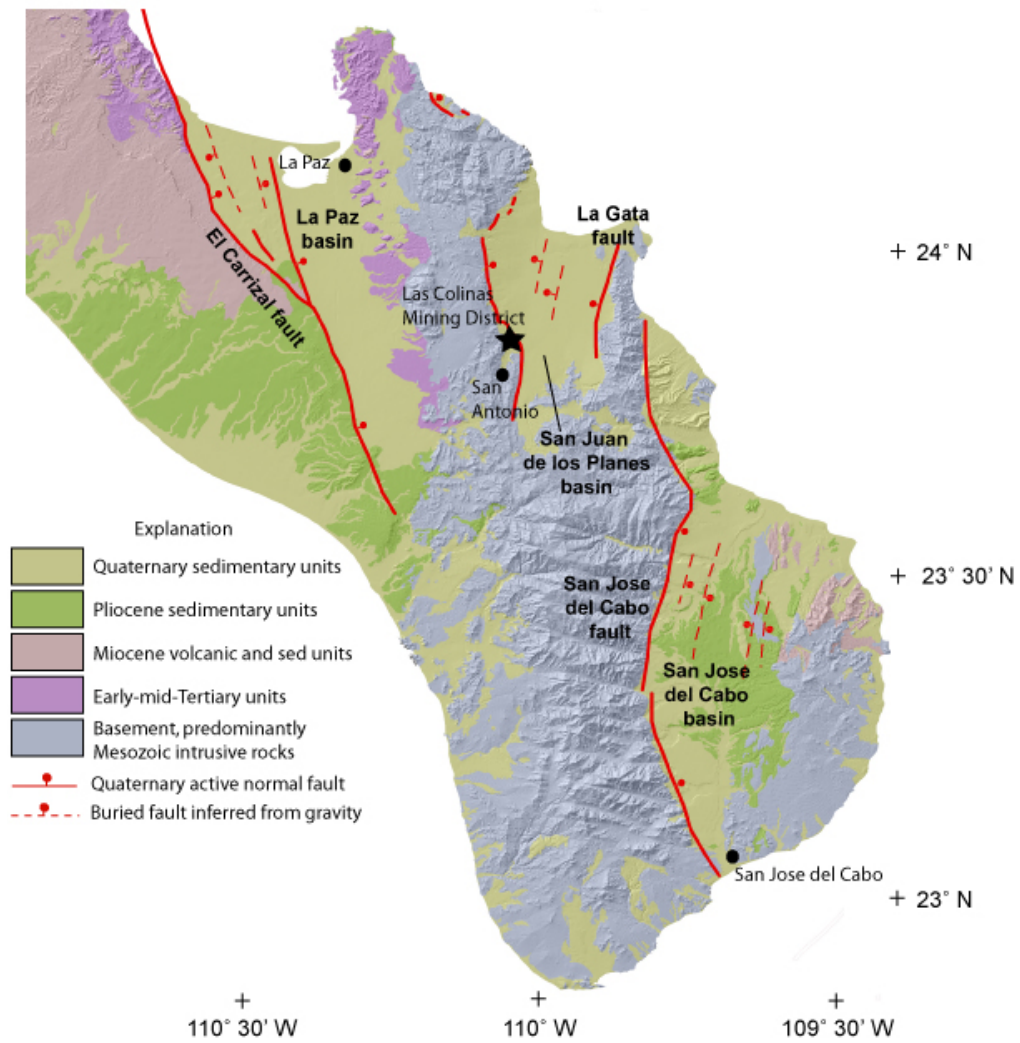


Figure 3.1: Shaded relief map of the southern tip of the Baja California Peninsula. Inset map shows the location on the Baja Peninsula. The black square shows the location of the Las Colinas Mining District. From Busch et al., 2011.

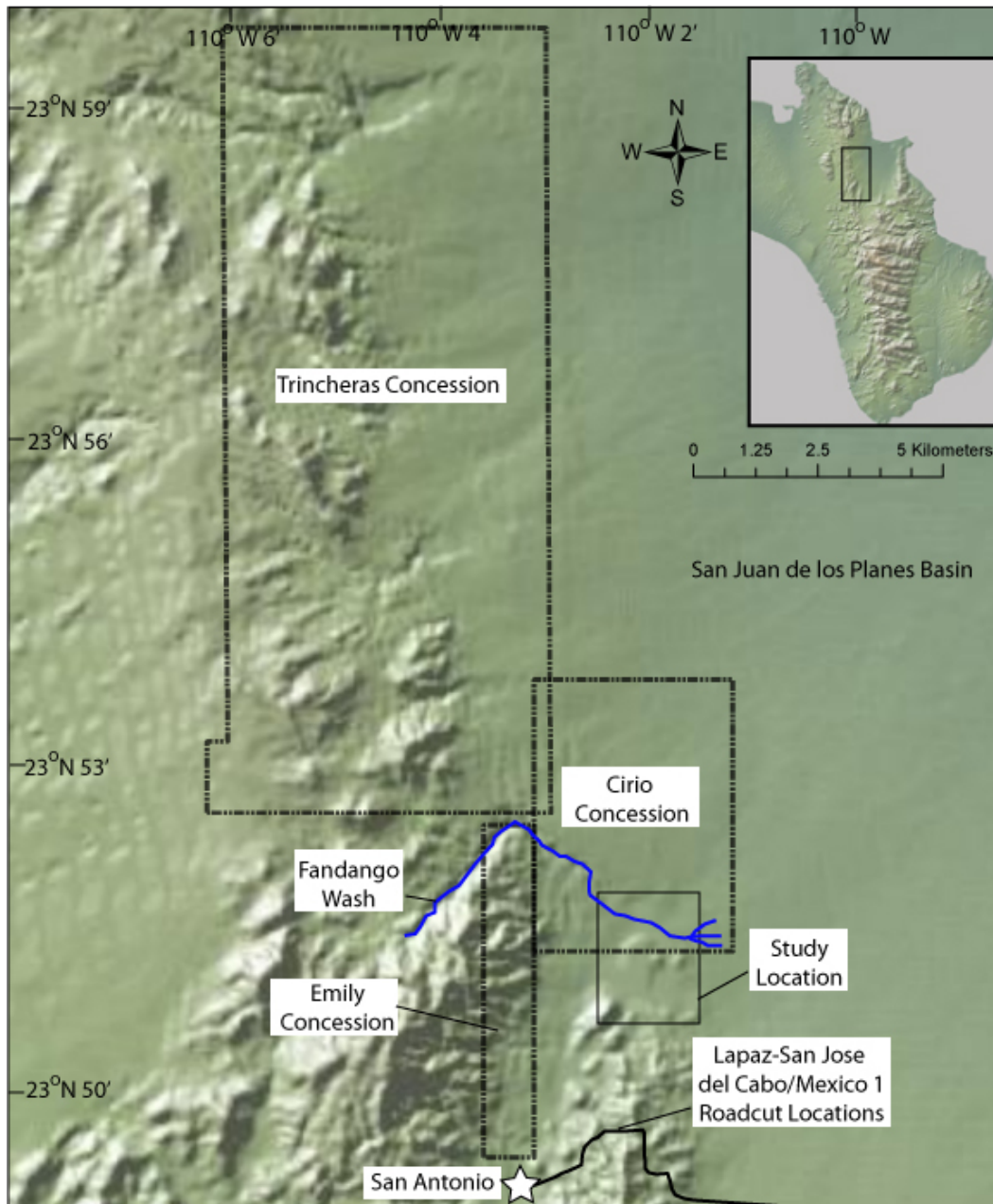


Figure 3.2: Map showing the location of the three concessions that comprise the Las Colinas Mining District (Trincheras, Cirio, and Emily). The main focus of our investigation was the Cirio Concession. The Cirio Concession is approximately 4500 meters in length in a north/south direction and 3300 meters wide in an east/west direction. Although the concession mostly lies north of the eastern extent of Fandango Wash, our investigation was primarily confined to a section south of Fandango Wash indicated by the solid box.

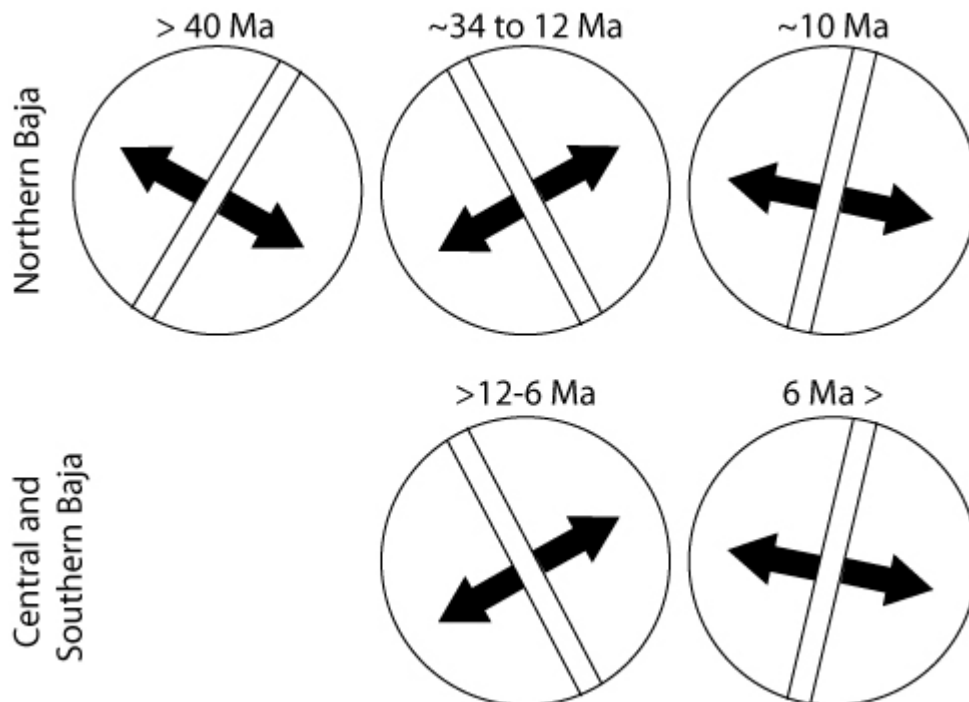


Figure 3.3: Principal orientations of extension occurring in the northern and southern portions of the Baja California Peninsula. (Source data from Angelier et al., 1981; Henry, 1989; Umhoefer et al., 2002).

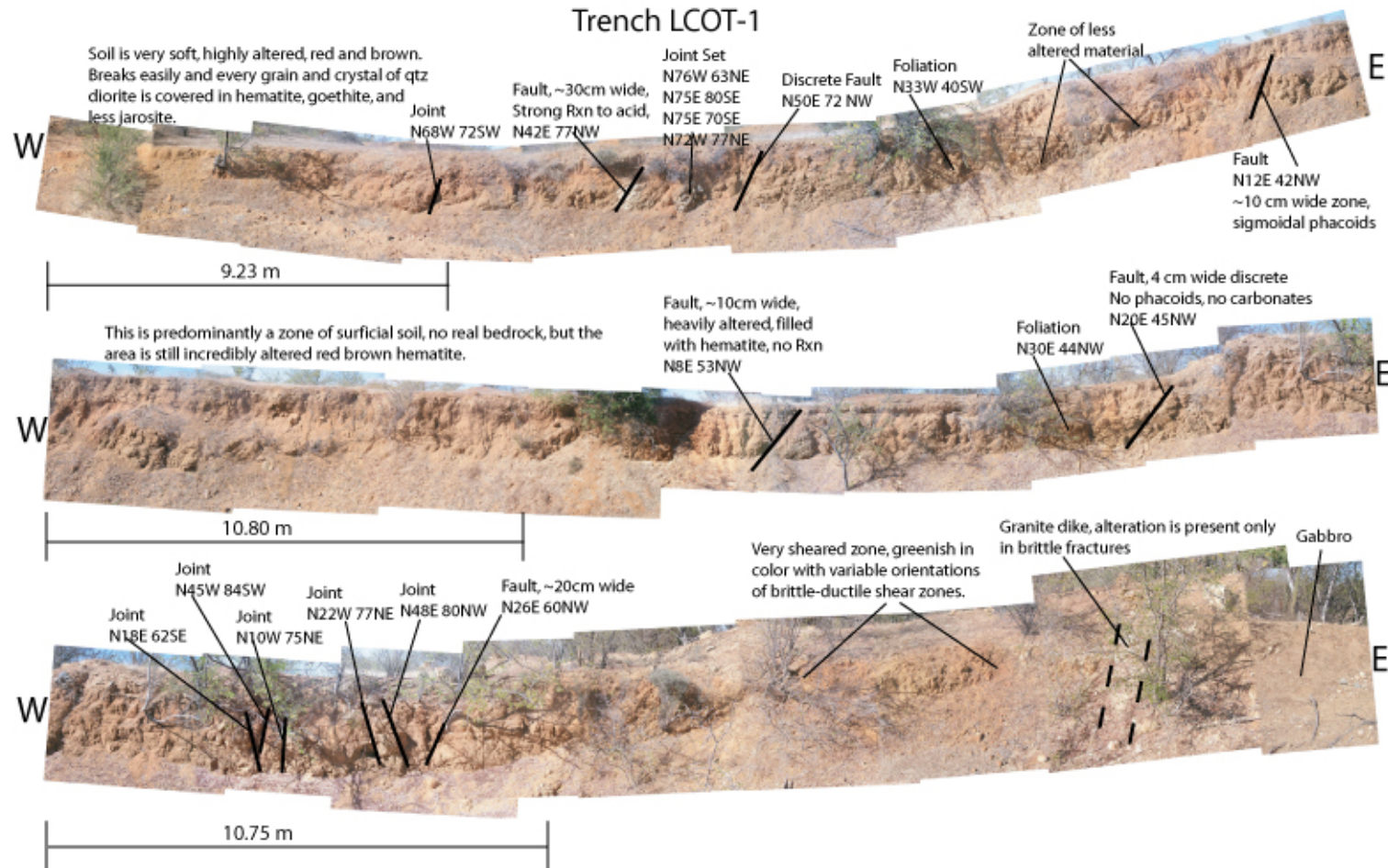


Figure 3.4: Las Colinas open trench (LCOT) number 1 photolog. The three panoramas are portions of a single continuous trench. The top panorama is the western-most portion of the trench, the middle panorama is the central portion of the trench, and the bottom panorama is the eastern-most portion of the trench.

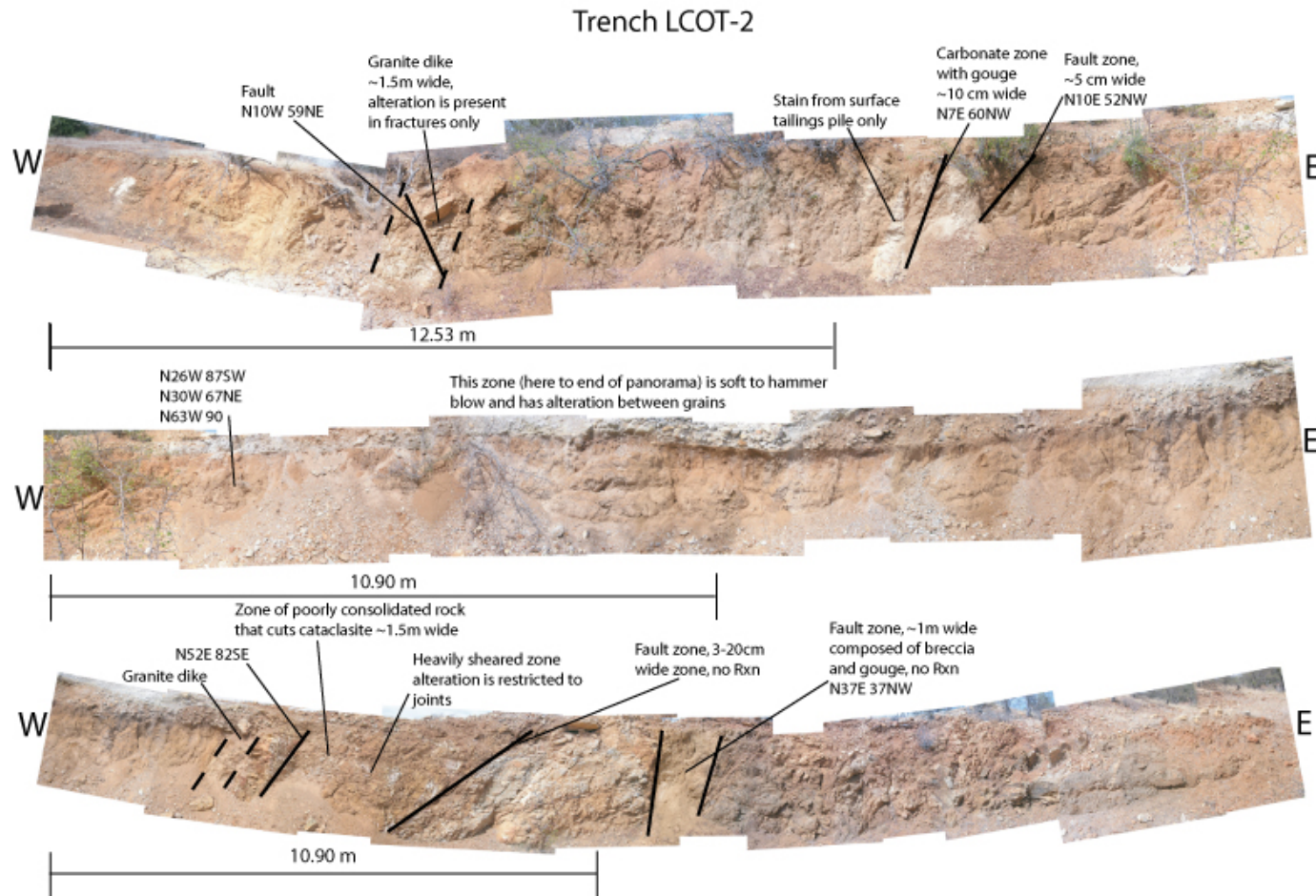


Figure 3.5: LCOT number 2 photolog. The three panoramas are portions of a single continuous trench. The top panorama is the western-most portion of the trench, the middle panorama is the central portion of the trench, and the bottom panorama is the eastern-most portion of the trench.

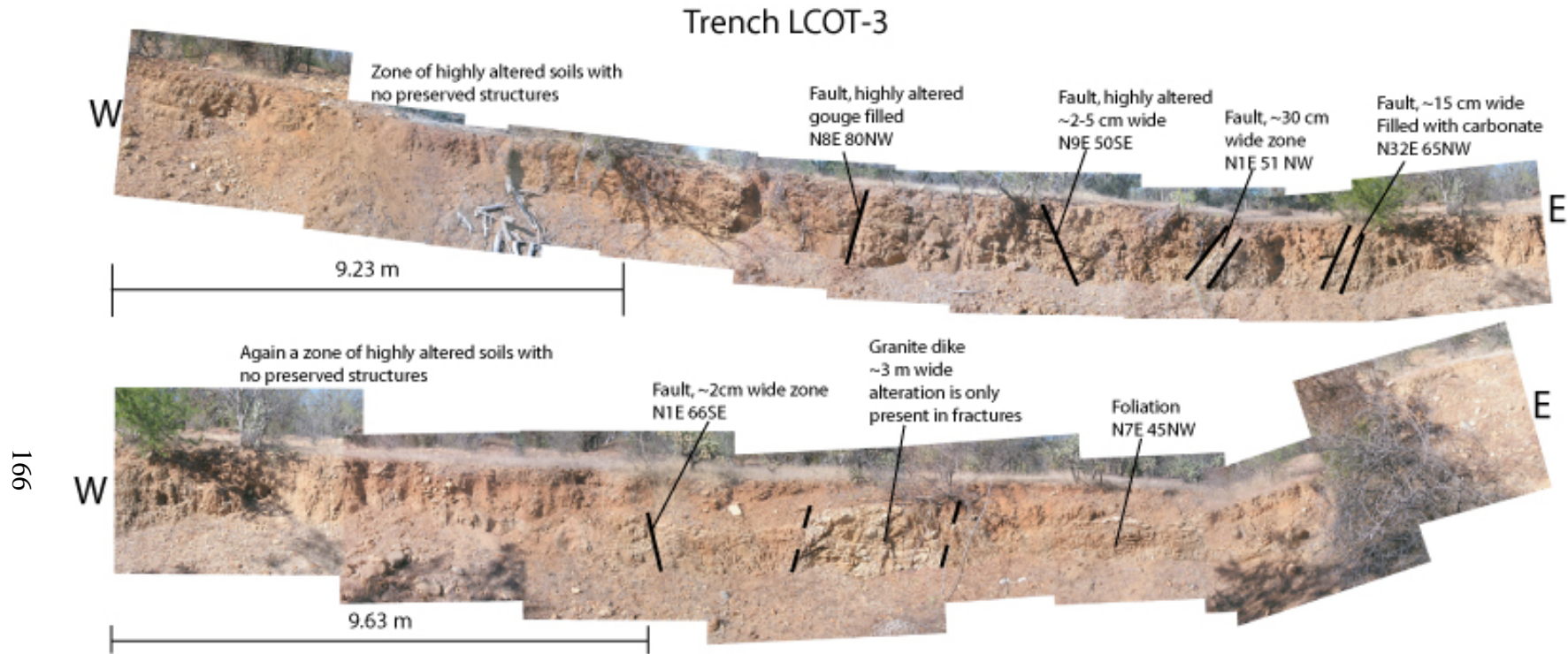


Figure 3.6: LCOT number 3 photolog. The two panoramas are portions of a single continuous trench. The top panorama is the western-most portion of the trench and the bottom panorama is the eastern-most portion of the trench.

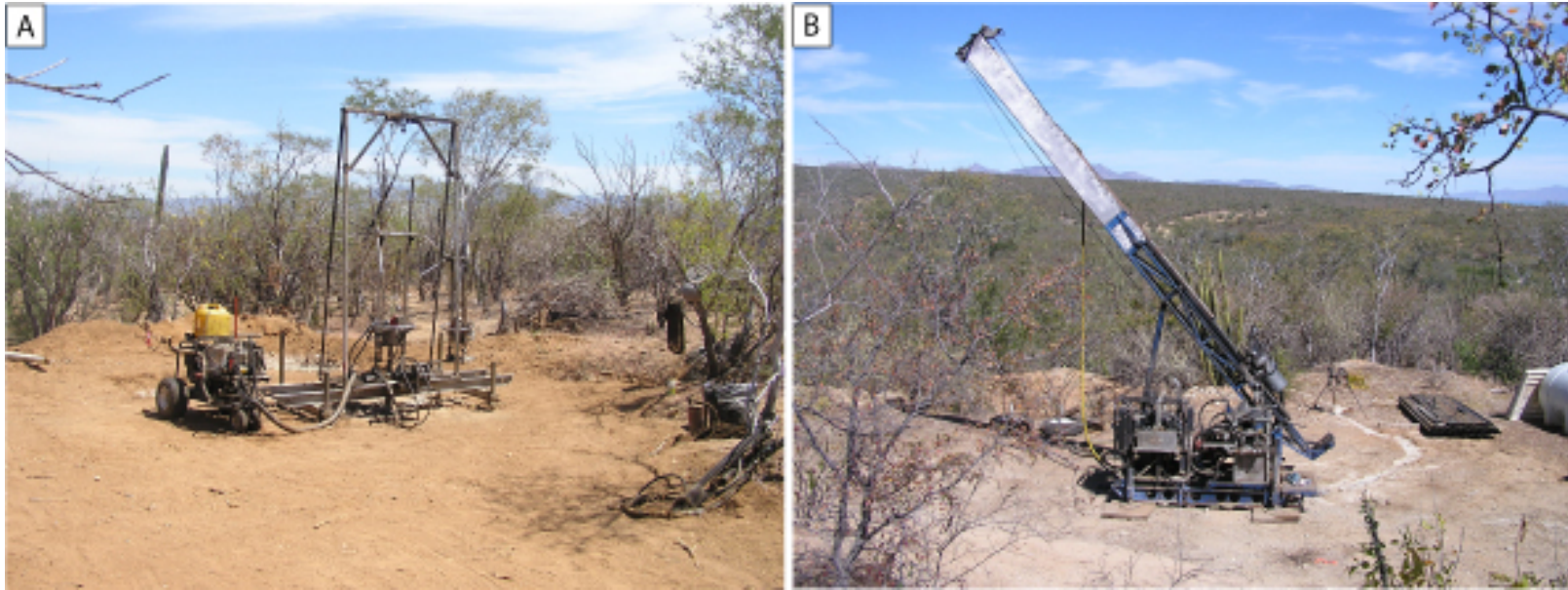


Figure 3.7: From January to June of 2007, thirteen boreholes were drilled by two different drilling machines, (A) a “winky”, which sampled to depths of 82 meters or less and (B) a larger, reverse circulation-drilling sled, which sampled to depths ranging from 117 to 182 meters.

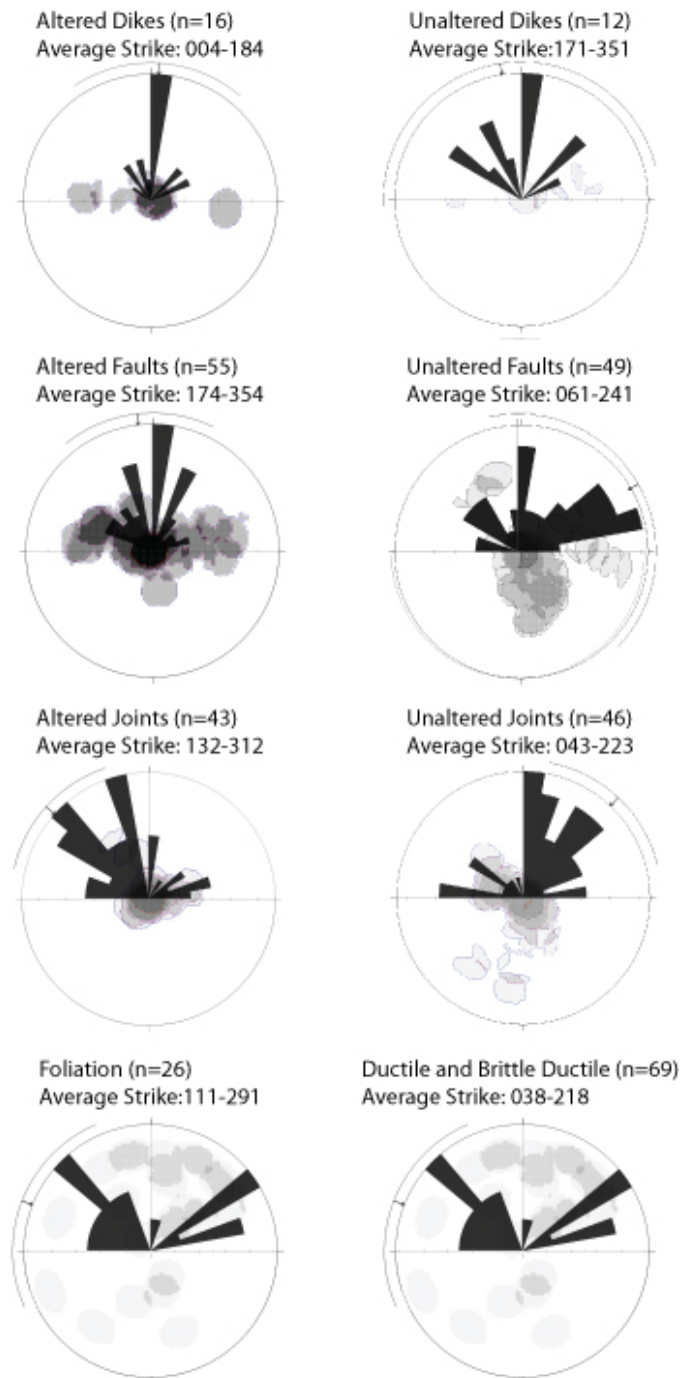


Figure 3.8: Structural measurements were plotted on an equal area projection stereonet (Schmidt net). Dip/dip direction trend and plunge vectors were contoured to create a dip-density diagram for each structure group. Dip density diagrams were merged with northern-hemisphere rose diagrams to illustrate strike and dip of each type of structure. The arrow on the periphery of each stereonet illustrates the mean strike. The arc along the periphery of each stereonet is the circular mean deviation about the median.

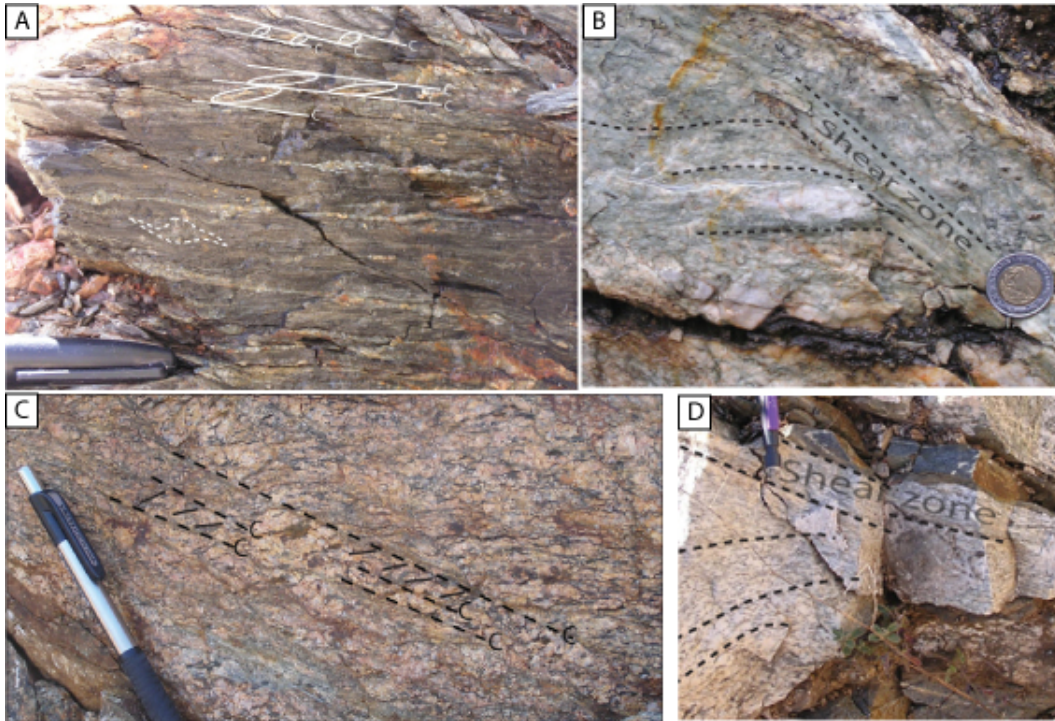


Figure 3.9: Sense-of-shear indicators used to determine the nature of deformation as determined by ductile and brittle-ductile structures. A) Contains both S-C fabrics and sigma-type winged porphyroclasts (dashed line) featuring “stair stepping”. B) Contains a ductile shear zone dipping to the right and sigmoidal foliation rotated downward. C) S-C fabrics demonstrating down-dip shear. The S-foliations planes lean over in the direction of shear. D) Sigmoidal foliation rotated parallel to the shear zone. In all cases, sense-of-shear indicators indicate a down-dip sense of shear or that of an evolving extensional environment. Note: a pen is present in figures A, C, and D and a coin is present in figure B to demonstrate scale.

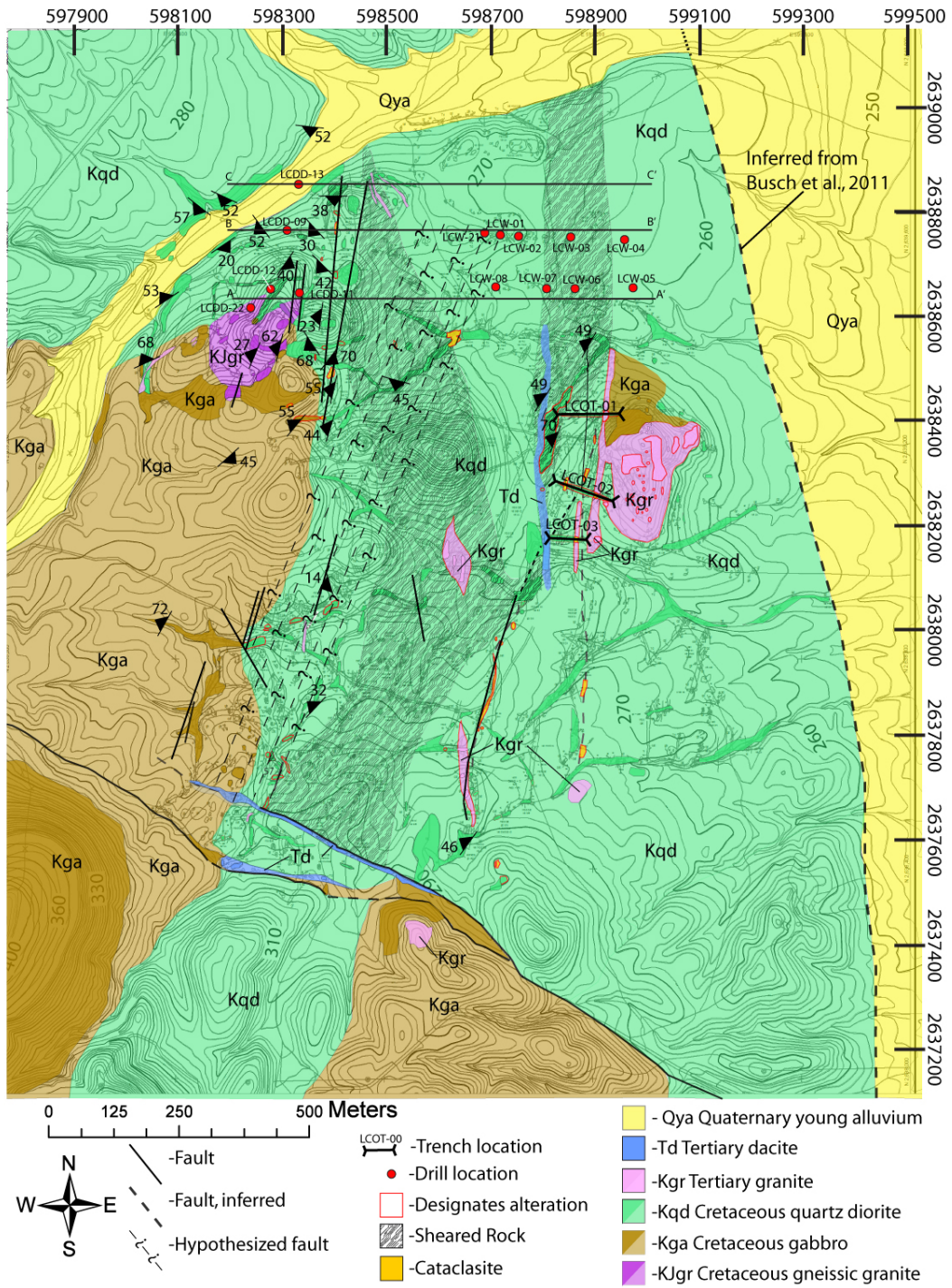


Figure 3.10: 1:4600 geologic map of the study area. Outcrops are darker in color and included in the map to display areas of maximum control.

Cross Section A-A' 1.5X Vertical Exaggeration

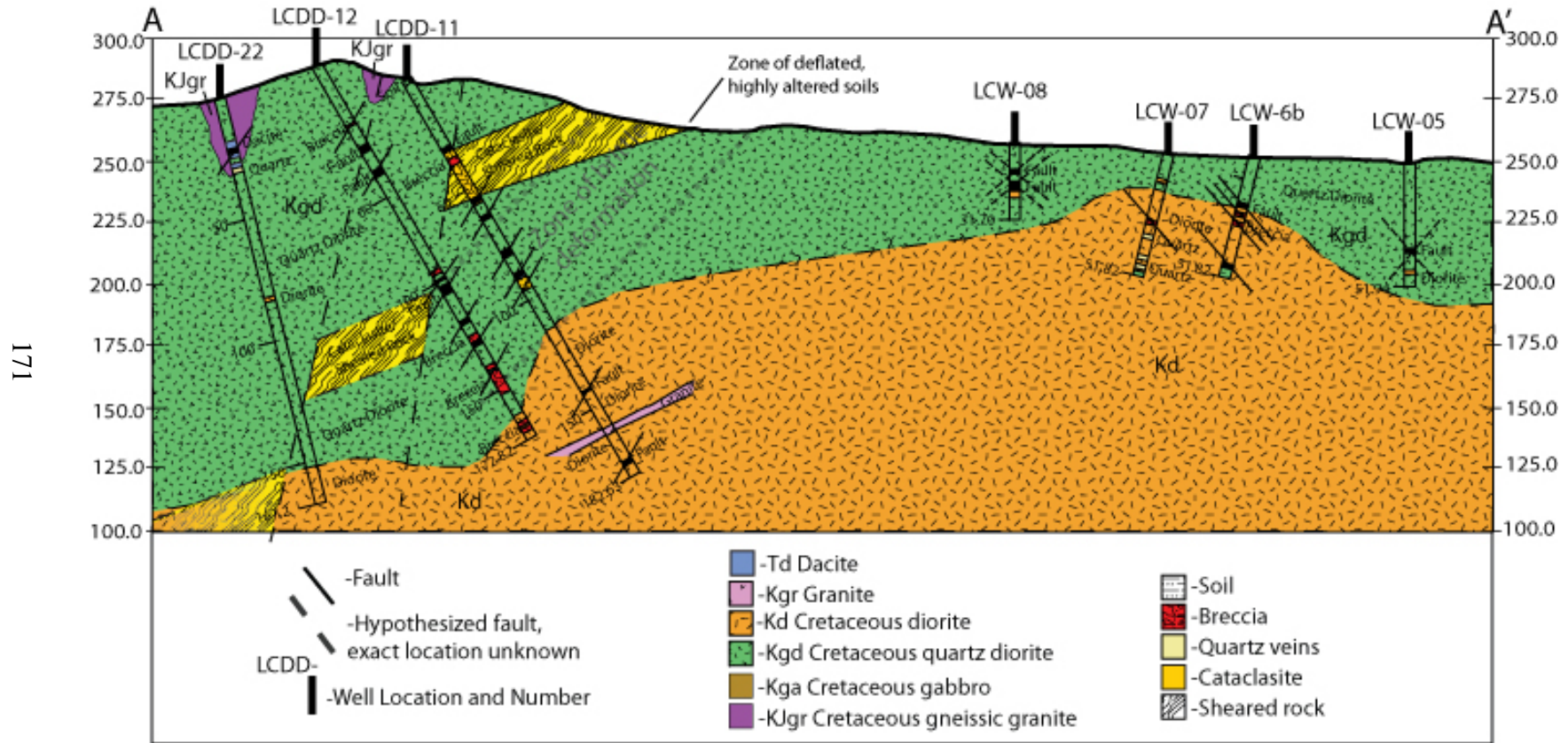


Figure 3.11: Geologic cross section A-A' was constructed from surface observations and core data.

Cross Section B-B' 1.5X Vertical Exaggeration

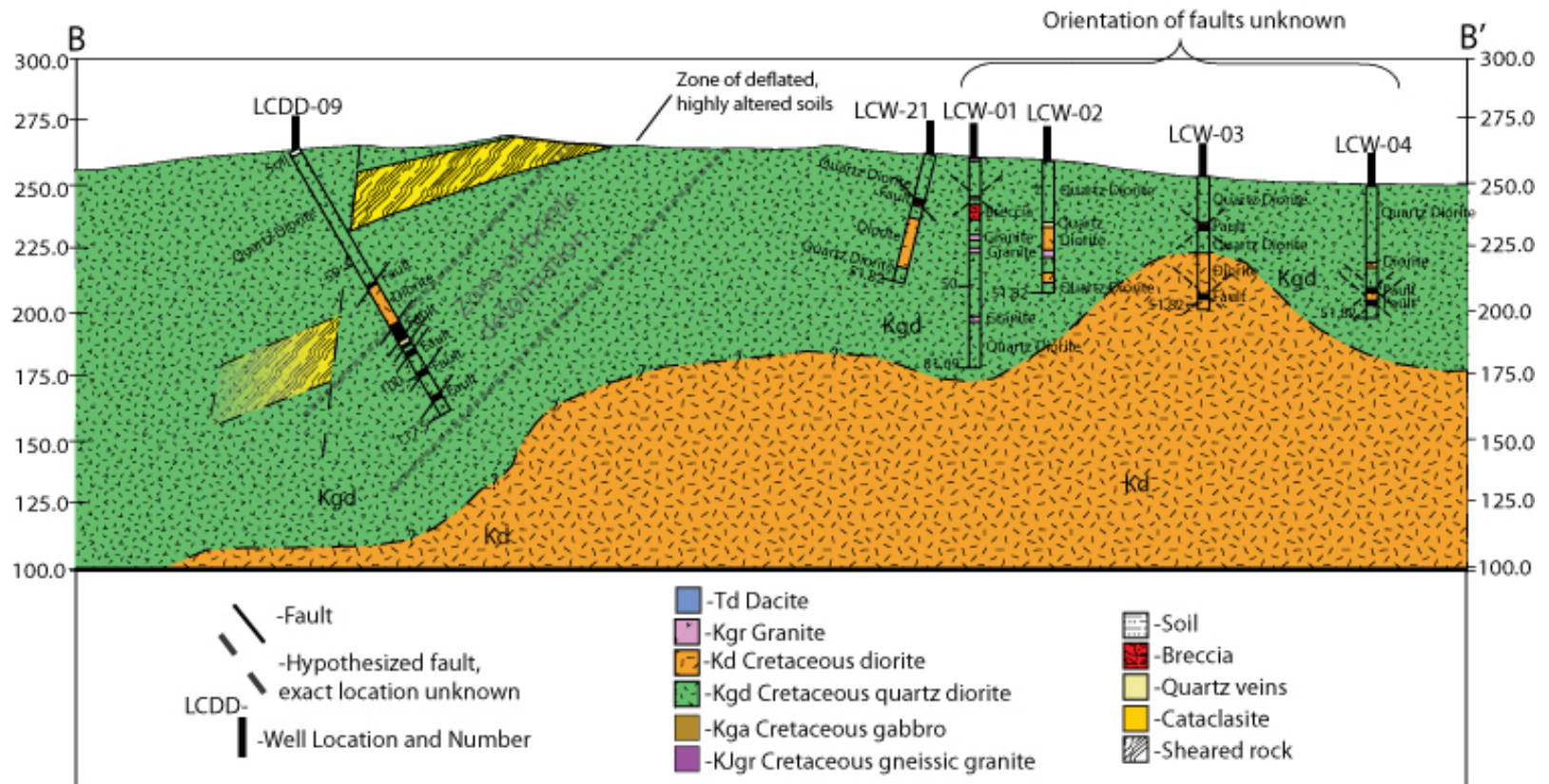


Figure 3.12: Cross Section B-B' was constructed from surface observations and core data.

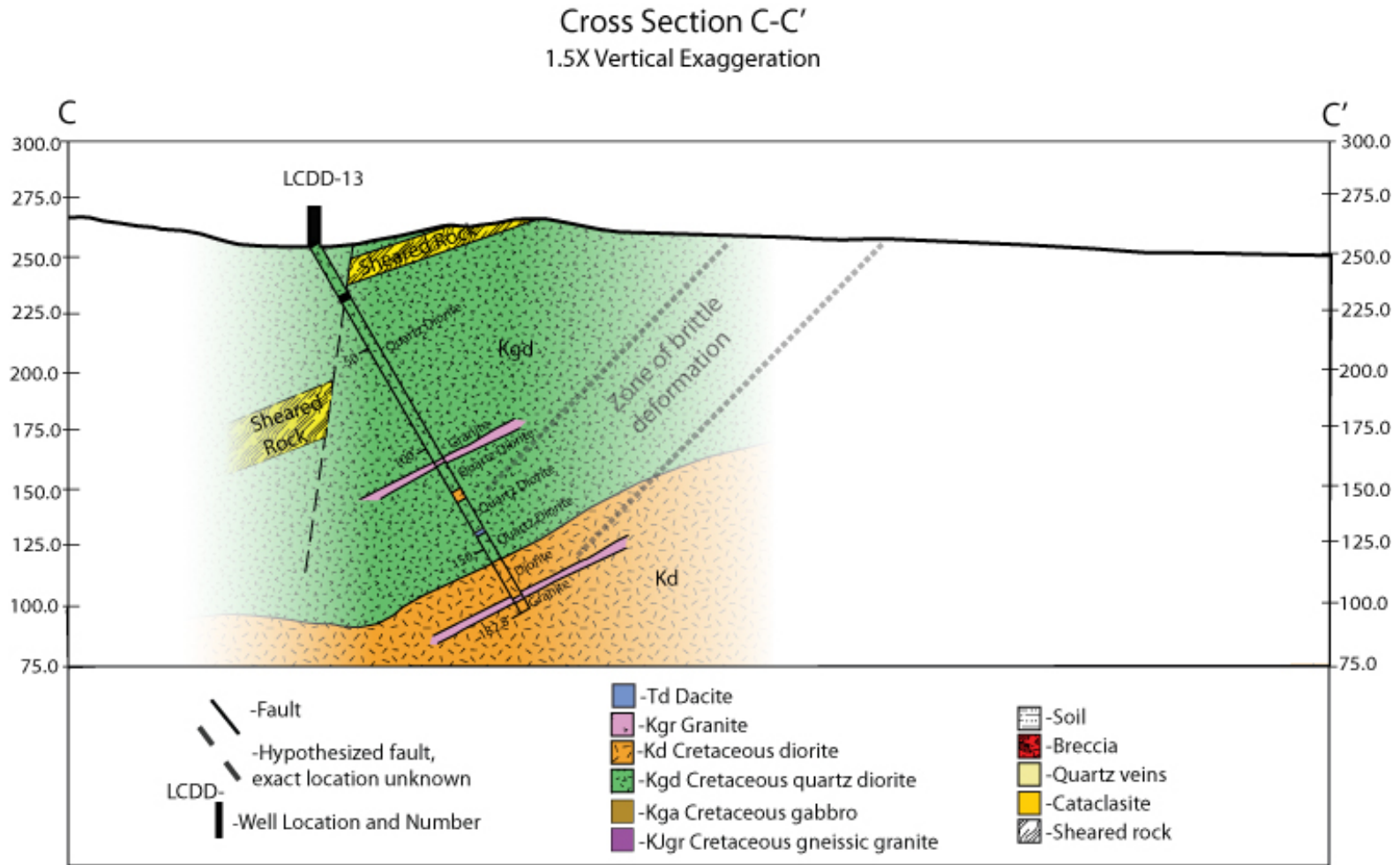


Figure 3.13: Cross section C-C' was constructed from surface observations and core data. The darker texture and color reflect our relative confidence in the presence and locations of interpreted structures and rock types.

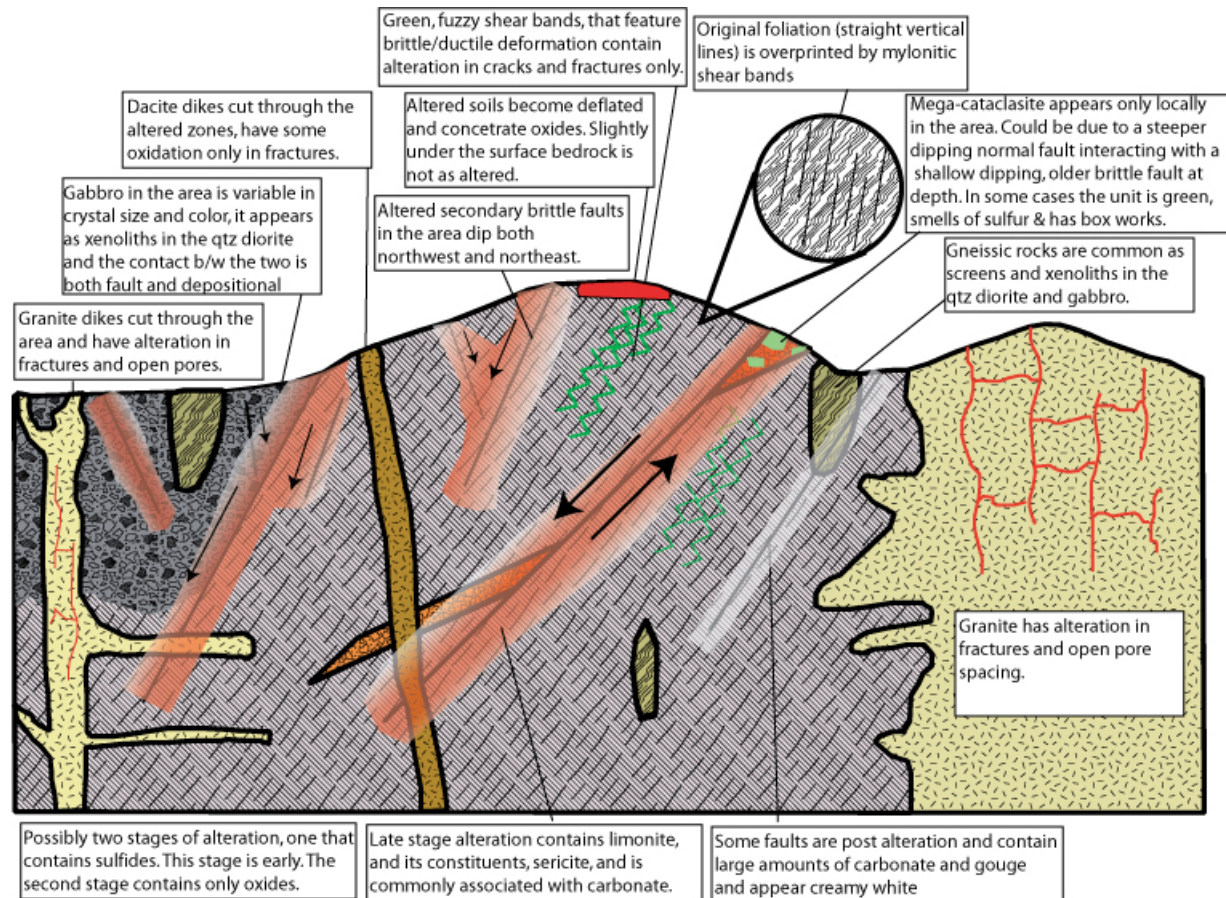


Figure 3.14: Annotated, schematic cross section through the southern portion of the Cirio Concession illustrating the relationships among rock types and mineralization. Note: Foliation dip orientations are generalized and may not coincide with dips in all locations.

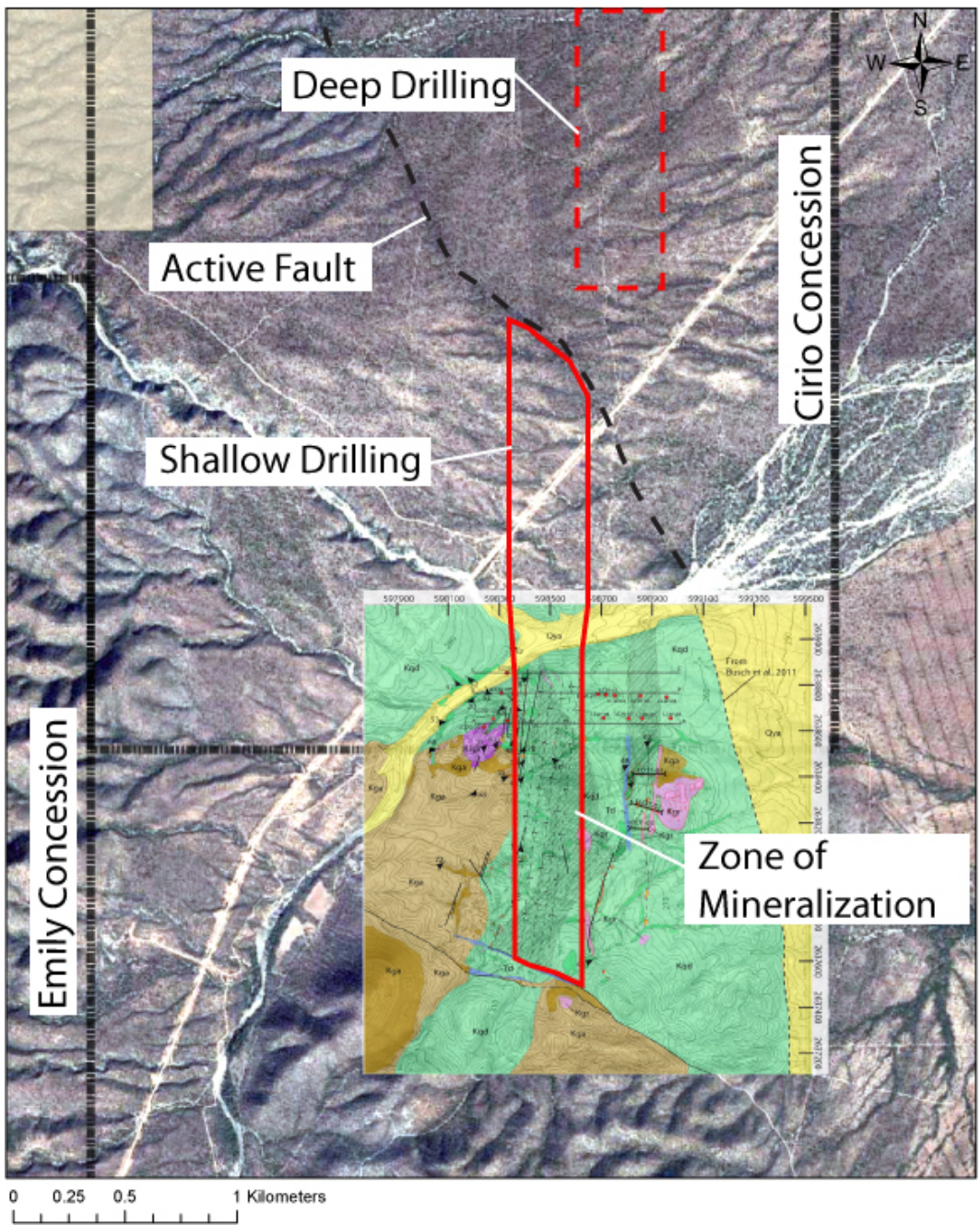


Figure 3.15: Recommendations for drilling and locations that shallow and deep drilling should occur.

APPENDIX A
PRETEST AND POSTTEST

**Geologic Landscapes Survey Pretest
School of Earth and Space Exploration
Arizona State University**

In order to improve this course, the School of Earth and Space Exploration would like to understand what students know before they participate in this experiment and how much they learn as a result of it. This survey is to help us assess these questions. You will not know the answers to some of these questions, but please just answer them the best you can and try to answer every question, even those you are uncertain about. We thank you for your cooperation.

What this Survey Covers

This survey is designed to determine the amount of previous knowledge you possess about landforms, the formation of landforms, and the effect that geologic processes have on the landscape. In this survey you will be asked the following types of questions:

1. How did a landscape feature form?
2. How is a geologic structure expressed in the landscape?
3. What affect does a geologic process have on the landscape?

Participant

Number: _____

- 1) What is your sex:
 - a. Male.
 - b. Female.

- 2) What is your age?
 - a. 18-22 years.
 - b. 22-27 years.
 - c. 27-32 years.
 - d. 33-45 years.
 - e. 45 years or older.

- 3) What type of geology experiences have you had:
 - a. Several geology classes and lots of geology experience.
 - b. This is my first geology class, but geology is a hobby of mine.
 - c. This is my first geology class, but I have a little geology experience.
 - d. This is my first geology class and I have no geology experience.

- 4) Do you commonly watch movies or shows where geology is the topic?
 - a. I often watch them.
 - b. I sometimes watch them.
 - c. I rarely watch them.
 - d. No, I do not watch them.

- 5) Do you commonly watch the Discovery Channel, Science Channel, or Learning Channel?
 - a. Yes, that's all I watch.
 - b. I regularly watch them.
 - c. I sometimes watch them.
 - d. I rarely watch them.
 - e. I do not watch them.

- 6) Do you have any military background or other training in reading maps?
 - a. Yes, I was in the active military or reserves for 4 or more years.
 - b. Yes, I was in the active military or reserves for less than 4 years.
 - c. No, I was not in the military but had training in reading maps.
 - d. No, I was not in the military and have no official training with maps.

- 7) Do you commonly ride the bus/light rail or drive yourself?
 - a. Ride the bus/ride the light rail.
 - b. Drive myself.
 - c. Someone else drives me.

- 8) When you are going on a trip, do you typically drive or ride in the passenger seat?
- a. I do most or all of the driving.
 - b. I ride in the passenger seat.
 - c. I share the driving more or less equally.

- 1) **What factors affect the shape of rocks in a river?**
 - a. **Hotness of the sun and coldness of the nights.**
 - b. **Elevation of a rock above sea level.**
 - c. **How far the rock has been transported.**
 - d. **How deep the rock has settled into the ground.**
 - e. **How much sand and gravel is surrounds the rock.**

- 2) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 3) **How does wind affect a landscape?**
 - a. **Wind aids in erosion, breaking down rock into sand and clay.**
 - b. **Wind pushes sediment downstream to the ocean.**
 - c. **Wind can move material, but only if water is present.**
 - d. **Wind causes Earth's surface to distort, forming valleys and hills.**
 - e. **Wind blows material into one area, forming huge mountains.**

- 4) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 5) **How does a sand dune form?**
 - a. **Sea level drops, revealing large sand dunes.**
 - b. **Sand in dried-up rivers is moved by large floods.**
 - c. **Harsh weather breaks sandstone blocks off nearby cliffs.**
 - d. **Wind blows sand, piling it up into mounds.**
 - e. **Rivers deposit eroded material into large dunes.**

6) How confident are you about your answer?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

7) Cross beds are:

- a. Tilted layers that form from compressional forces.
- b. Two layers that cross one another, forming an X-shaped pattern.
- c. Riverbeds that cross, like channels in a braided stream.
- d. Thin, inclined layers in a rock layer deposited as ancient sand dunes.
- e. Layers that have been tilted until they are vertical.

8) How confident are you about your answer (Circle one)?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

9) A joint is:

- a. A large fault that has displaced the rocks on either side of it.
- b. Where two rock types join and become cemented together.
- c. The location where rocks first become tilted.
- d. A crack-like fracture in the rock.
- e. The location where lava first erupts from a volcano.

10) How confident are you about your answer (Circle one)?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

11) How does a joint influence the development of a landscape? A fracture:

- a. Creates large mountains.
- b. May fold rock layers and form new rock layers.
- c. Provides a pathway for weathering by water, plants, and animals.
- d. Allows new sedimentary layers form.
- e. Can unfold layers, making them horizontal.

12) How confident are you about your answer (Circle one)?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

13) Flat-lying layers are evidence that:

- a. There has been no tectonic activity acting on the layers.
- b. Faulting has occurred, causing the layers to be horizontal.
- c. Weathering and erosion carved the layers, making them be flat lying.
- d. The spinning Earth causes layers to settle and become flat.

14) How confident are you about your answer (Circle one)?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

15) How do rock layers typically get tilted?

- a. Water erodes one end, causing the land to sink beneath one part.
- b. Strong wind tilts the layers.
- c. Over time, some rocks get weak and crack, causing them to sag.
- d. Forces, like compression, cause rock layers to bend and tilt.

16) How confident are you about your answer?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

17) A fold is expressed in the landscape as:

- a. Bent or kinked layers that are curved.
- b. One or more large cracks.
- c. A single large crack.
- d. Cracked and jumbled fragments that are angular.
- e. Smooth bends near a river.

18) How confident are you about your answer?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 19) **An unconformity is:**
- When the rocks are tilted and folded into a circular shape.**
 - Formed from an eroded volcano that is unlike the surrounding area.**
 - An erosion surface that formed in the past and has since been buried.**
 - What happens when faults displace horizontal layers.**
 - The surface between joints or faults.**

20) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 21) **A volcanic neck forms when:**
- Magma explodes outward, making a large neck-like shape.**
 - The internal buildup of gasses in a volcano collapses the volcano.**
 - Lava pushes between two tectonic plates, commonly along a fault.**
 - Where the ground sinks in, forming a large pit before an eruption.**
 - Hard rocks within a volcanic conduit erode more slowly than material around it, and so stick up in the landscape.**

22) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 23) **A fault is:**
- An interruption in the deposition of horizontal layers.**
 - A fracture that has offset the rocks on one side relative to the other.**
 - A fracture where there is no movement on either side.**
 - A large amount of lava that shakes the ground when it moves.**
 - A feature related to the full moon and ocean tides.**

24) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 25) **How is a fault expressed on the surface of the earth?**
- A subtle boundary within sedimentary rocks, signifying no deposition.**
 - As upside-down layers.**
 - As a crack or step in the surface, with uneven land on either side.**
 - Like a gray mountain with no layers.**
 - Faults are underground and cannot be seen on the surface.**

26) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 27) **Faulting can tilt layers by:**
- Causing resistance as two masses of rock shear past one another.**
 - Creating large open spaces, into which rocks can crumble.**
 - Eroding the edges, which allows the rocks to slump.**
 - Allowing lava to flow into the crack and bow down the rock layers.**
 - Dissolving some parts, causing layers to slide down hill.**

28) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 29) **Mud cracks form when:**
- Animals die and their bones become preserved in mud.**
 - Lava cools and contracts, leaving large crack-like openings.**
 - Mud contracts as it dries leaving spaces, which can get filled with sand.**
 - A river moves from its original channel, leaving behind a large pit or crack.**

30) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 31) What does a lava flow look like in the landscape?
- a. Like a large crack in the earth.
 - b. Rounded stones trapped within a finer-grained material.
 - c. Angular stones that form thin layers.
 - d. A usually dark-colored, river-shaped or tongue-shaped mass of rocks.
 - e. A nearly vertical layer of rock, which is folded into interesting shapes.

32) How confident are you about your answer?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

**Geologic Landscapes Survey Posttest
School of Earth and Space Exploration
Arizona State University**

Participant

Number: _____

**We ask that you please not discuss your participation in this study
with your classmates or peers. We don't want to bias the results.
Thank you.**

1) What factors affect the shape of rocks in a river?

- a. Hotness of the sun and coldness of the nights.**
- b. Elevation of a rock above sea level.**
- c. How far the rock has been transported.**
- d. How deep the rock has settled into the ground.**
- e. How much sand and gravel is surrounds the rock.**

2) How confident are you about your answer?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

3) How does wind affect a landscape?

- a. Wind aids in erosion, breaking down rock into sand and clay.**
- b. Wind pushes sediment downstream to the ocean.**
- c. Wind can move material, but only if water is present.**
- d. Wind causes Earth's surface to distort, forming valleys and hills.**
- e. Wind blows material into one area, forming huge mountains.**

4) How confident are you about your answer?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

5) How does a sand dune form?

- a. Sea level drops, revealing large sand dunes.**
- b. Sand in dried-up rivers is moved by large floods.**
- c. Harsh weather breaks sandstone blocks off nearby cliffs.**
- d. Wind blows sand, piling it up into mounds.**
- e. Rivers deposit eroded material into large dunes.**

6) How confident are you about your answer?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 7) **Cross beds are:**
- a. **Tilted layers that form from compressional forces.**
 - b. **Two layers that cross one another, forming an X-shaped pattern.**
 - c. **Riverbeds that cross, like channels in a braided stream.**
 - d. **Thin, inclined layers in a rock layer deposited as ancient sand dunes.**
 - e. **Layers that have been tilted until they are vertical.**

8) **How confident are you about your answer (Circle one)?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 9) **A joint is:**
- a. **A large fault that has displaced the rocks on either side of it.**
 - b. **Where two rock types join and become cemented together.**
 - c. **The location where rocks first become tilted.**
 - d. **A crack-like fracture in the rock.**
 - e. **The location where lava first erupts from a volcano.**

10) **How confident are you about your answer (Circle one)?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 11) **How does a joint influence the development of a landscape? A fracture:**
- a. **Creates large mountains.**
 - b. **May fold rock layers and form new rock layers.**
 - c. **Provides a pathway for weathering by water, plants, and animals.**
 - d. **Allows new sedimentary layers form.**
 - e. **Can unfold layers, making them horizontal.**

12) **How confident are you about your answer (Circle one)?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 13) Flat-lying layers are evidence that:
- There has been no tectonic activity acting on the layers.
 - Faulting has occurred, causing the layers to be horizontal.
 - Weathering and erosion carved the layers, making them be flat lying.
 - The spinning Earth causes layers to settle and become flat.

14) How confident are you about your answer (Circle one)?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 15) How do rock layers typically get tilted?
- Water erodes one end, causing the land to sink beneath one part.
 - Strong wind tilts the layers.
 - Over time, some rocks get weak and crack, causing them to sag.
 - Forces, like compression, cause rock layers to bend and tilt.

16) How confident are you about your answer?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 17) A fold is expressed in the landscape as:
- Bent or kinked layers that are curved.
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 - A single large crack.
 - Cracked and jumbled fragments that are angular.
 - Smooth bends near a river.

18) How confident are you about your answer?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 19) **An unconformity is:**
- When the rocks are tilted and folded into a circular shape.**
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 - The surface between joints or faults.**

20) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 21) **A volcanic neck forms when:**
- Magma explodes outward, making a large neck-like shape.**
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 - Lava pushes between two tectonic plates, commonly along a fault.**
 - Where the ground sinks in, forming a large pit before an eruption.**
 - Hard rocks within a volcanic conduit erode more slowly than material around it, and so stick up in the landscape.**

22) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 23) **A fault is:**
- An interruption in the deposition of horizontal layers.**
 - A fracture that has offset the rocks on one side relative to the other.**
 - A fracture where there is no movement on either side.**
 - A large amount of lava that shakes the ground when it moves.**
 - A feature related to the full moon and ocean tides.**

24) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 25) **How is a fault expressed on the surface of the earth?**
- A subtle boundary within sedimentary rocks, signifying no deposition.**
 - As upside-down layers.**
 - As a crack or step in the surface, with uneven land on either side.**
 - Like a gray mountain with no layers.**
 - Faults are underground and cannot be seen on the surface.**

26) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 27) **Faulting can tilt layers by:**
- Causing resistance as two masses of rock shear past one another.**
 - Creating large open spaces, into which rocks can crumble.**
 - Eroding the edges, which allows the rocks to slump.**
 - Allowing lava to flow into the crack and bow down the rock layers.**
 - Dissolving some parts, causing layers to slide down hill.**

28) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 29) **Mud cracks form when:**
- Animals die and their bones become preserved in mud.**
 - Lava cools and contracts, leaving large crack-like openings.**
 - Mud contracts as it dries leaving spaces, which can get filled with sand.**
 - A river moves from its original channel, leaving behind a large pit or crack.**

30) **How confident are you about your answer?**

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

- 31) What does a lava flow look like in the landscape?
- a. Like a large crack in the earth.
 - b. Rounded stones trapped within a finer-grained material.
 - c. Angular stones that form thin layers.
 - d. A usually dark-colored, river-shaped or tongue-shaped mass of rocks.
 - e. A nearly vertical layer of rock, which is folded into interesting shapes.

32) How confident are you about your answer?

Not Confident	Somewhat Confident	Confident	Fairly Confident	Very Confident
a	b	c	d	e

Please continue to the next page.

- 1) In general what did you think of the video?
 - a. I thought it was very interesting.
 - b. I thought it was somewhat interesting.
 - c. I have no strong opinion about the movie.
 - d. I thought it was not very interesting.
 - e. I thought it was not interesting at all.
- 2) In general what did you think of the narration?
 - a. Very good, kept me engaged.
 - b. Okay, but could be better.
 - c. No opinion.
 - d. Not very good, hard to follow.
 - e. Not good at all, made me tired.
- 3) In general what did you think of the photographs in the video?
 - a. Very good, kept me engaged.
 - b. Okay, but could be better.
 - c. No opinion.
 - d. Not very good, hard to follow.
 - e. Not good at all, made me tired.
- 4) I liked the photographs that had people or other things in them.
 - a. Strongly agree.
 - b. Somewhat agree.
 - c. No opinion.
 - d. Somewhat disagree.
 - e. Strongly disagree.
- 5) I feel like photographs containing people and objects distracted me from observing the geologic features.
 - a. Strongly agree.
 - b. Somewhat agree.
 - c. No opinion.
 - d. Somewhat disagree.
 - e. Strongly disagree.
- 6) I feel like the photographs that had people and things in them helped me to connect to the topic better.
 - a. Strongly agree.
 - b. Somewhat agree.
 - c. No opinion.
 - d. Somewhat disagree.
 - e. Strongly disagree.
- 7) This video would hold my attention better if it was animated.
 - a. Strongly agree.
 - b. Somewhat agree.

- c. No opinion.
 - d. Somewhat disagree.
 - e. Strongly disagree.
- 8) In general I learn best by:
- a. Watching movies and taking notes.
 - b. Reading the textbook.
 - c. Attending lectures.
 - d. Explaining the topic to someone else.
 - e. I use all of these techniques equally.
- 9) While participating in this activity, I was distracted by the eye-tracking equipment on my face.
- a. Strongly agree.
 - b. Somewhat agree.
 - c. No opinion.
 - d. Somewhat disagree.
 - e. Strongly disagree.
- 10) While participating in this activity I was distracted by the idea that someone might be monitoring what I am looking at.
- a. Strongly agree.
 - b. Somewhat agree.
 - c. No opinion.
 - d. Somewhat disagree.
 - e. Strongly disagree.
- 11) I was self-conscious while I was being eye tracked.
- a. Strongly agree.
 - b. Somewhat agree.
 - c. No opinion.
 - d. Somewhat disagree.
 - e. Strongly disagree.
- 12) My behavior would have been the same whether or not I was being eye tracked.
- a. Strongly agree.
 - b. Somewhat agree.
 - c. No opinion.
 - d. Somewhat disagree.
 - e. Strongly disagree.
- 13) Please list any changes you would recommend for the educational video.

APPENDIX B

PRETEST AND POSTTEST ITEM ANALYSIS

Item Analysis

examSYSTEM[®] II

Date Run: 04/14/2009 Test Date: 04/13/2009 Page 1 of 3
 Test Name: GLG 101 X3 Test ID: 000000 Class: All
 Instructor: JOHNSON Grade: All
 Scoring: Raw Score

Question		Upper Quartile	Lower Quartile	Total Count	Total %	Discrimination Index	Difficulty Factor	Weight
1	1	0	1	1	2	-0.1	0.806	1
	2	0	1	1	2	-0.1		
	3*	16	6	50	81	0.6		
	4	0	5	5	8	-0.3		
	5	0	2	4	6	-0.1		
	Oth	0	1	1	2	-0.1		
2	1*	16	11	53	85	0.3	0.855	1
	2	0	2	5	8	-0.1		
	3	0	0	0	0	0.0		
	4	0	2	3	5	-0.1		
	5	0	0	0	0	0.0		
	Oth	0	1	1	2	-0.1		
3	1	2	4	10	16	-0.1	0.661	1
	2	0	1	1	2	-0.1		
	3	1	0	4	6	0.1		
	4*	13	6	41	66	0.4		
	5	0	4	5	8	-0.3		
	Oth	0	1	1	2	-0.1		
4	1	5	0	13	21	0.3	0.210	1
	2	1	4	11	18	-0.2		
	3	2	4	13	21	-0.1		
	4*	7	0	13	21	0.4		
	5	1	7	11	18	-0.4		
	Oth	0	1	1	2	-0.1		
5	1	2	5	11	18	-0.2	0.516	1
	2	1	3	11	18	-0.1		
	3	0	3	7	11	-0.2		
	4*	13	4	32	52	0.6		
	5	0	0	0	0	0.0		
	Oth	0	1	1	2	-0.1		
6	1	0	0	2	3	0.0	0.419	1
	2	2	8	24	39	-0.4		
	3*	13	3	26	42	0.6		
	4	1	2	7	11	-0.1		
	5	0	2	2	3	-0.1		
	Oth	0	1	1	2	-0.1		

Number of Respondents: 62
 Total in Upper Quartile: 16
 Total in Lower Quartile: 16

Number of Test Items: 16
 Kuder Richardson 20: 0.72
 Kuder Richardson 21: 0.64

Item Analysis

examSYSTEM II

Date Run: 04/14/2009 Test Date: 04/13/2009 Page 2 of 3
 Test Name: GLG 101 X3 Test ID: 000000 Class: All
 Instructor: JOHNSON Grade: All
 Scoring: Raw Score

Question		Upper Quartile	Lower Quartile	Total Count	Total %	Discrimination Index	Difficulty Factor	Weight
7	1*	13	3	34	55	0.6	0.548	1
	2	0	6	7	11	-0.4		
	3	3	6	20	32	-0.2		
	4	0	0	0	0	0.0		
	5	0	0	0	0	0.0		
	Oth	0	1	1	2	-0.1		
8	1	0	1	1	2	-0.1	0.935	1
	2	0	0	0	0	0.0		
	3	0	1	2	3	-0.1		
	4*	16	13	58	94	0.2		
	5	0	0	0	0	0.0		
	Oth	0	1	1	2	-0.1		
9	1*	16	10	53	85	0.4	0.855	1
	2	0	3	4	6	-0.2		
	3	0	2	3	5	-0.1		
	4	0	0	1	2	0.0		
	5	0	0	0	0	0.0		
	Oth	0	1	1	2	-0.1		
10	1	0	1	2	3	-0.1	0.661	1
	2	0	4	4	6	-0.3		
	3*	16	5	41	66	0.7		
	4	0	1	10	16	-0.1		
	5	0	4	4	6	-0.3		
	Oth	0	1	1	2	-0.1		
11	1	2	4	21	34	-0.1	0.306	1
	2	3	1	4	6	0.1		
	3	2	6	13	21	-0.3		
	4	1	1	4	6	0.0		
	5*	8	3	19	31	0.3		
	Oth	0	1	1	2	-0.1		
12	1	0	2	5	8	-0.1	0.839	1
	2*	16	10	52	84	0.4		
	3	0	3	4	6	-0.2		
	4	0	0	0	0	0.0		
	5	0	0	0	0	0.0		
	Oth	0	1	1	2	-0.1		

Number of Respondents: 62
 Total in Upper Quartile: 16
 Total in Lower Quartile: 16

Number of Test Items: 16
 Kuder Richardson 20: 0.72
 Kuder Richardson 21: 0.64

Item Analysis

examSYSTEM II

Date Run: 04/14/2009 Test Date: 04/13/2009 Page 3 of 3
 Test Name: GLG 101 X3 Test ID: 000000 Class: All
 Instructor: JOHNSON Grade: All
 Scoring: Raw Score

Question		Upper Quartile	Lower Quartile	Total Count	Total %	Discrimination Index	Difficulty Factor	Weight
13	1	0	0	1	2	0.0	0.790	1
	2	0	2	2	3	-0.1		
	3*	16	7	49	79	0.6		
	4	0	1	3	5	-0.1		
	5	0	5	5	8	-0.3		
	Oth	0	1	2	3	-0.1		
14	1*	12	9	43	69	0.2	0.694	1
	2	1	2	6	10	-0.1		
	3	2	1	4	6	0.1		
	4	0	0	2	3	0.0		
	5	1	3	6	10	-0.1		
	Oth	0	1	1	2	-0.1		
15	1	0	0	0	0	0.0	0.790	1
	2	0	2	3	5	-0.1		
	3*	16	10	49	79	0.4		
	4	0	3	9	15	-0.2		
	5	0	0	0	0	0.0		
	Oth	0	1	1	2	-0.1		
16	1	1	2	5	8	-0.1	0.823	1
	2	0	1	3	5	-0.1		
	3	0	0	1	2	0.0		
	4*	15	11	51	82	0.3		
	5	0	1	1	2	-0.1		
	Oth	0	1	1	2	-0.1		

Total Weight: 16

Number of Respondents: 62 Number of Test Items: 16
 Total in Upper Quartile: 16 Kuder Richardson 20: 0.72
 Total in Lower Quartile: 16 Kuder Richardson 21: 0.64

Absolute Frequency Distribution

examSYSTEM II

Date Run: 04/14/2009 Test Date: 04/13/2009 Page 1 of 1
 Test Name: GLG 101 X3 Test ID: 000000 Class: All
 Instructor: JOHNSON Grade: All
 Scoring: Raw Score

Score	Frequency	%ile					
			1	2	3	4	5
16	1	99 *					
15	2	97 **					
14	7	90 *****					
13	10	76 *****					
12	9	60 *****					
11	7	48 *****					
10	4	39 ****					
9	9	28 *****					
8	5	17 *****					
7	5	9 *****					
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4	0	3					
3	1	2 *					
2	0	2					
1	0	2					
0	1	1 *					

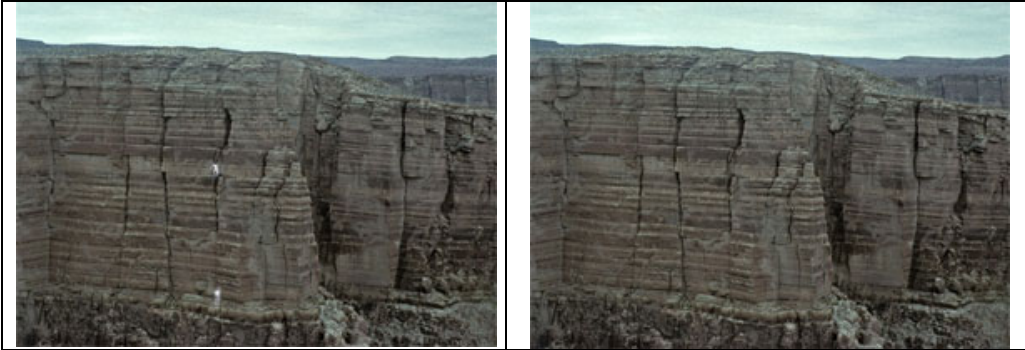
Number of Respondents: 62 Average Score: 10.71 Highest Score: 16
 Number of Items: 16 Median Score: 11.00 Lowest Score: 0
 Std. Deviation: 2.97

Note: Each *** = 1 Respondent

APPENDIX C

CHAPTER 1 SLIDE SHOW MATERIALS

Image 1.



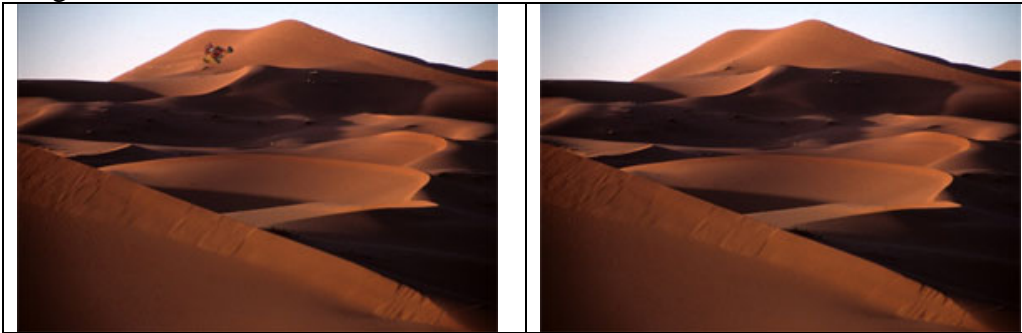
Joints/fractures- Most fractures form as simple cracks representing places where the rock has pulled apart by a small amount. These cracks are called joints and are the most common type of fracture. The thin dark lines that cross the rock faces are joints. Joints are also one of the most commonly observed structures in rocks. These joints are natural cracks along which the rock brittlely broke and separated into two pieces. Rock bodies do not slide past each other on joints. Joints may form for a variety of reasons including the rock being pulled a part or when a rock cools and contracts. Almost all outcrops contain joints. Some joints are fairly planar, some curving, and some irregular. Joints can break rocks into large or small rectangular blocks, sheets, chunks, or pillar-like columns.

Image 2.



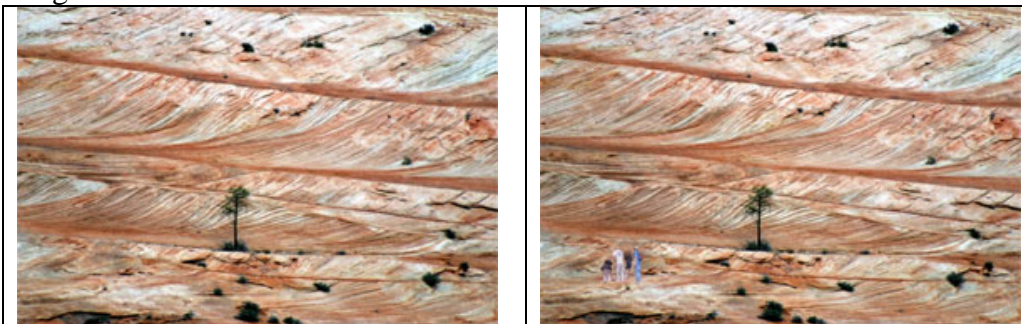
Baby Rocks- Where joints are oriented approximately parallel to one another, a joint set can be defined. In this example a joint set has formed in response to compressive stress. Joints strongly control weathering because jointed rocks weather faster than unjointed rocks. Here weathering along joints carves grooves and notches, leaving rocks between joints as small as pillars. Weathering tends to be concentrated along joints, and in many areas like this they can create interesting shapes and geometries.

Image 3.



Sand dunes- Wind is capable of moving sand and finer sediment. If wind velocity is great enough, it can roll grains of sand and silt and other loose materials across the ground. Very strong wind can lift sand grains, carry them short distances, and drop them to form sand dunes. Sand dunes are mounds of loose sand grains heaped up by a moving current, in this case a current of air. Dunes are most likely to develop in areas with strong winds that generally blow in the same direction, like in deserts and near beaches where sand is blown inland. Some dunes have a crescent shape, with tails pointing in the direction of the prevailing wind. Other dunes are long and more linear or gently curved, such as the ones pictures here. Many dunes take on more irregular, complex shapes, such as the dunes shown here.

Image 4.



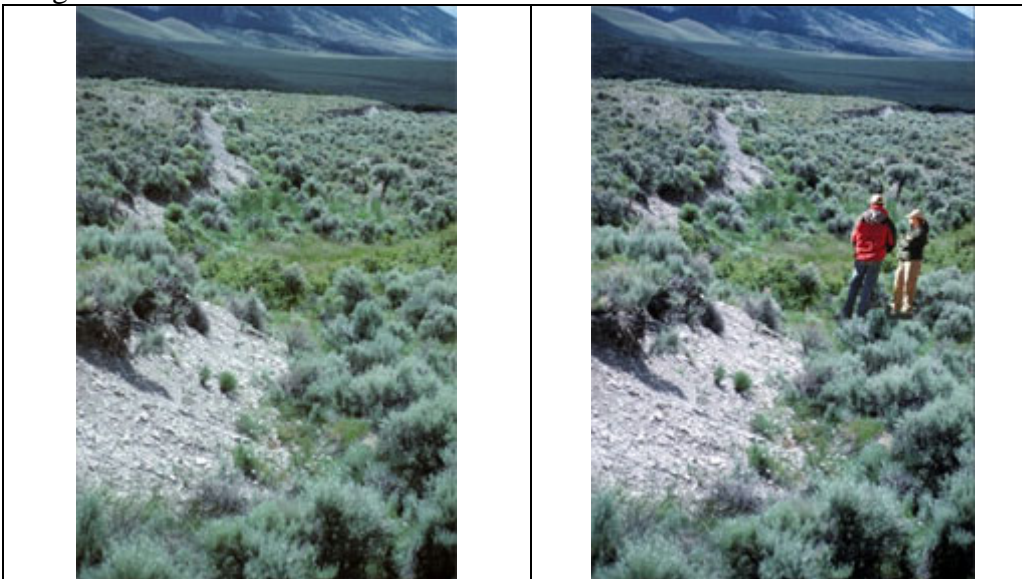
Cross beds- As sand is deposited on the downwind side of the dune layers form that are inclined in the direction the wind is blowing. These sloping layers are called cross beds because they are at an angle to other beds in the same rock. When sand from sand dunes become cemented or lithified and forms sandstone the cross beds may be preserved. Crossbeds are a specialized type of bedding that is not horizontal. Crossbeds are a combination of a series of thin, inclined layers within a larger bed of rock. The cross beds form a distinct angle to the horizontal bedding planes of the larger rock unit. Cross beds preserve the curved profile of the dune and the direction the wind was blowing when the sediment was deposited.

Image 5.



Layers- Most sediment and many volcanic units are deposited in layers that originally are more or less horizontal, a principle called original horizontality. If layers are not longer horizontal, some event affected the layers after they formed. These canyon walls expose horizontal gray tan and red layers. These layers were deposited horizontally and remained so for many millions of years.

Image 6.



Faults with a visible scarp- When fault movement offsets Earth's surface, it can cause a step on the ground surface, called a fault scarp. A fault scarp is a long, low cliff created by movement along a fault. It represents the exposed surface of the fault prior to modification by weathering and erosion. This dirt colored fault scarp formed during the 1983 Borah Peak Earthquake in SE Idaho.

Image 7.



Mud cracks- As a mud layer dries up the mud shrinks producing cracks, it cracks into roughly hexagonal plates that typically curl up at the edges. Because drying requires air, mud cracks only form in sediment exposed above water. Later the fill with sediment and are preserved. These ancient preserved mud crack casts probably formed in flood-deposited sediment as a river level dropped and exposed the wet mud. Later sand flowed over the mud and filled in the cracks.

Image 8

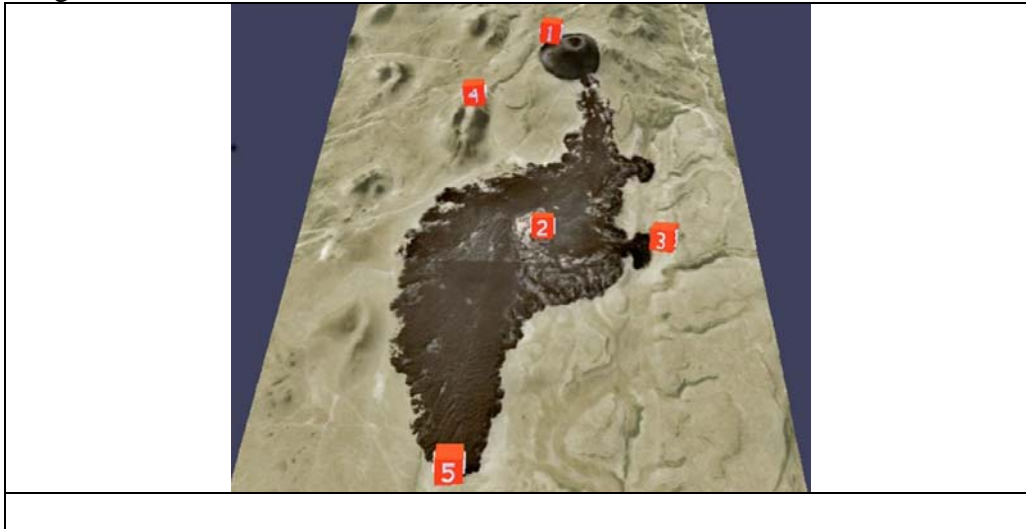
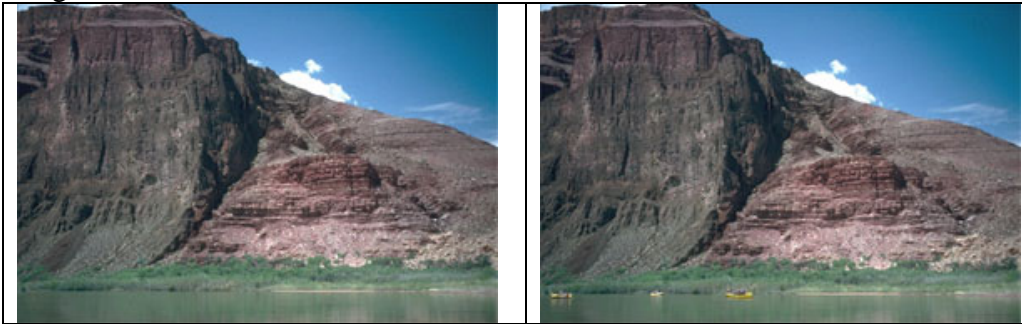


Image 9.



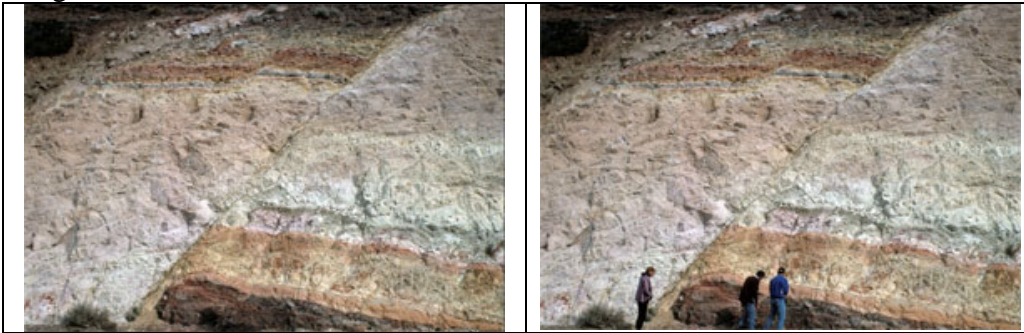
Faults with discontinuous layers- Faults are fractures along which rocks have slipped. Fault surfaces can have any orientation, from vertical to horizontal, and slip along a fault can be up and down, side to side, or at some other angle. Faults riddle the earth's crust. Some are currently active, but most are inactive. A fault can displace the rocks on one side relative to the other side. We commonly recognize faults because of offset or abrupt terminations of layers. Here a curved fault truncates bedding in red sedimentary rocks juxtaposing them against dark basalt.

Image 10.



Faults with notch- As two masses of rock shear past one another, resistance along the zone causes rocks on opposite sides become crushed and powdered. The rocks along faults that are highly fractured and erode easily. As a result, many fault zones erode in a linear topographic notches or linear valleys. In this photo the notch is the location of the fault and the fine-grained material has been eroded

Image 11.



Fault (general)- This fault truncates layers and forms a thin straight line. Faults can slice the crust into a series of fault-bounded blocks that can tilt during movement. Faults are characterized by intense deformation caused when one rock mass shears past another. Notice how the layers are abruptly truncated.

Image 12.



Tilted rocks- Rocks within the earth are subjected to forces from the weight of overlying rocks, from tectonic forces pushing or pulling on the rocks, from cooling and heating, and from pressurized fluids, such as water and magma. A volume of rock may be rotated in response to stresses, Rotation can tilt the volume of rock or spin it horizontally the rock layers in the photograph were deposited as horizontal layers, but the layers have since been tilted.

Image 13.



River with rounded boulders and cobbles- As streams and rivers transport boulders and cobbles, their sharp, angular corners break off because they are the most exposed and they are the weakest part of the clast. The clasts wear into well-rounded cobbles, pebbles, and sand particles. Through transportation, angular clasts gradually become rounded clasts by grinding away of sharp edges and corners. Rounding occurs in sand and gravel as rivers, glaciers, or waves cause particles to hit and scrape against one another or against a rock surface such as a rocky streambed.

Image 14.



Anticlines- Before folding, most rock layers are horizontal because most sedimentary and volcanic layers form with more or less a horizontal orientation. Compressive stress causes shortening, often accommodated by folding of the layers. If the rock layers warp up, in the shape of an A, the fold is generally called an anticline. In an anticline, the oldest rocks are in the center of the fold. This fold is an anticline. Layers dip away from the center of the fold.

Image 15.



Unconformity- Erosion surfaces, formed in the past, can be buried and preserved within a section of rocks. Such buried erosion surfaces are called unconformities. There is an obvious unconformity between the tilted layers below the nearly flat lying layers above. Rocks below the unconformity were tilted or folded before the unconformity developed. This unconformity cuts across the underlying layers; the layers below have a different orientation from the layers above. This surface represents a gap in the geologic record, with the rock unit immediately above the contact being considerably younger than the rock beneath.

Image 16.



Volcanic Neck- Magma that erupts from volcanoes is fed through conduits that may be circular, planar, or both. After the volcano erodes away, the solidified harder rock that makes up the conduit can form a steep topographic feature called a volcanic neck. This volcanic neck is composed of fragmented rocks and connects to dikes that radiate out from the central conduit. This isolated, steep-sided, erosional remnant consisting of lava that once occupied the vent of a volcano are only exposed after the surrounding land is lowered by weathering and erosion.

APPENDIX D

CHAPTER 2 SLIDE SHOW MATERIALS



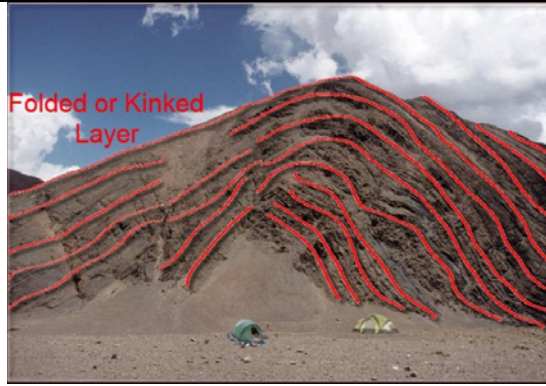
Eruptions of basaltic magma can form a variety of rock types and landforms. This variety is largely controlled by the gas in the magma, because gas affects the style of eruption and the solidification of lava. A single eruption of basaltic magma can produce a wide range of volcanic features and rock textures. Based on the texture, geologists divide basaltic magmas into two main types of lava flows, Pahoehoe and AA. Pahoehoe is a lava flow that has an upper surface with small billowing folds that form a ropy texture. A pahoehoe flow is usually fed by a lava tube and grows as a series of tongues. Pahoehoe lava flows relatively smoothly and easily compared to AA. AA is a type of rough-surfaced lava flow and is shown here. It is formed when the lava breaks apart into a mass of jumbled rocks as it flows. AA flows occur in open channels or as irregularly shaped flows as it moves. Angular blocks of hardened lava may tumble down the front of the flow as it moves. An AA flow has a very rough surface and is covered with dark, jagged rocks.



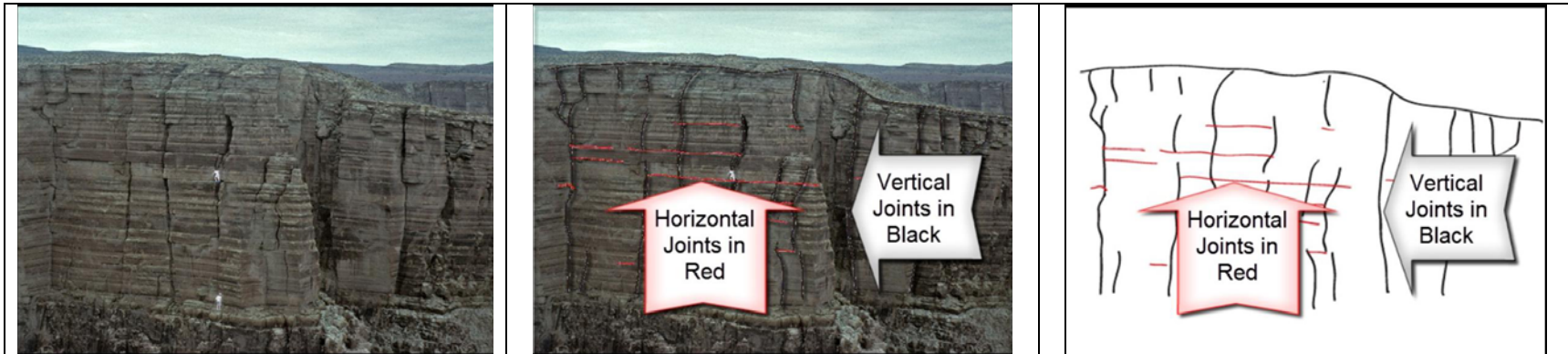
Water is an active chemical agent that can weather and dissolve rocks on the surface. The same is true for groundwater, which can dissolve rock and other materials beneath the surface of the earth. Groundwater may completely dissolve limestone and other soluble rocks, leaving openings. When this happens, caves, sinkholes, or other features can form. Collapse of a cave may produce a sinkhole at the surface, the one shown here formed in 1964 when parts of Anchorage Alaska experienced an earthquake on the scale of 9.2. The shaking from the earthquake caused underlying land to slip and collapse. The overlying land essentially fell into the cavity damaging buildings, vehicles, and injuring several people. In this photograph some building sank so much that their second stories were level with the ground. In other areas, severe damage occurred where a layer of weak clay liquefied and caused houses to shift and shatter. Also landslides of rock and soil destroyed buildings and caused large-scale evacuations.



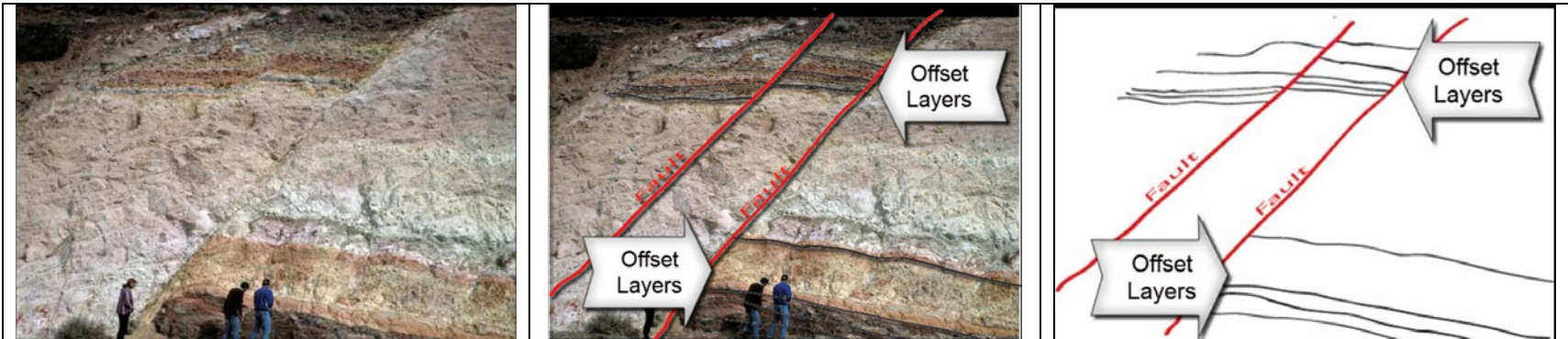
Layers- Most sedimentary and volcanic units are deposited in layers that originally are more or less horizontal. If layers are no longer horizontal, some event, like mountain building, affected the layers after they formed. The canyon walls shown here expose a series of horizontal layers with shades of gray, tan, and red. Each layer represents a geologic event, like a flood, or a change from one geologic environment to another, such as from a setting along a river to a seaside beach setting. The layers in this photograph were deposited horizontally and remained so for many millions of years, indicating that the geologic events that affected this area did not include significant tilting or folding of rock layers. Instead, the rocks layers were deposited one on top of another in horizontal layers, were buried without being tilted, and then were uplifted back to the surface where the still-horizontal layers could be exposed in the canyon.



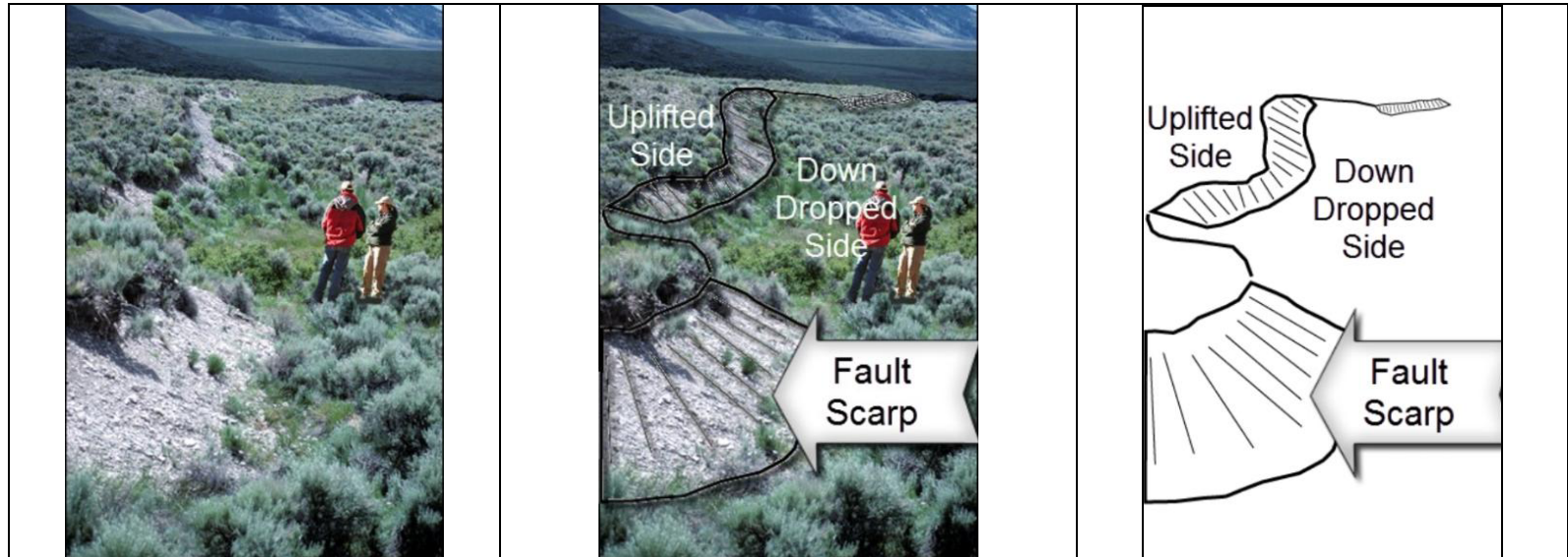
Folds- Most rock layers are horizontal because most sedimentary and volcanic layers form with more or less a horizontal orientation. After they form, layers are subjected to forces that can compress and shorten the layers, causing the layers to fold like a bunched-up rug. If the rock layers warp up, in the shape of an A, the fold is generally called an anticline. If the rock layers warp downward, in the shape of a V or U, the fold is generally called a syncline. The fold in this photograph is an anticline, with layers dipping away from the center of the fold. In an anticline, the oldest rocks are in the center of the fold.



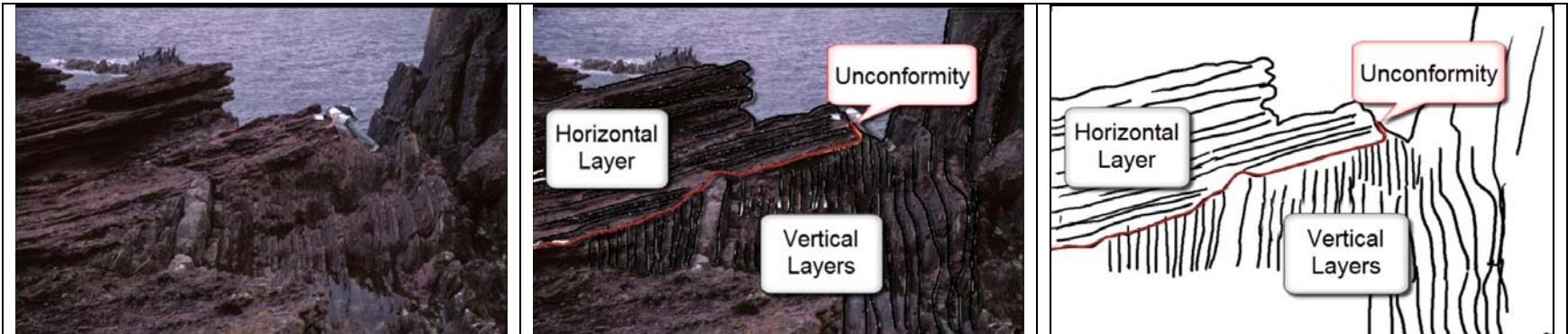
Joints/fractures- Most fractures form as simple cracks representing places where the rock has pulled apart by a small amount. These cracks are called joints and are the most common type of fracture. The thin dark lines that cross the rock faces are joints. Joints are also one of the most commonly observed structures in rocks. These joints are natural cracks along which the rock brittlely broke and separated into two pieces. Rock bodies do not slide past each other on joints. Joints may form for a variety of reasons including the rock being pulled apart or when a rock cools and contracts. Almost all outcrops contain joints. Some joints are fairly planar, some curving, and some irregular. Joints can break rocks into large or small rectangular blocks, sheets, chunks, or pillar-like columns. Joints strongly control how rocks decompose, or weather, when subjected to the environment, because they provide pathways into the rock for water, air, animals, and plants. Jointed rocks therefore decompose faster than rocks without joints, and rocks near the joint decompose faster than parts of the rock away from the joint. As a result, weathering along joints can carve grooves and notches or create interesting natural shapes in the rocks.



Fault planes that cut layers- Faults are fractures along which rocks have slipped past each other, displacing the rocks on one side relative to the other side. Fault surfaces can have any orientation, from vertical to horizontal, and the direction of slip along a fault can be up and down, side to side, or some combination. Earth's crust contains countless faults, some of which are currently active, but most are inactive. Some faults are exposed as thin straight lines that truncate layers. Rocks along the fault can be fractured and pulverized within a wide zone, or faulting can be restricted to a single fracture surface, as shown here. Faulting has displaced rocks on either side of the fault, so that the layers on the two sides are offset and no longer match up. Notice in this photograph how the volcanic layers are abruptly truncated and offset along a single, discrete fault surface. We commonly recognize faults because of offset or abrupt terminations of layers or because they juxtapose two different kinds of rocks. Faulting has displaced rocks on either side of the fault, so that the layers on the two sides are offset and no longer match up. Notice in this photograph how the volcanic layers are abruptly truncated and offset along a single, discrete fault surface.



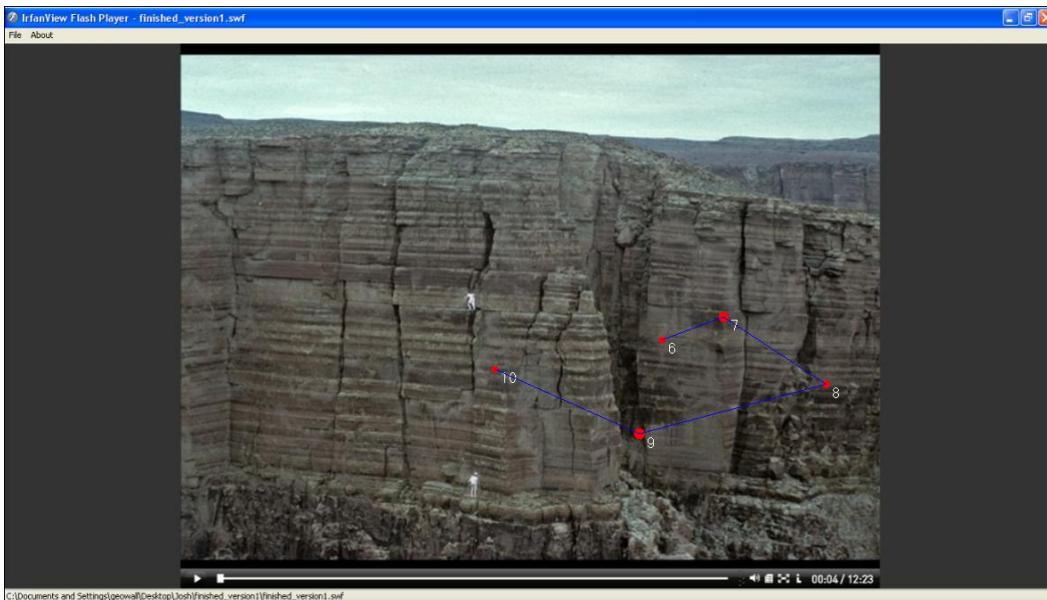
Faults that cut the earth's surface- When fault movement during an earthquake offsets the earth's surface, it can displace the land on one side of the fault relative to the other side. This offset can form a step or ledge on the ground surface, called a fault scarp. Most fault scarps are several meters high when first formed, and can be tens to hundreds of kilometers long. The dirt-colored fault scarp in this photograph formed during the 1983 Borah Peak Earthquake in Idaho. Over time, the loose materials in this scarp will slump downhill, and the scarp will become eroded or buried and covered by vegetation and soil, and so will become more obscure with time.

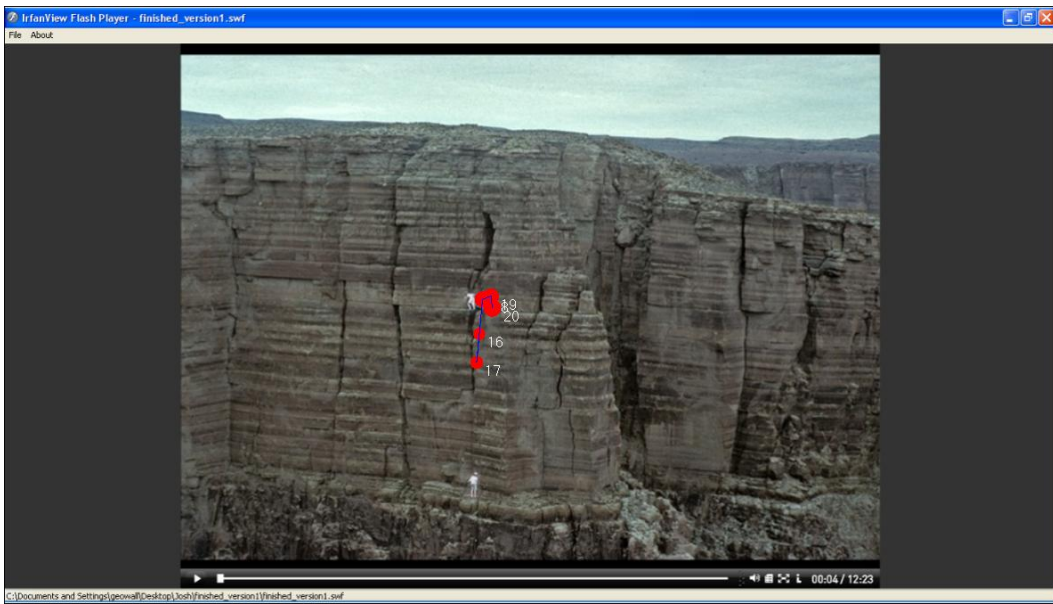
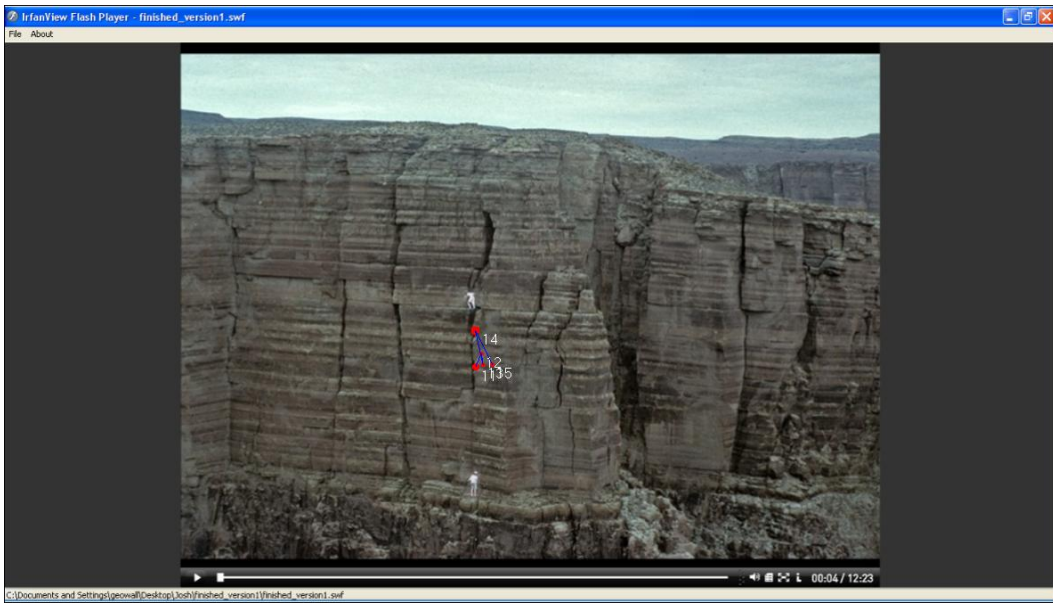


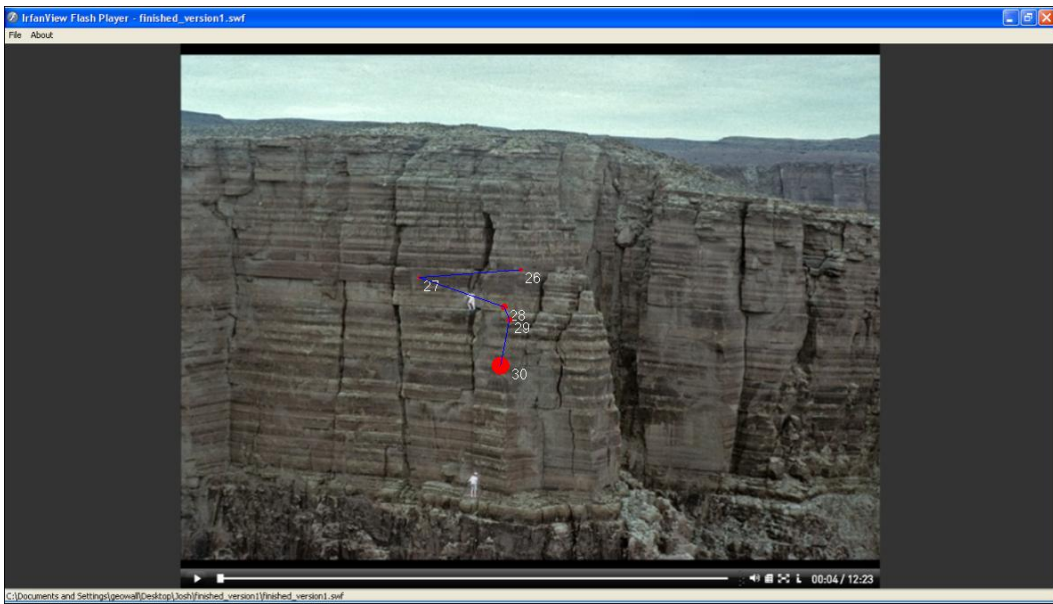
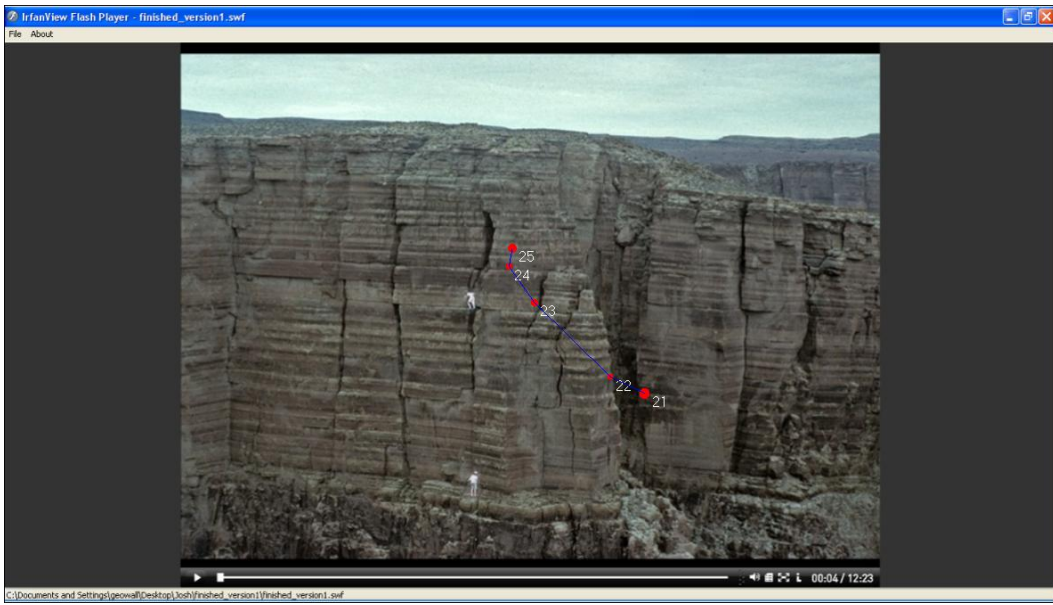
Unconformity- Erosion surfaces, formed in the past, can be buried and preserved within a section of rocks. Such buried erosion surfaces are called unconformities. In this photograph, there is an obvious unconformity between the steeply tilted layers in the bottom half of the photograph and more gently tilted layers above. The unconformity cuts across the underlying layers, separating layers with very different orientations. Rocks below the unconformity were tilted or folded before the unconformity developed, whereas rocks above the unconformity were deposited after this episode of tilting and folding. An unconformity represents a major change in the geology, with the rocks below an unconformity being considerably older than rocks above the unconformity. Most unconformities represent a gap in the geologic record, spanning millions or even billions of Earth history.

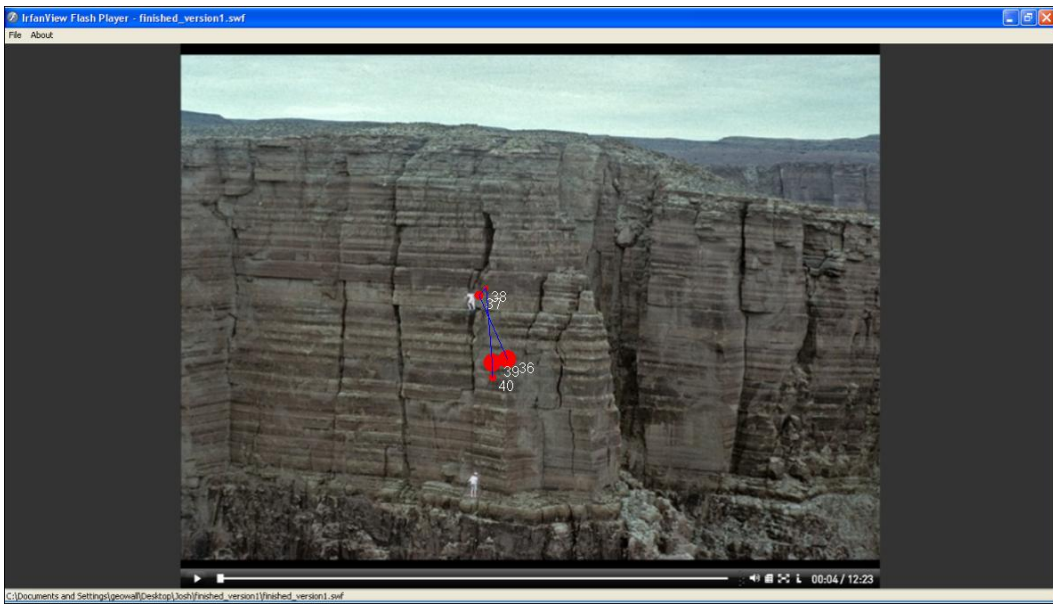
APPENDIX E
FIXATION SEQUENCE DIAGRAMS

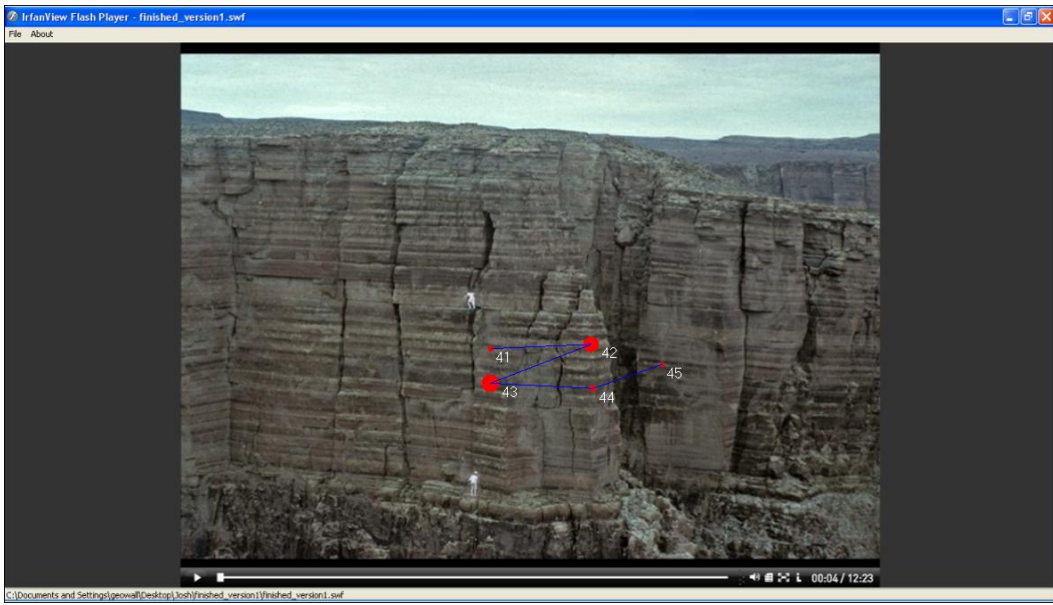
Fixation sequence diagrams for image 1 for an individual who has low distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.

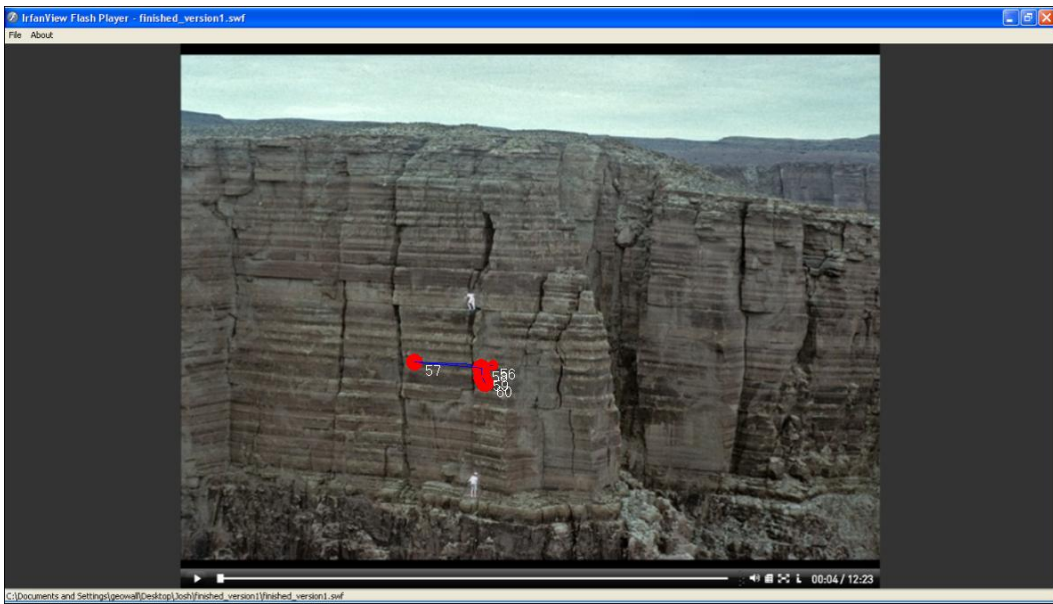
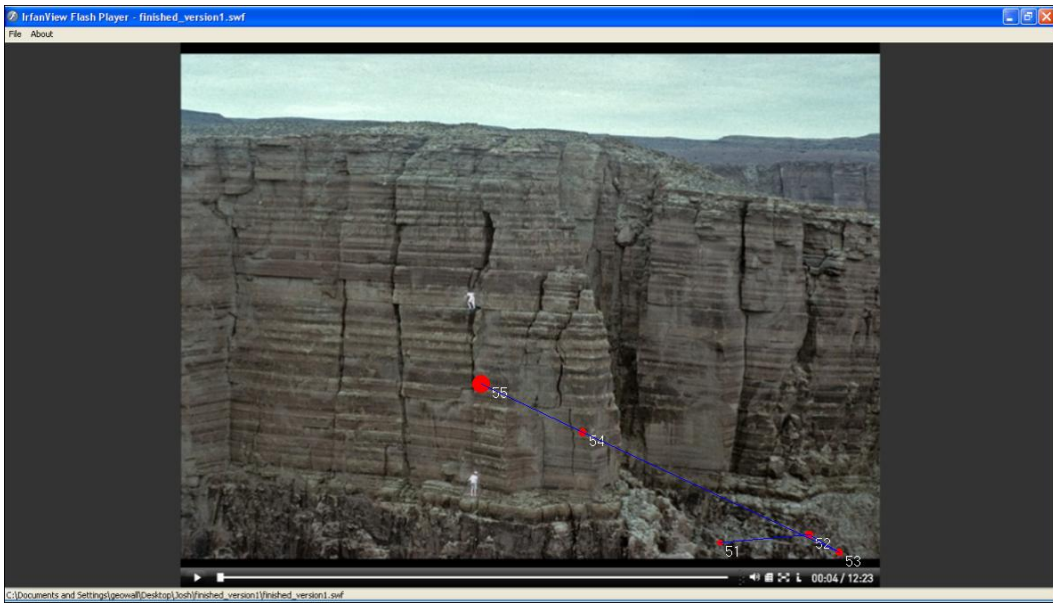


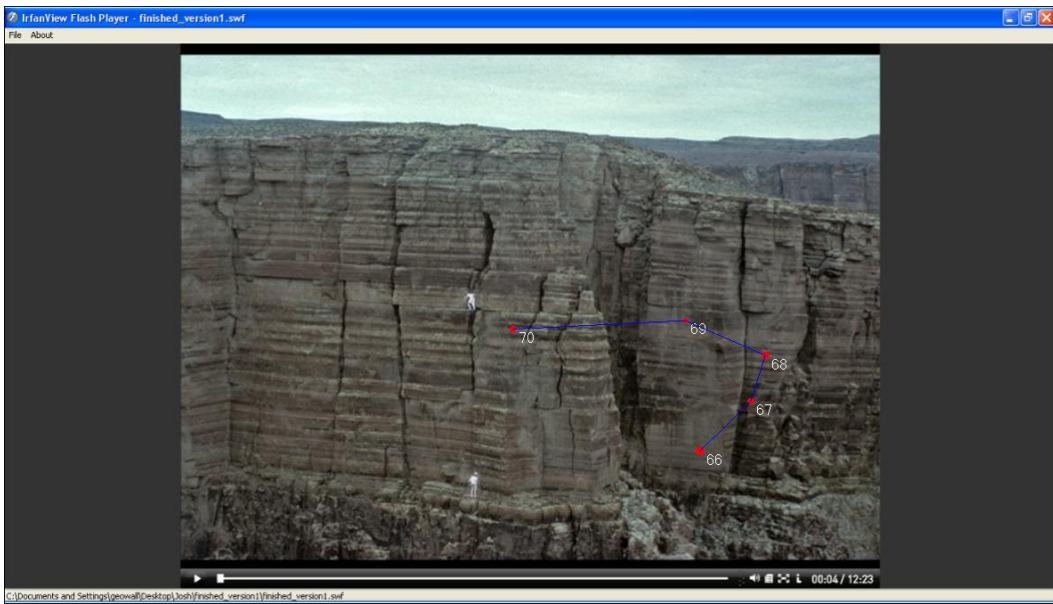


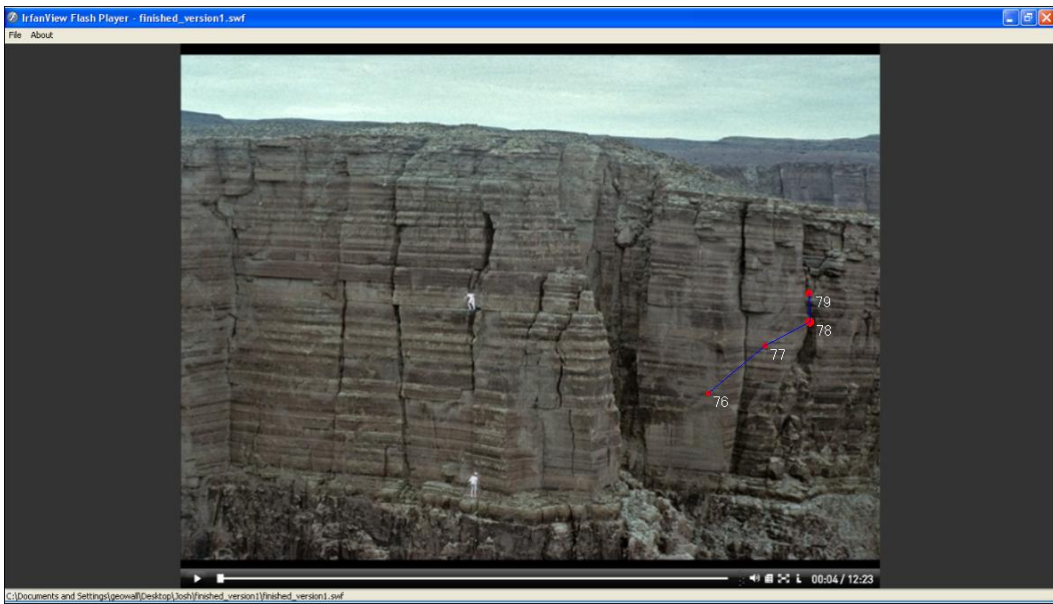




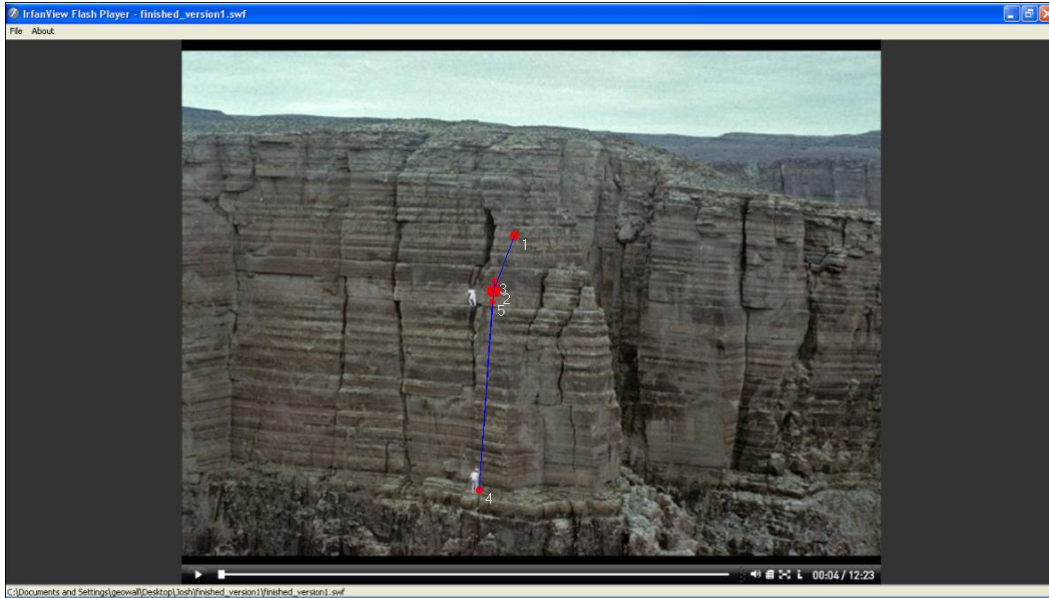


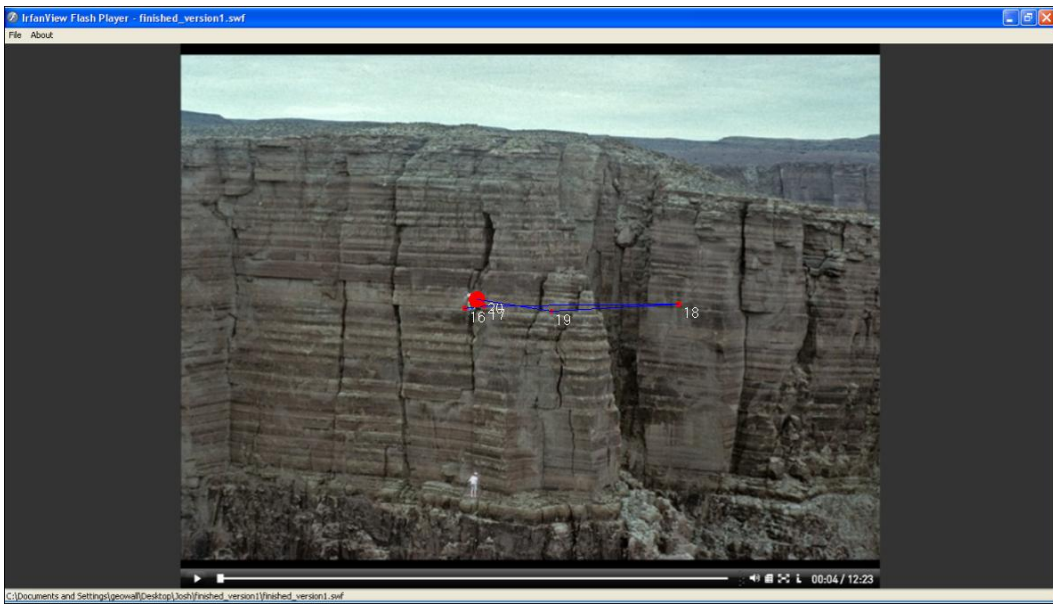


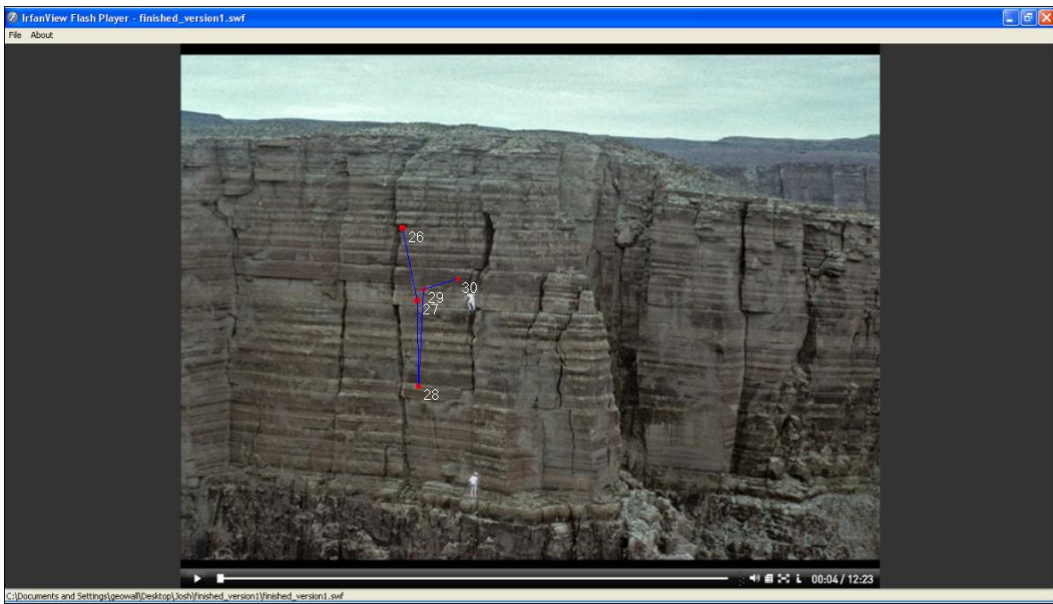
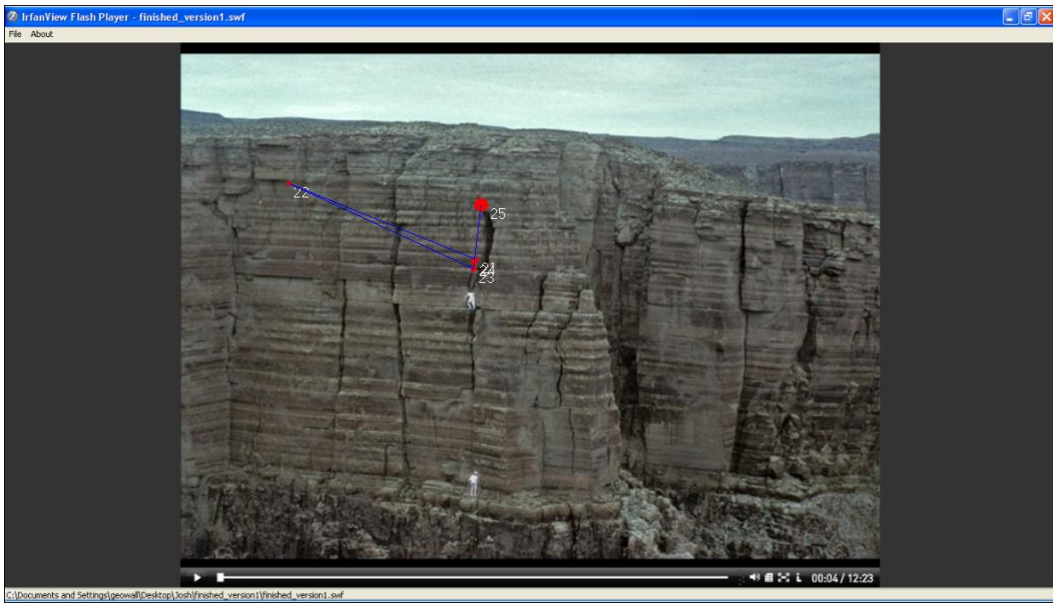


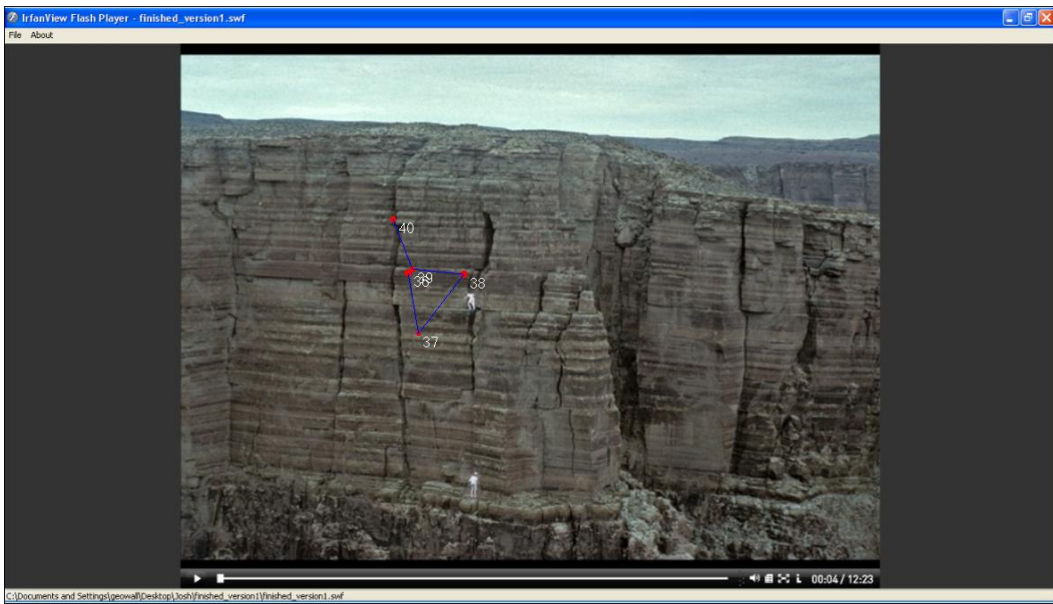
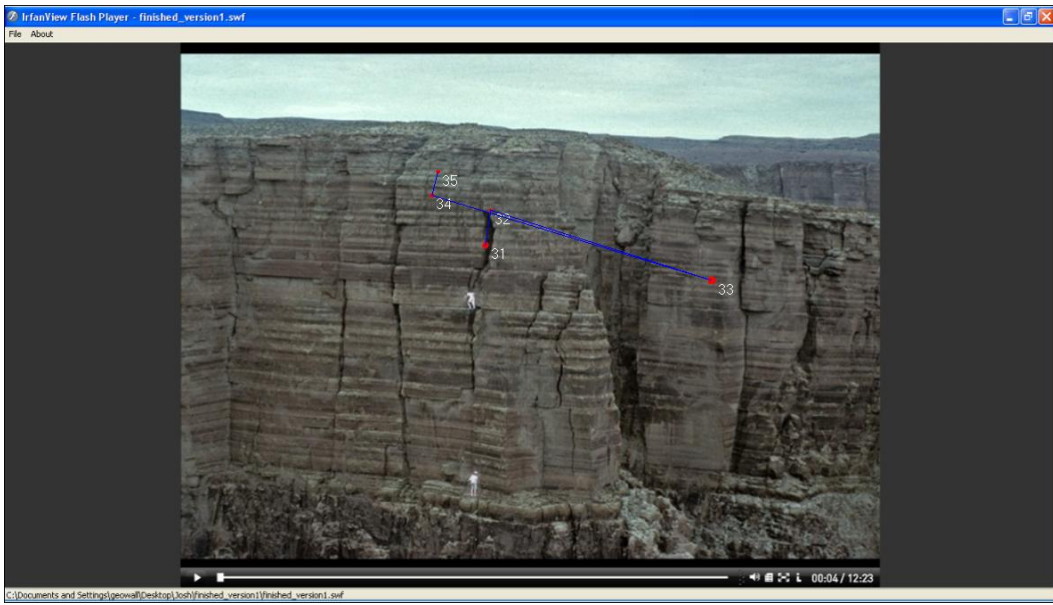


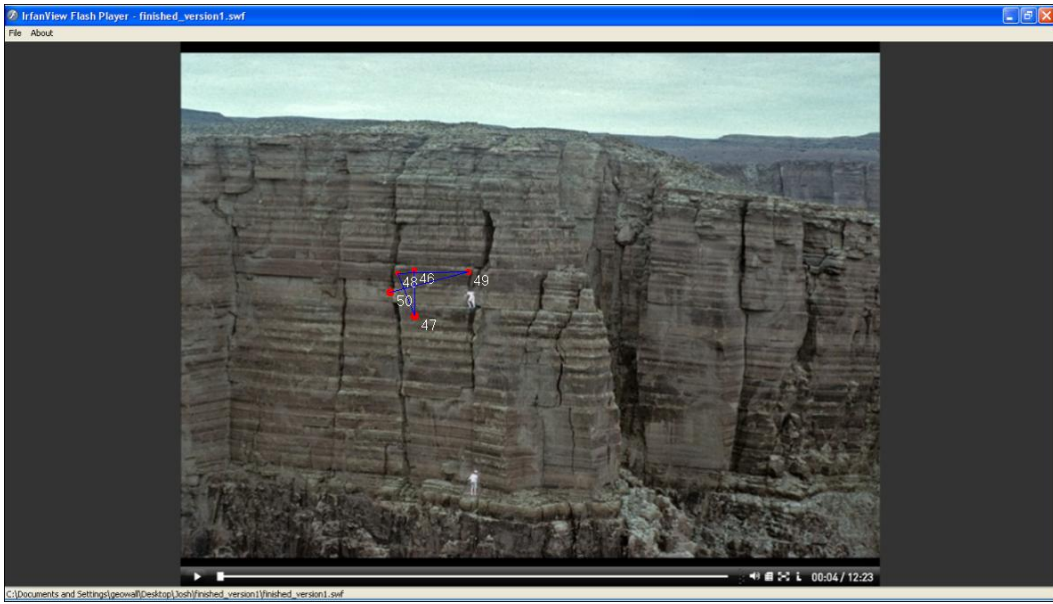
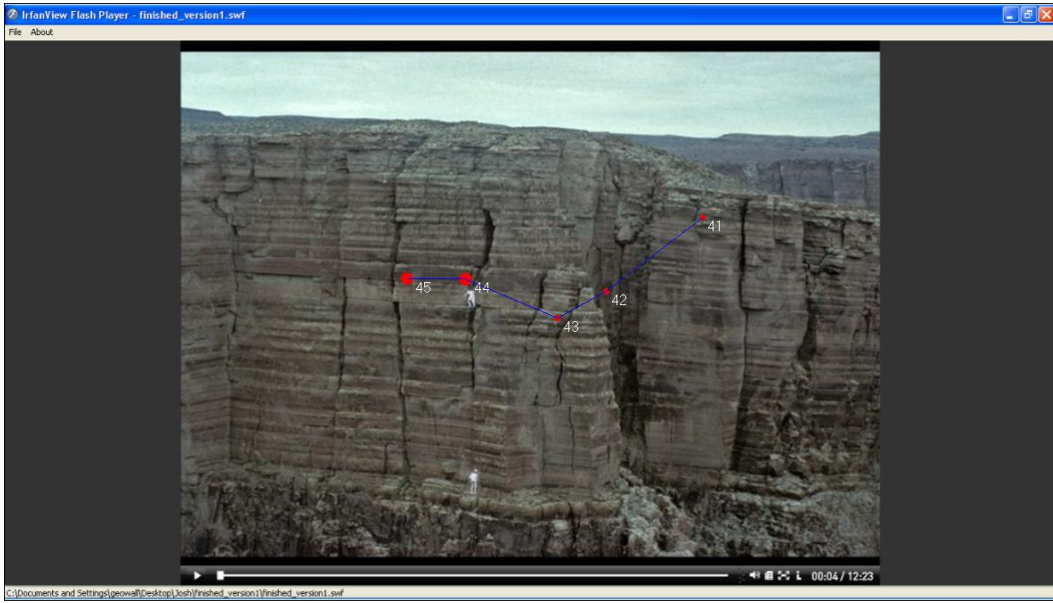
Fixation sequence diagrams for image 1 for an individual who has average distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.

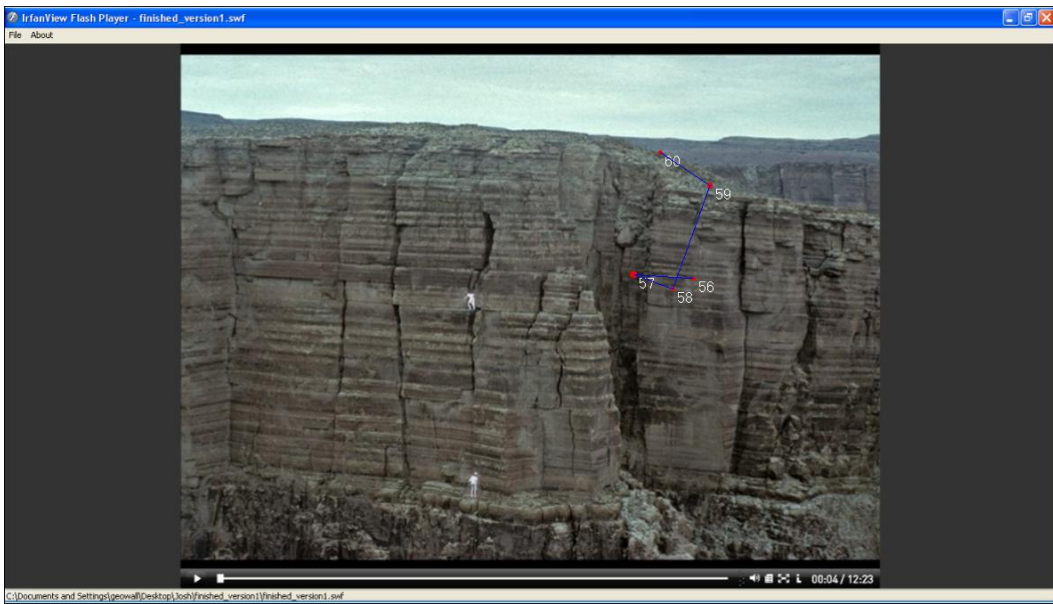
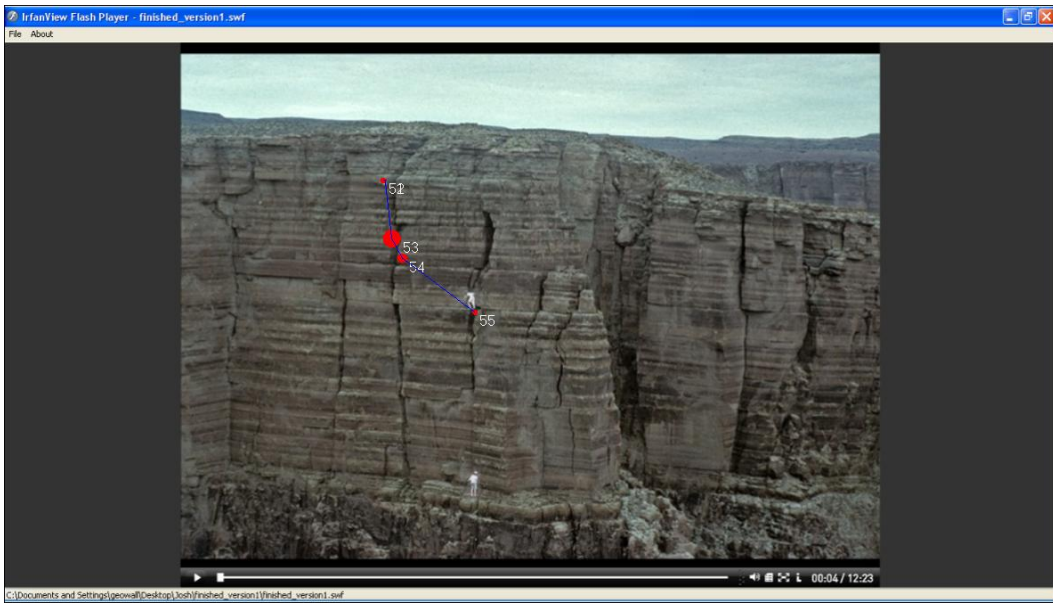


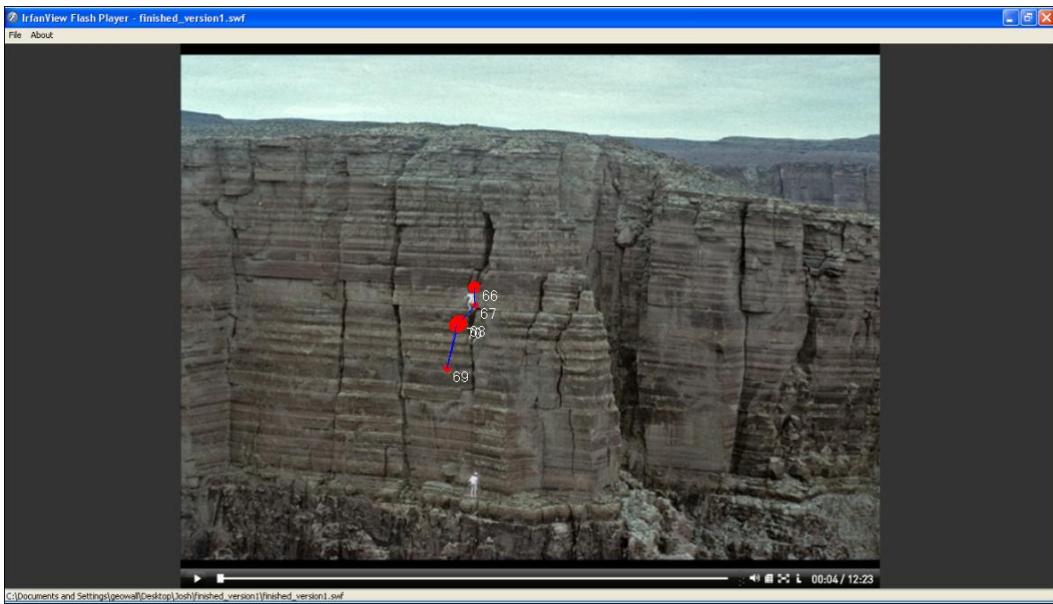


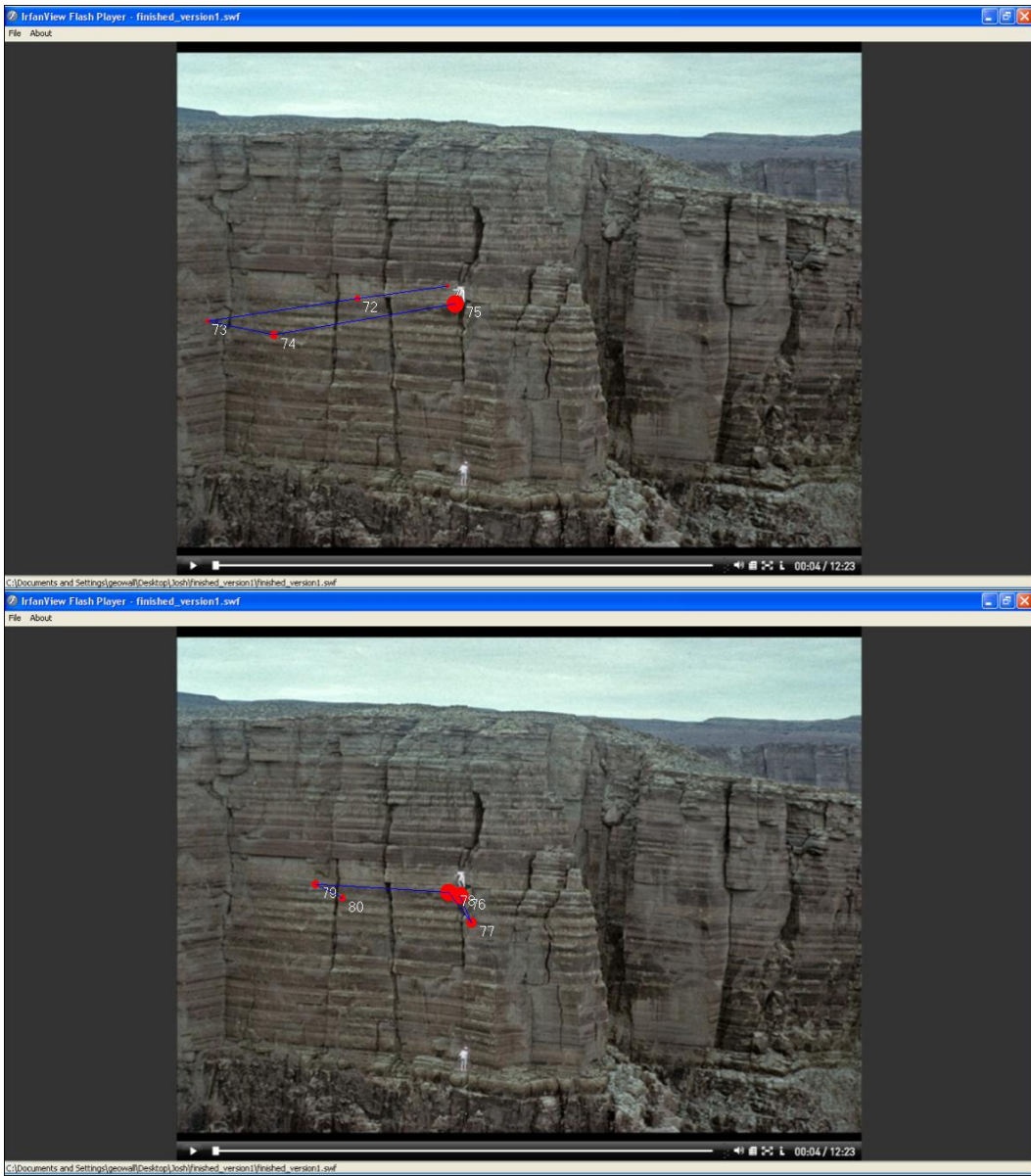


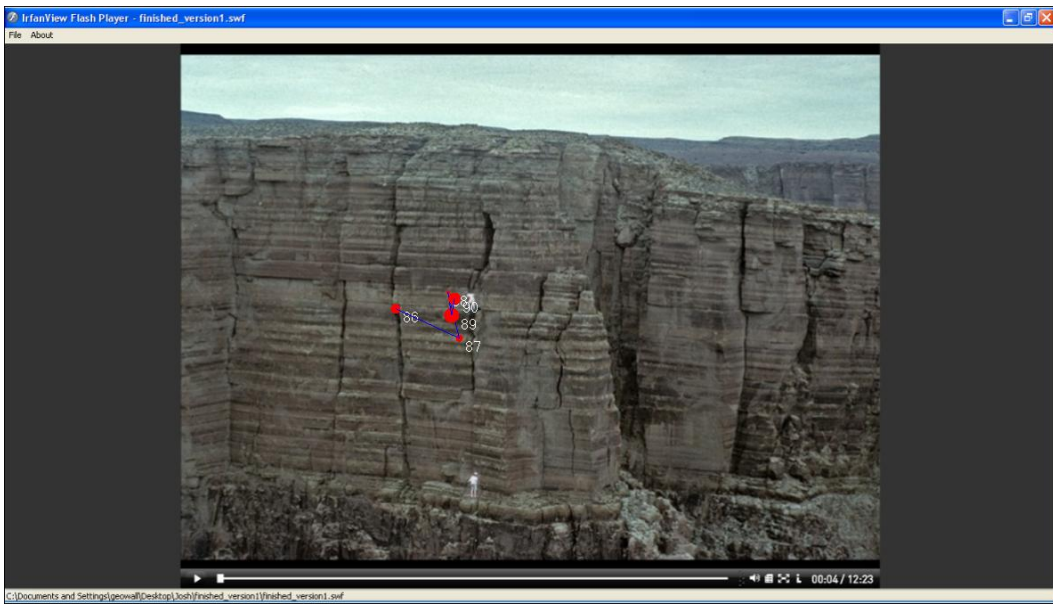
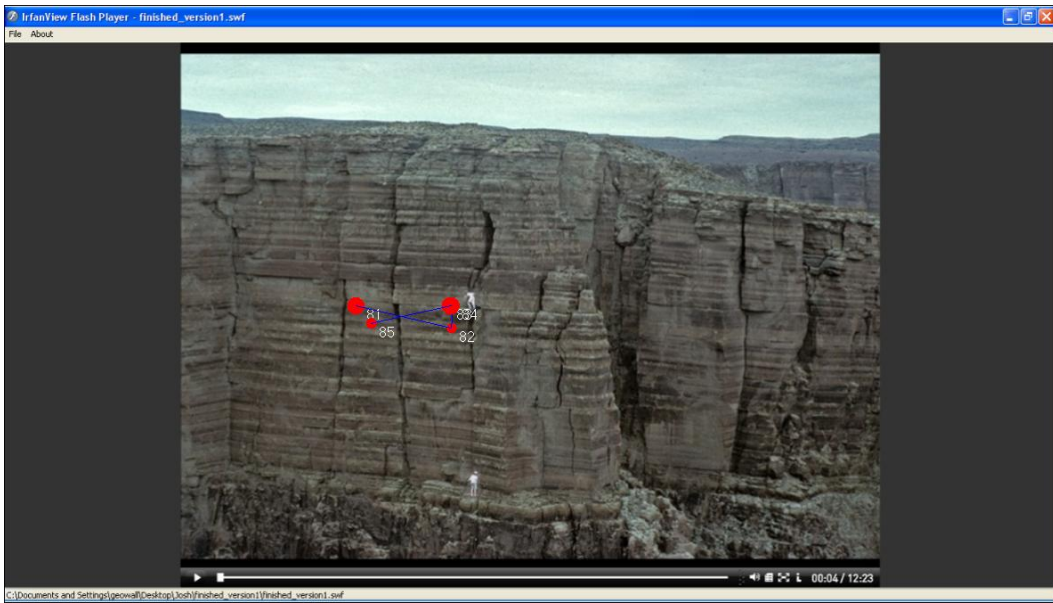


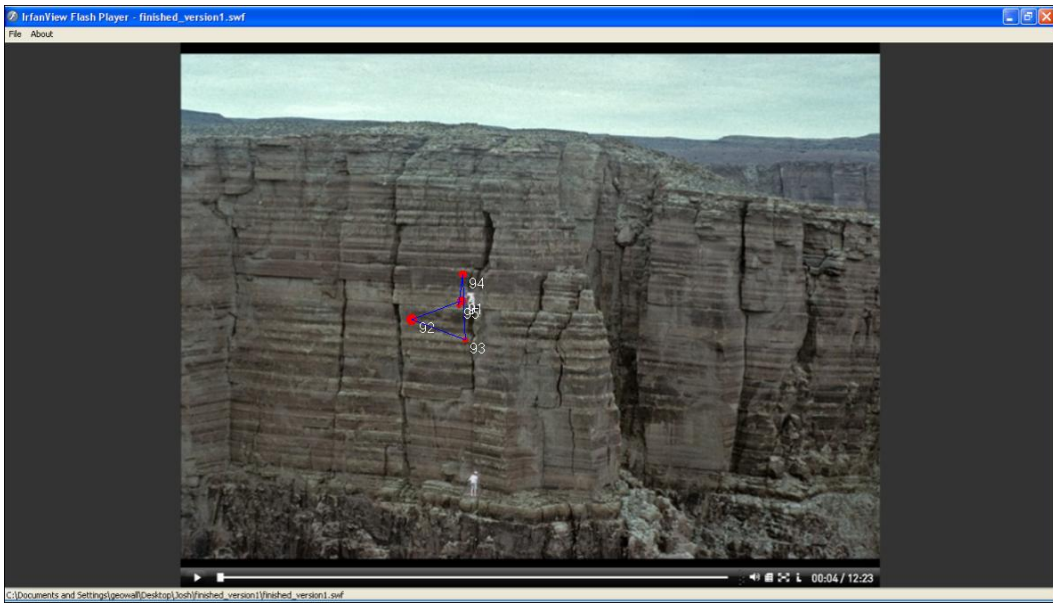


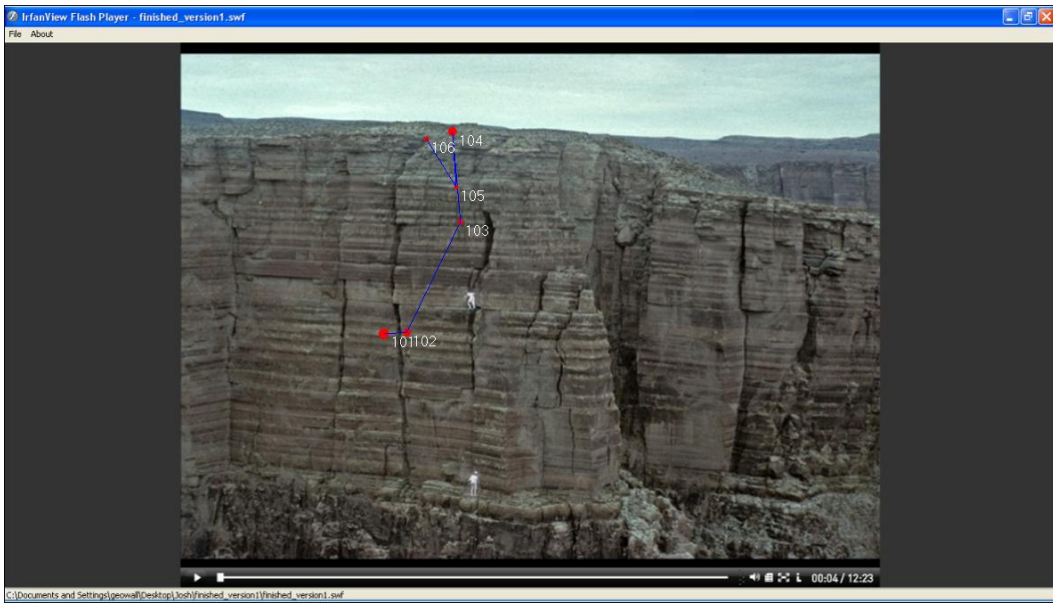




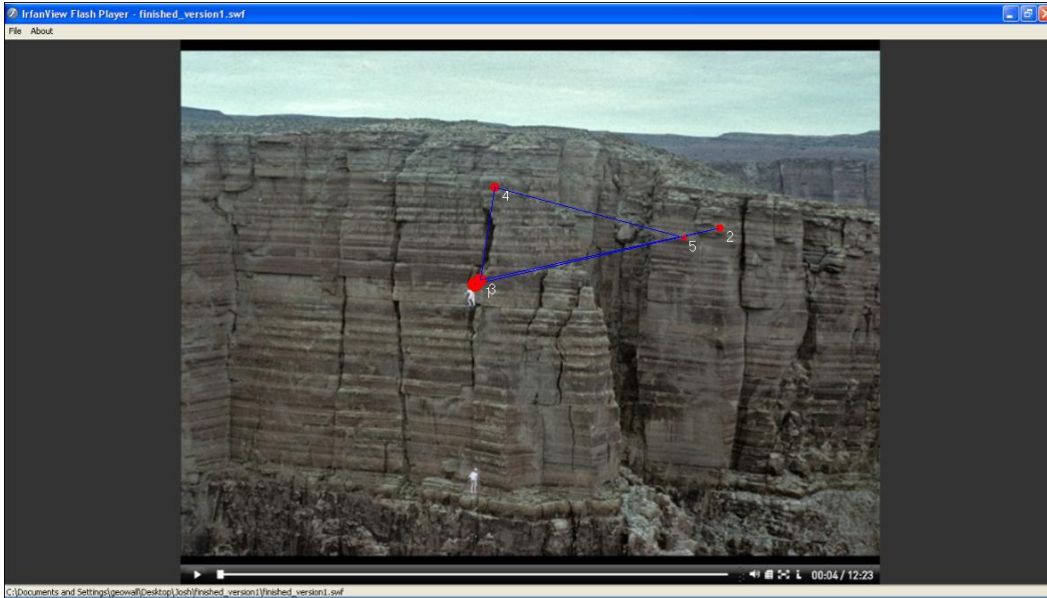


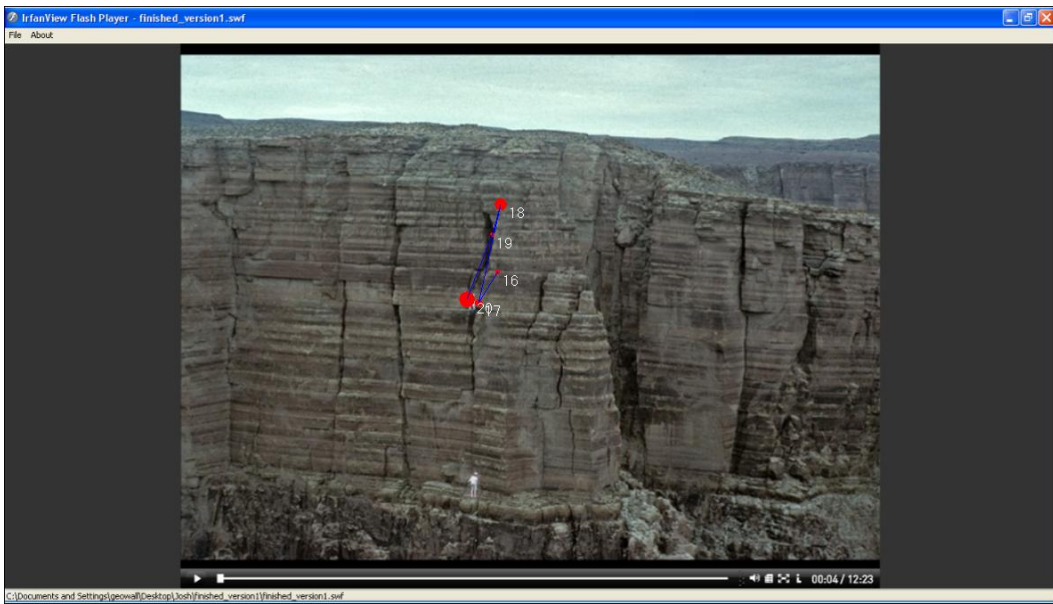
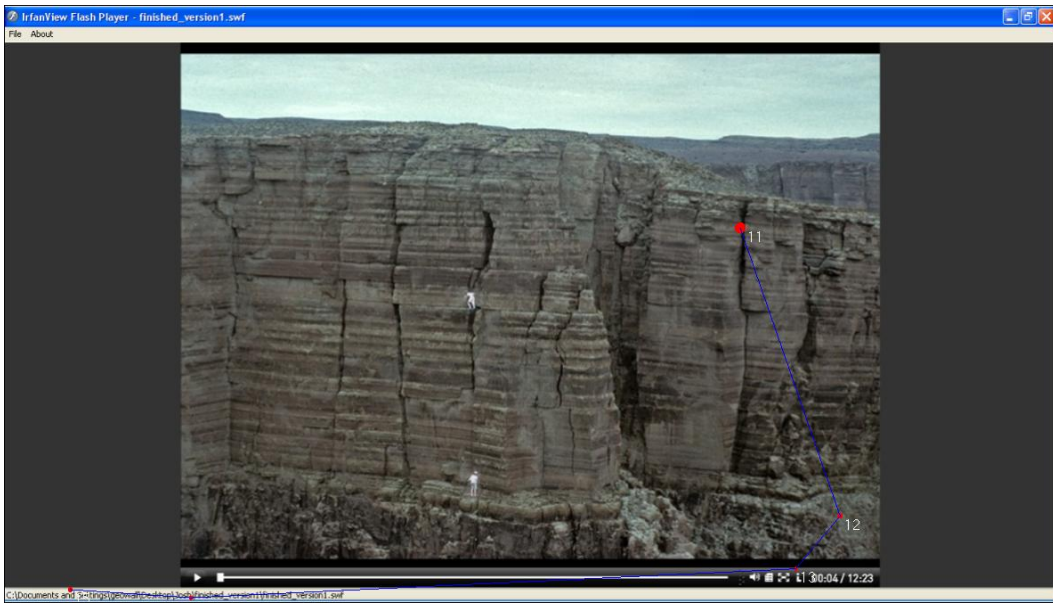


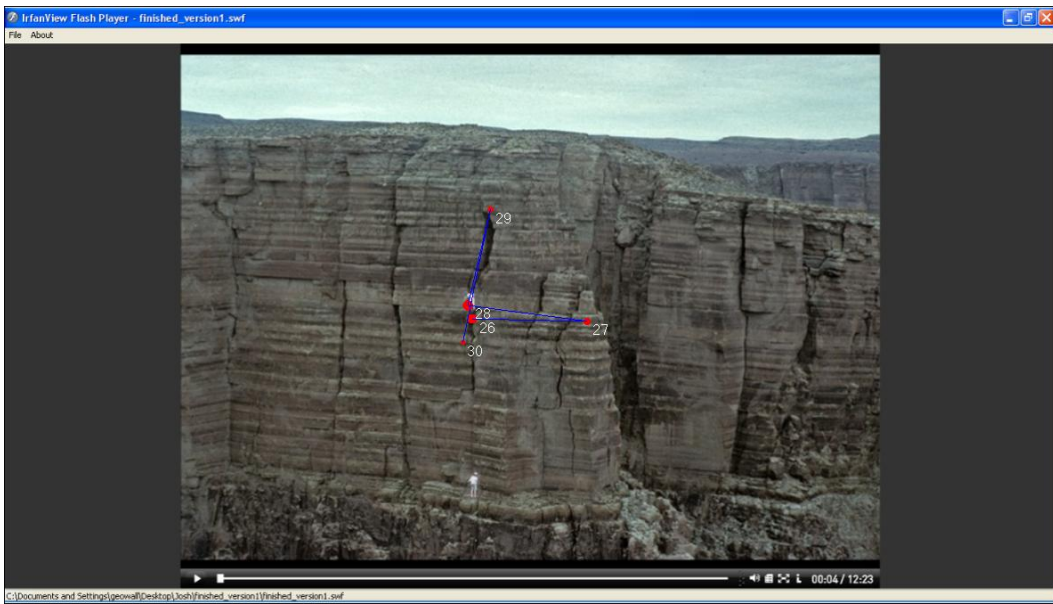
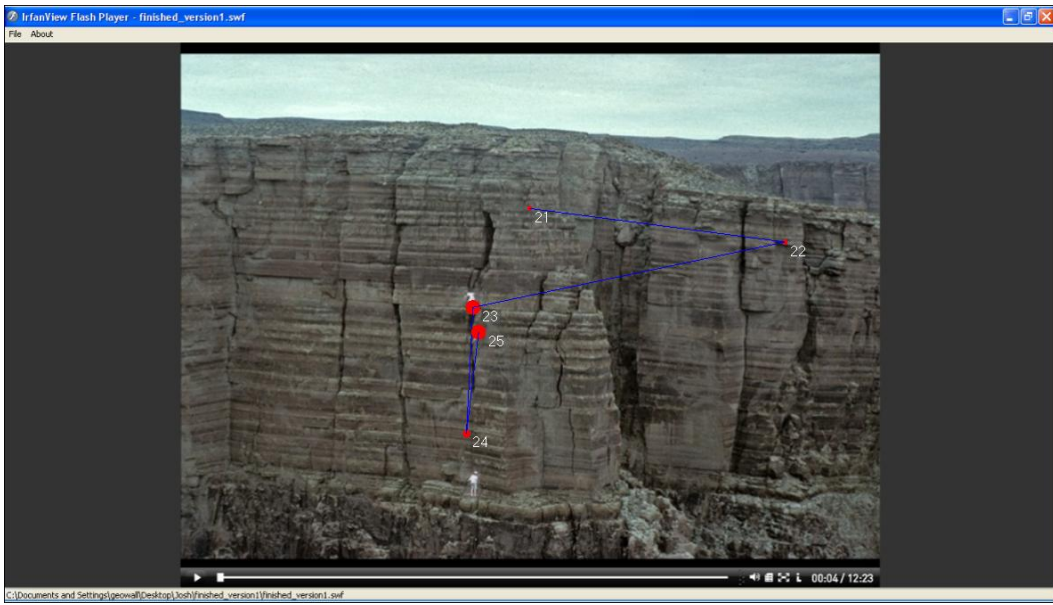




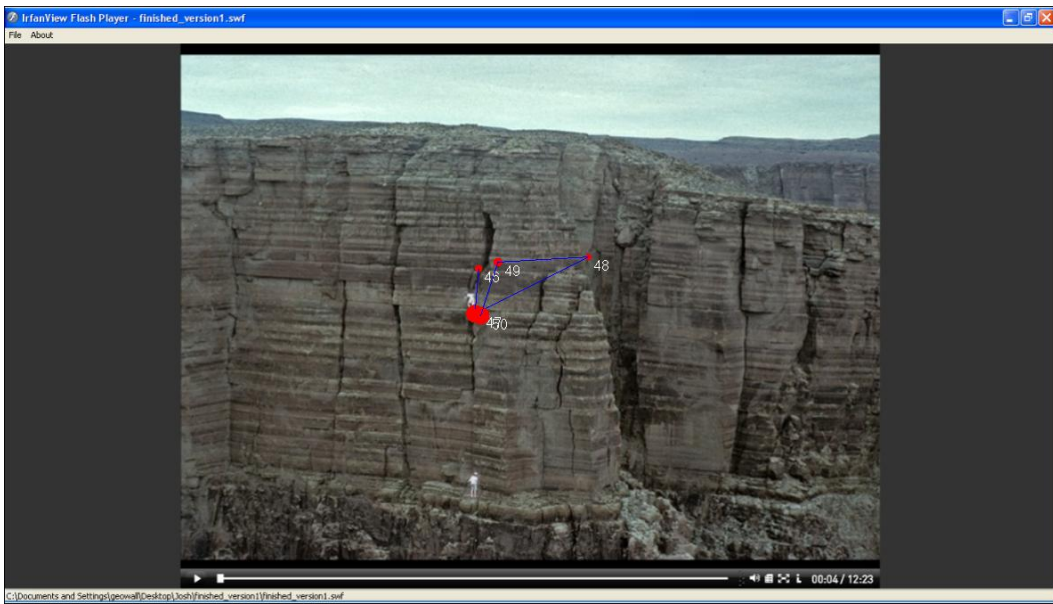
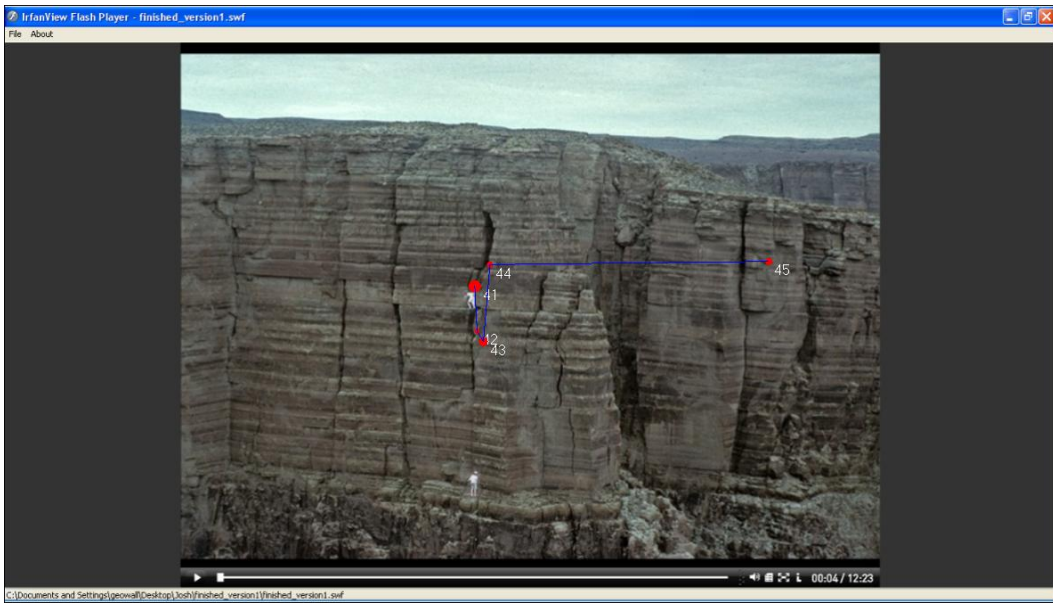
Fixation sequence diagrams for image 1 for an individual who has high distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.

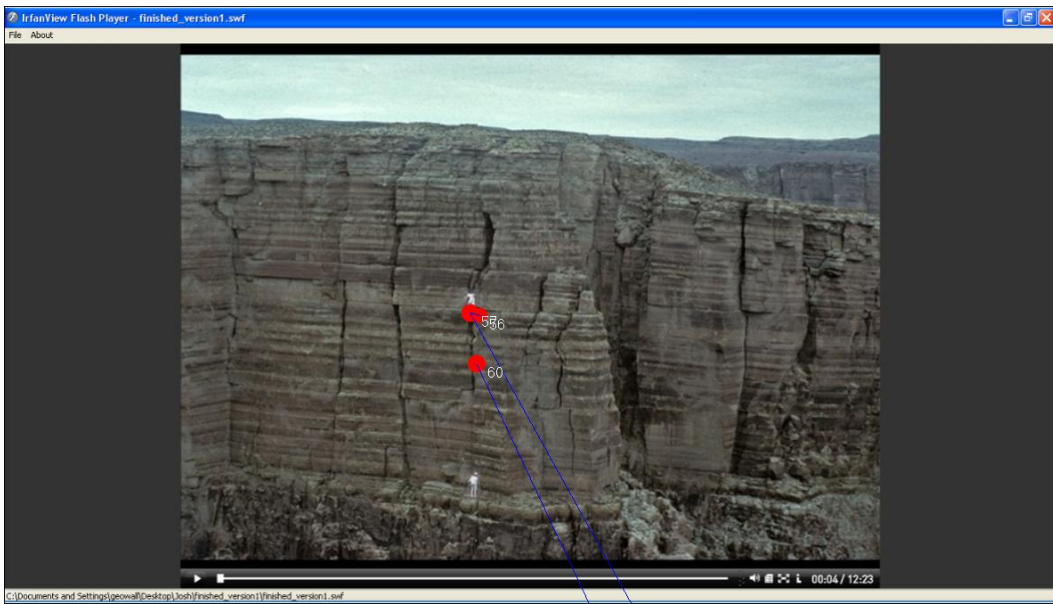
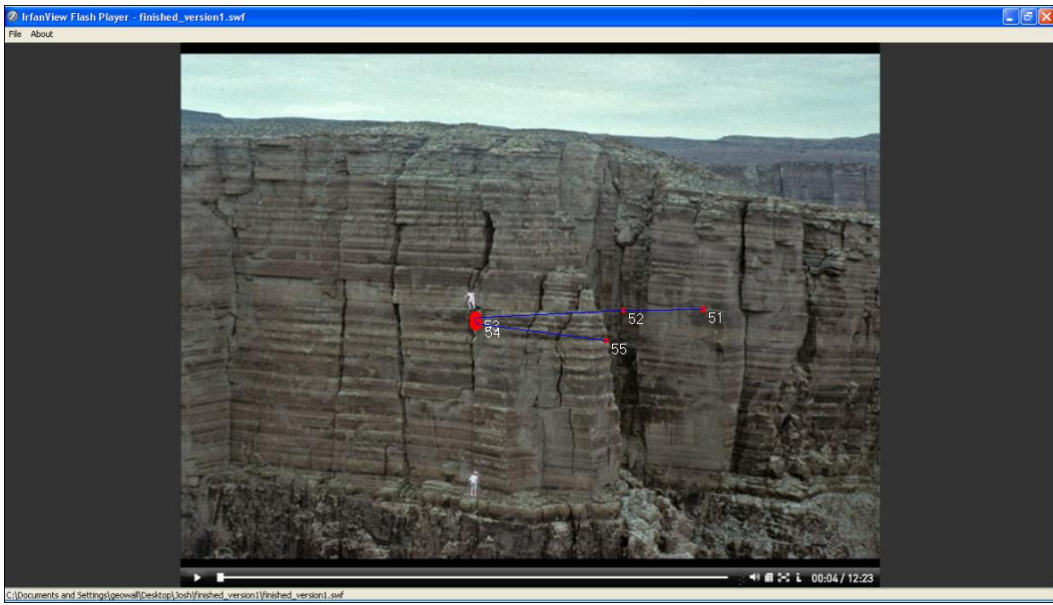


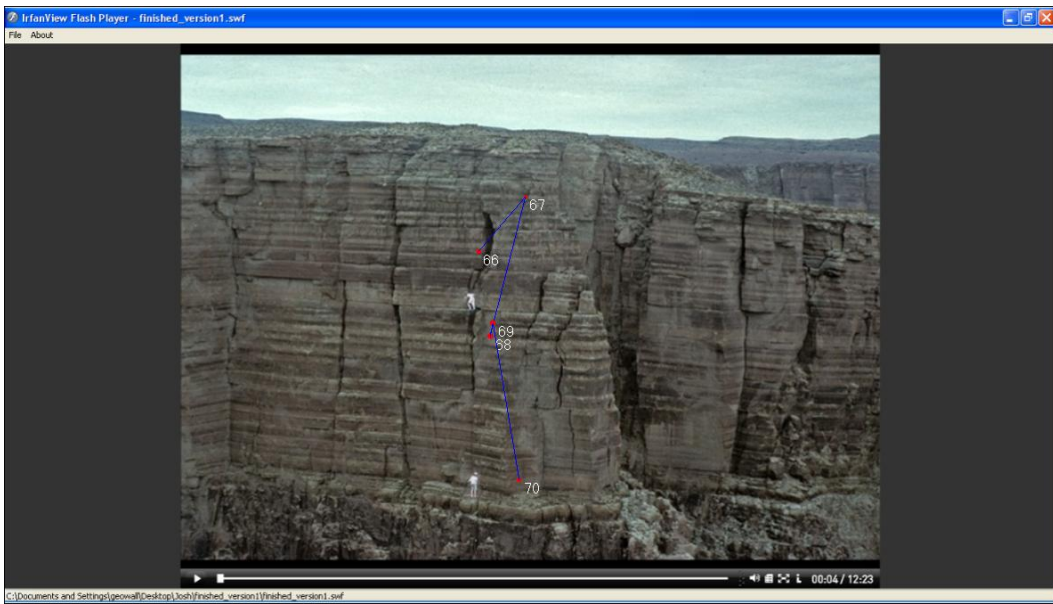
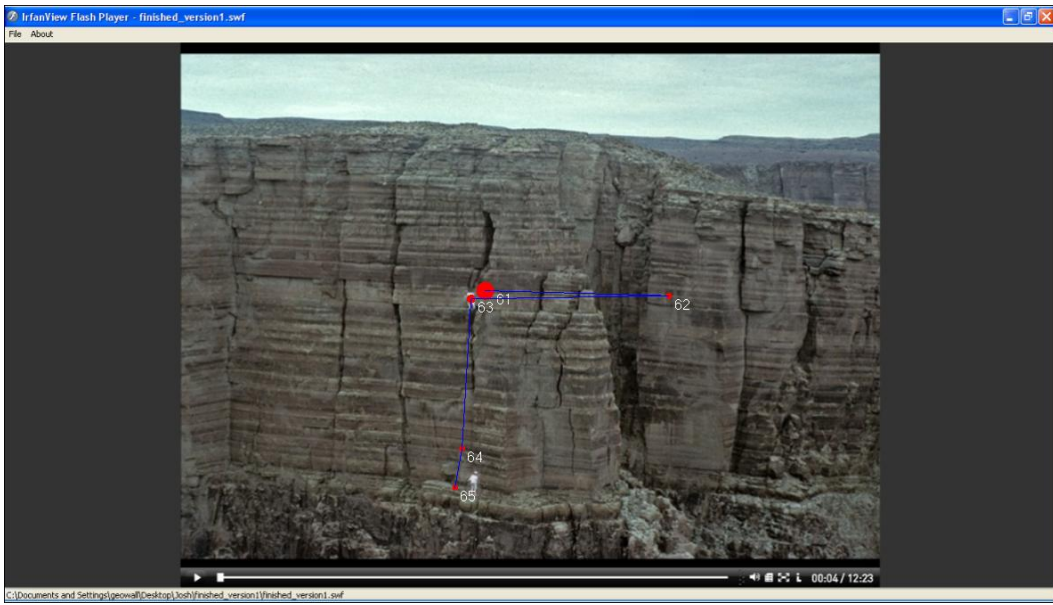


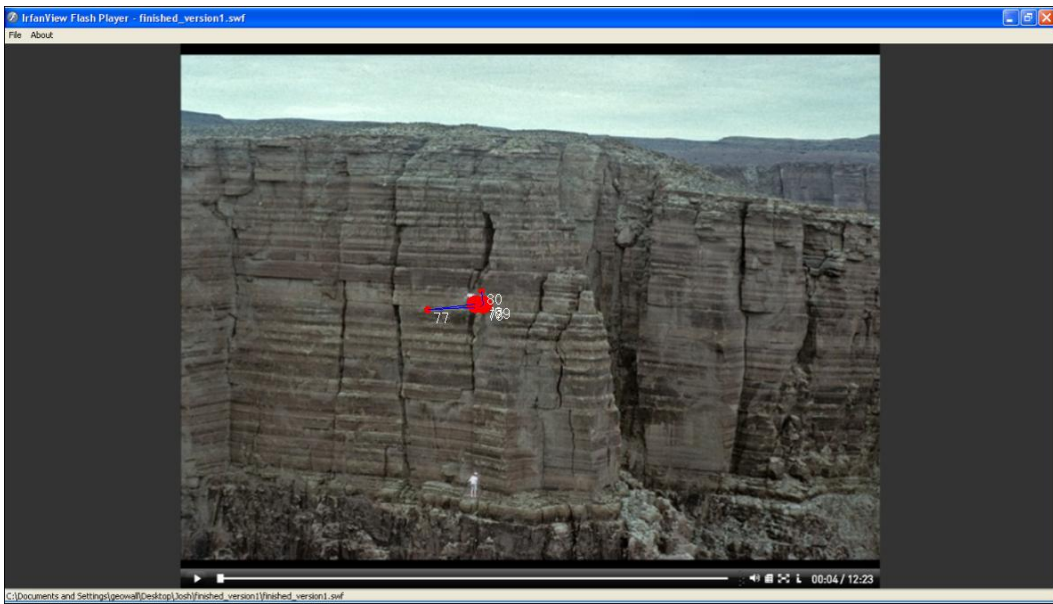
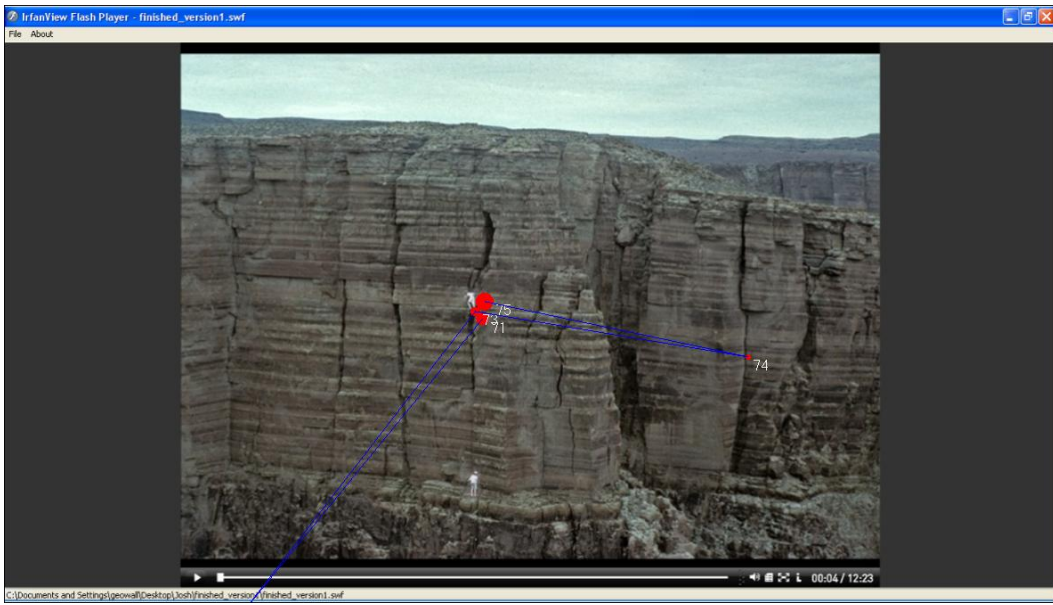


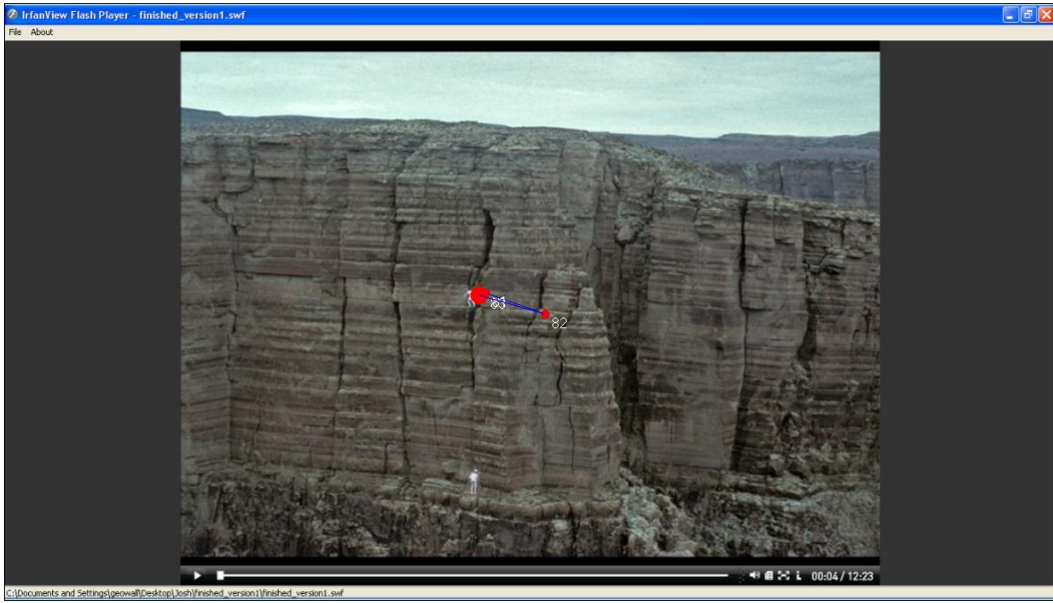




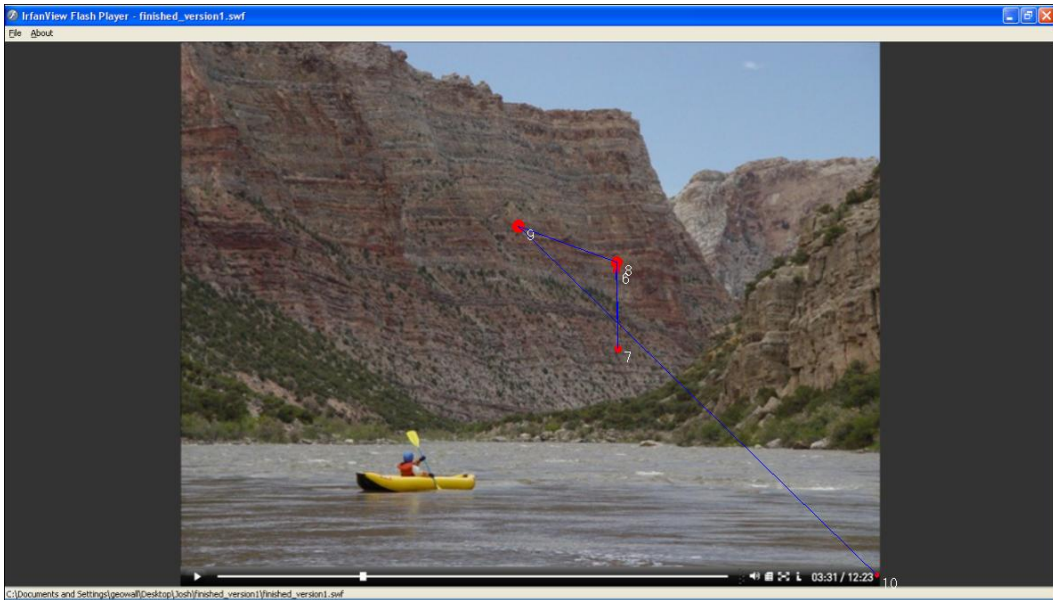
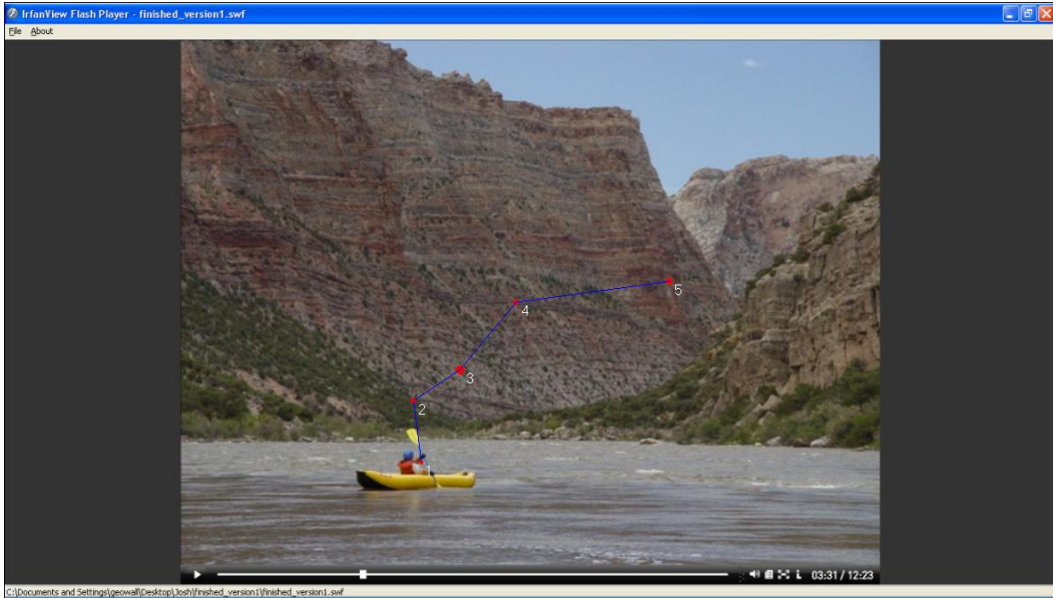


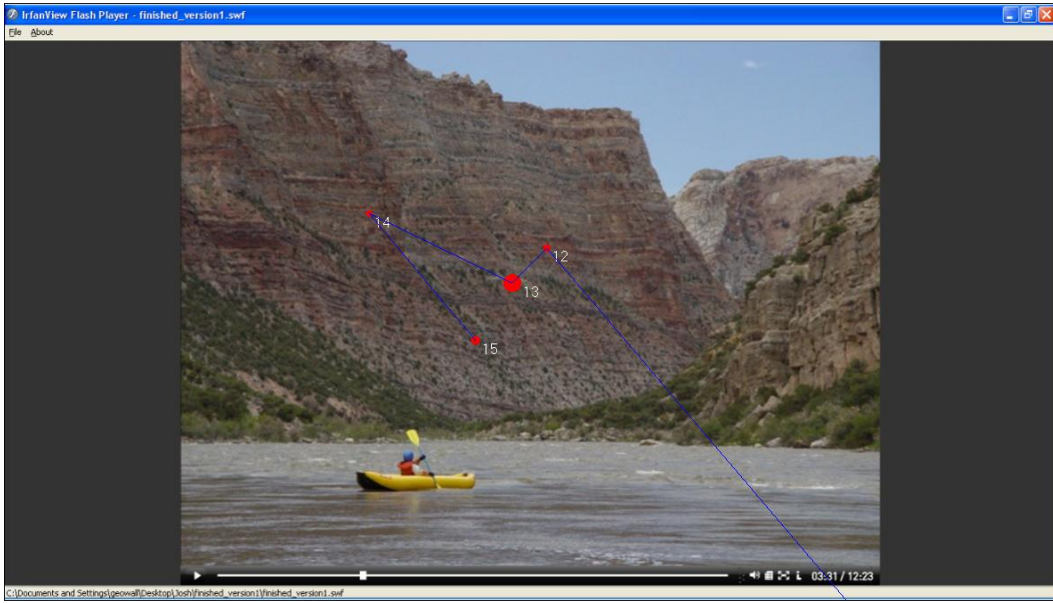


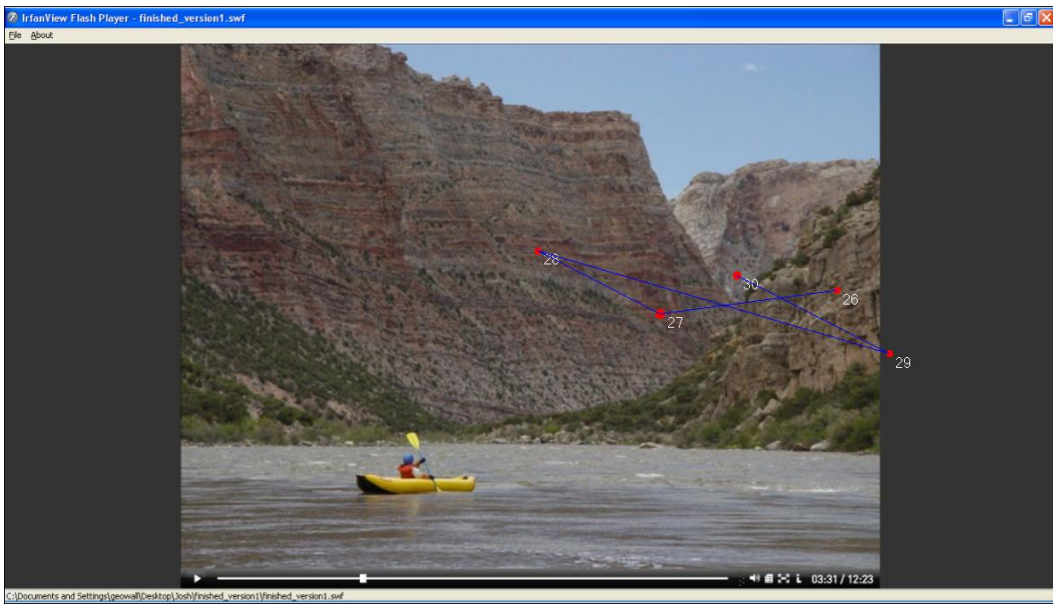
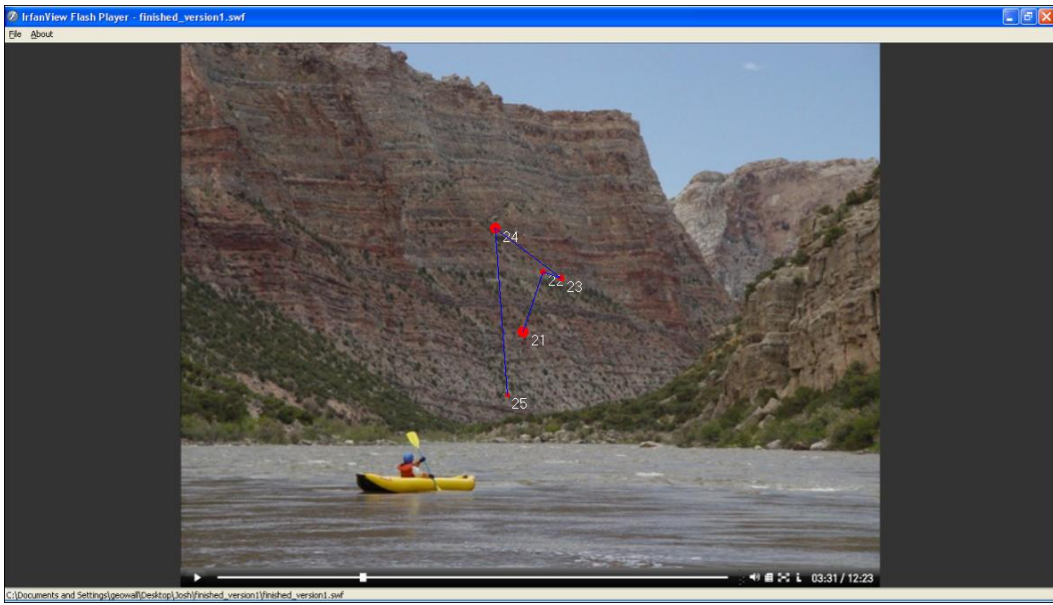


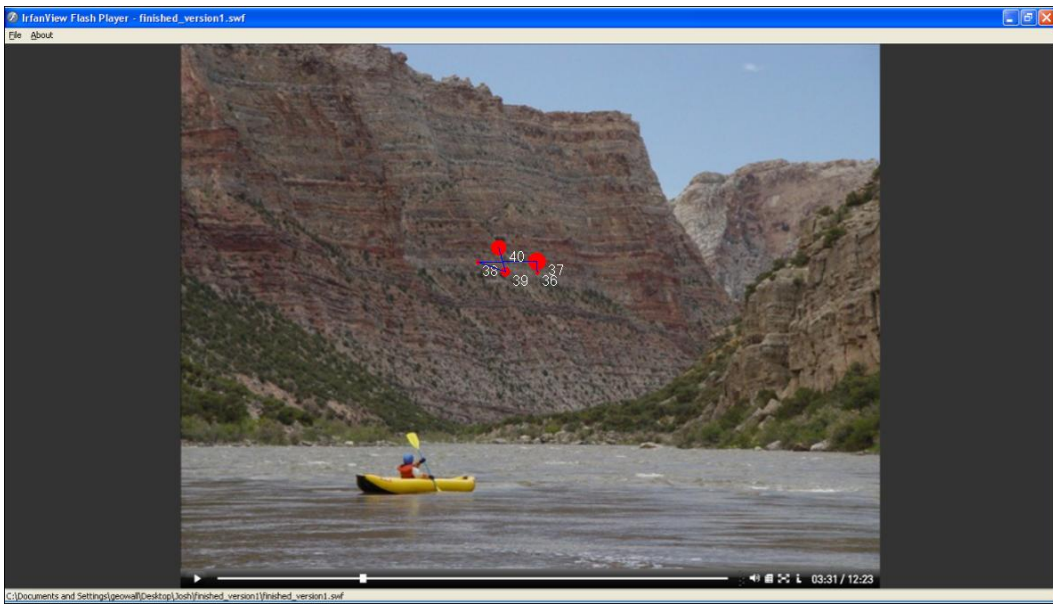
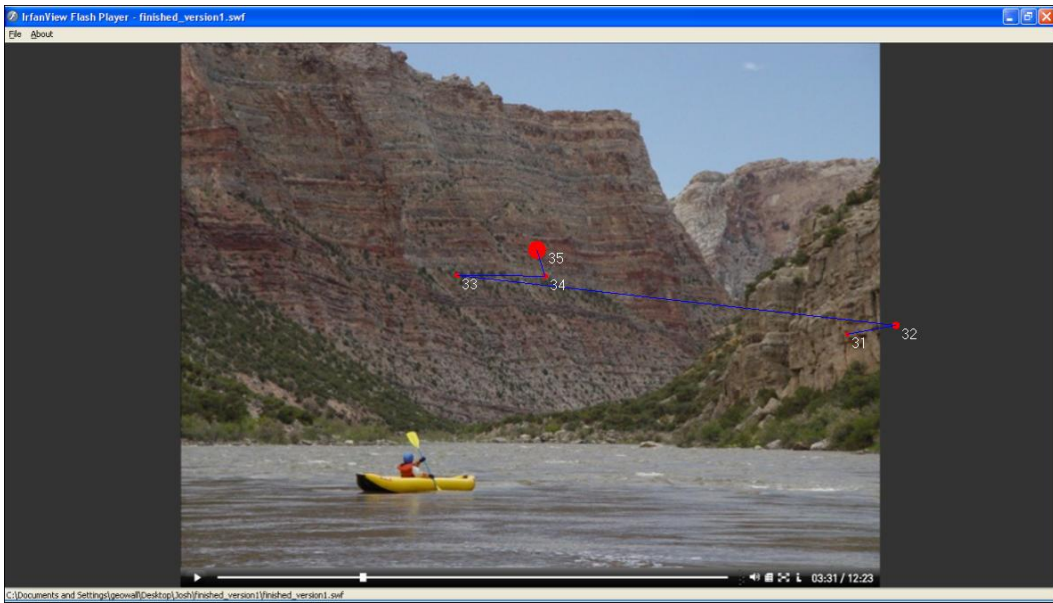


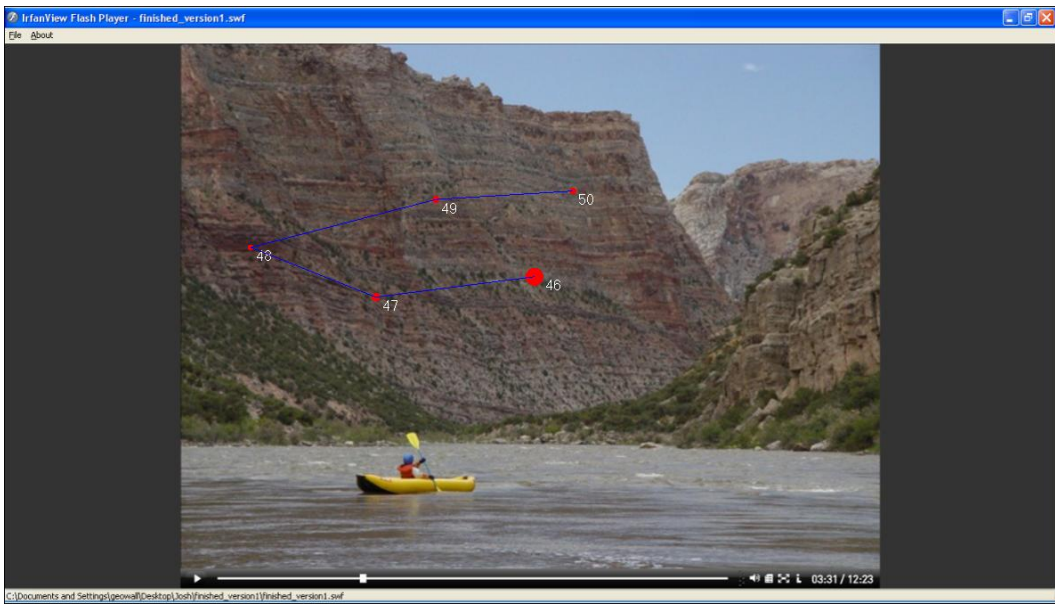
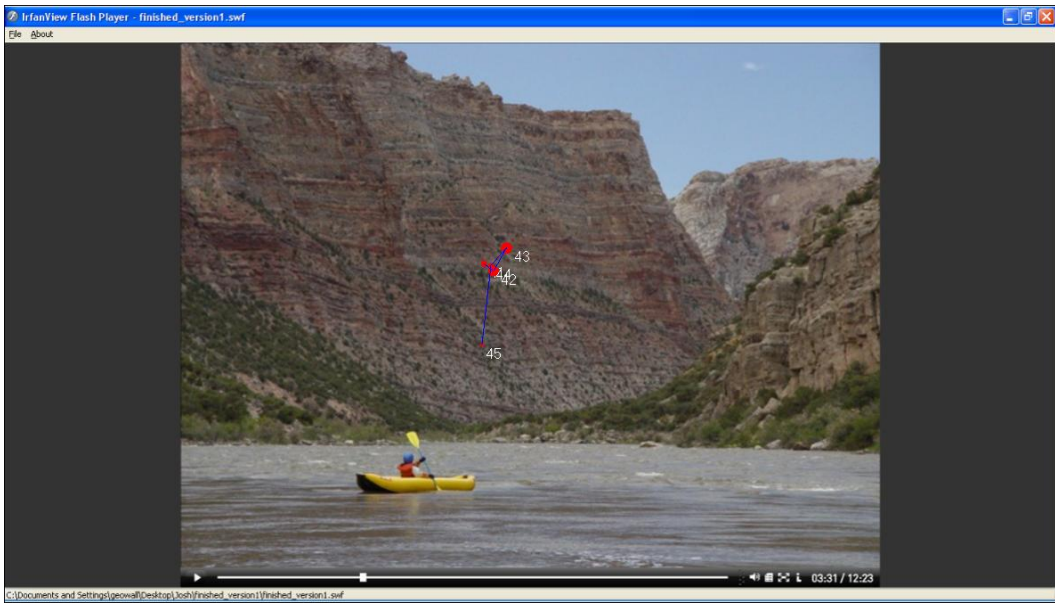
Fixation sequence diagrams for image 5 for an individual who has low distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.

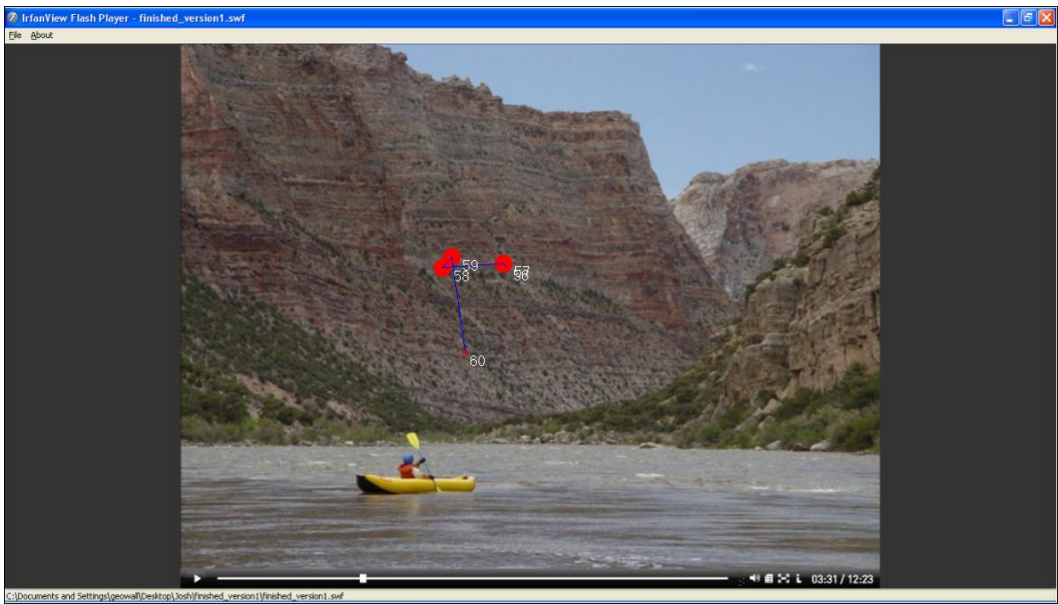
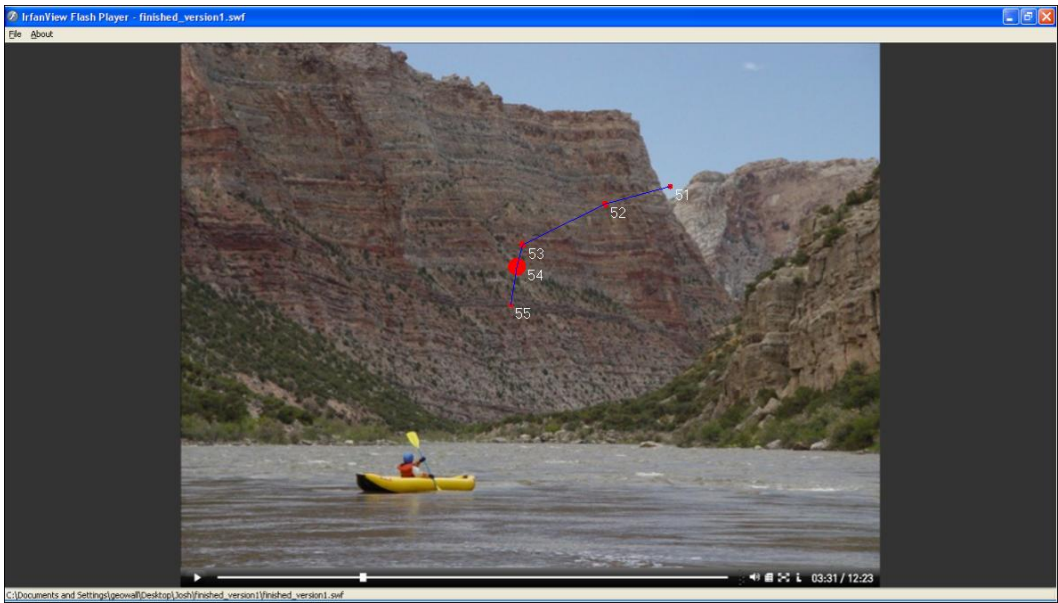


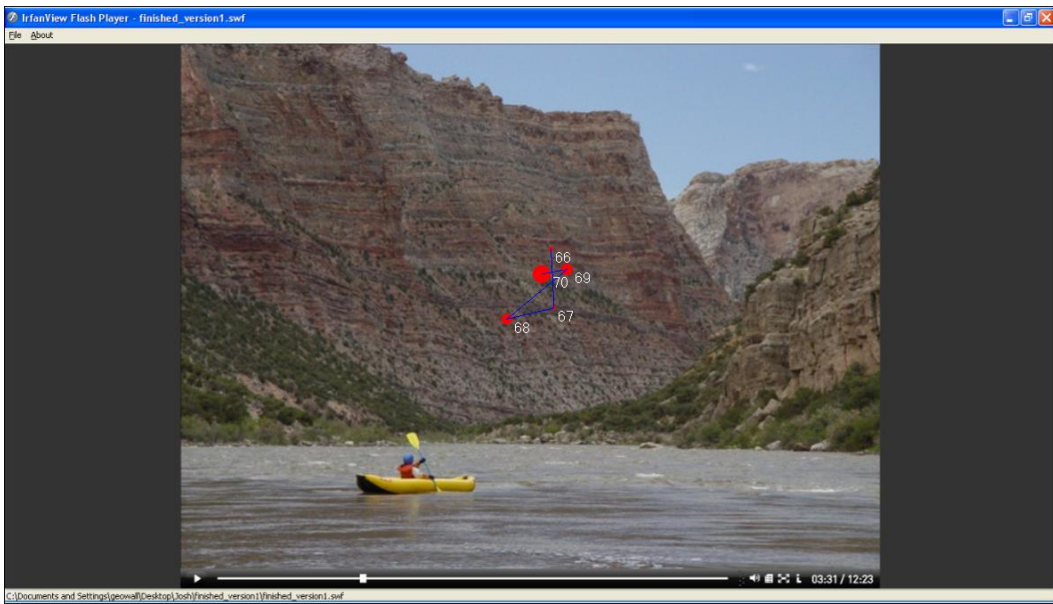




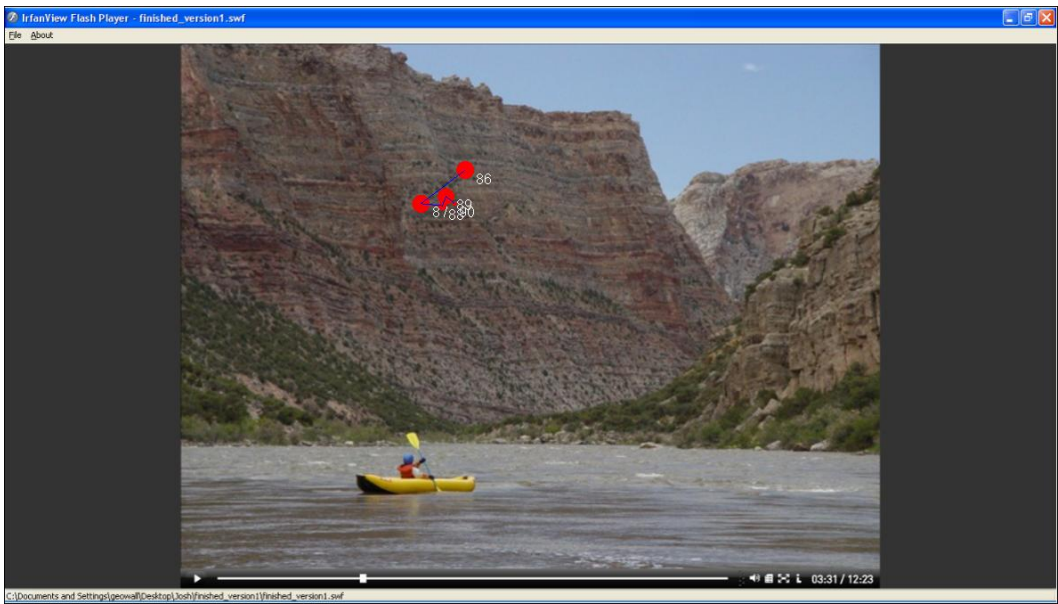
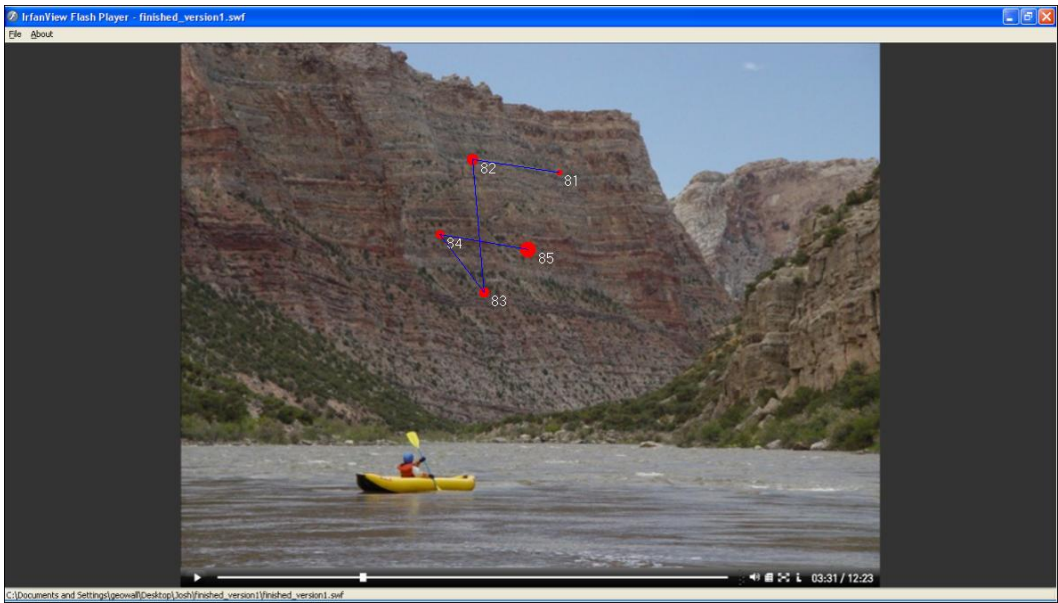


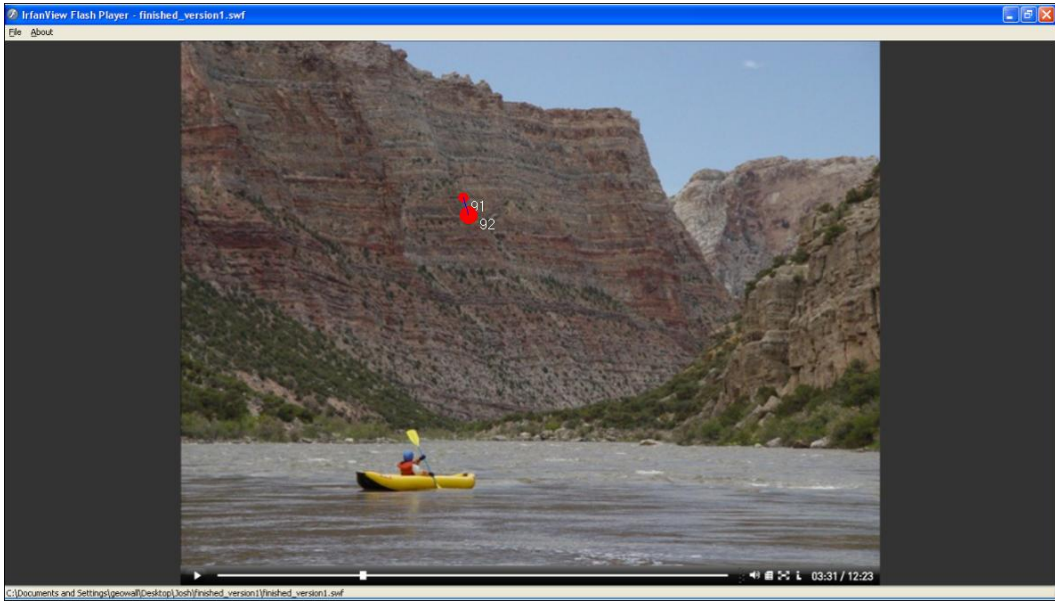






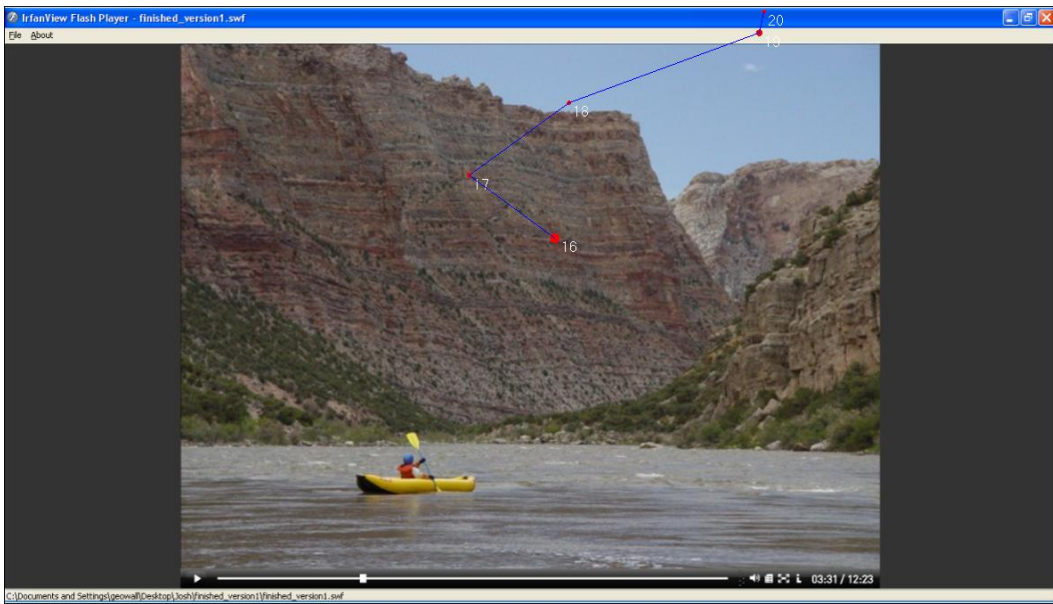
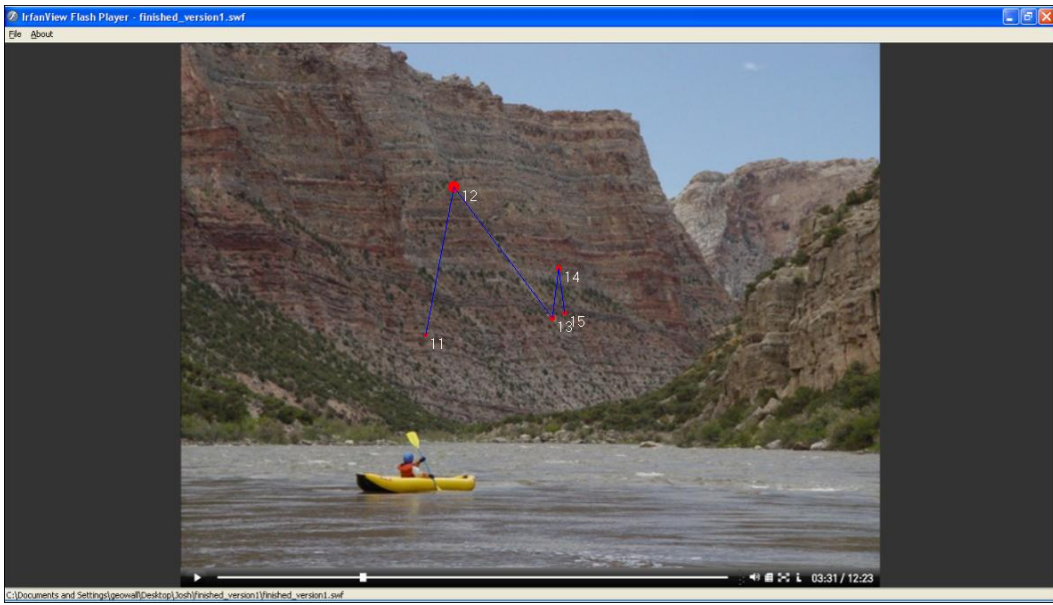


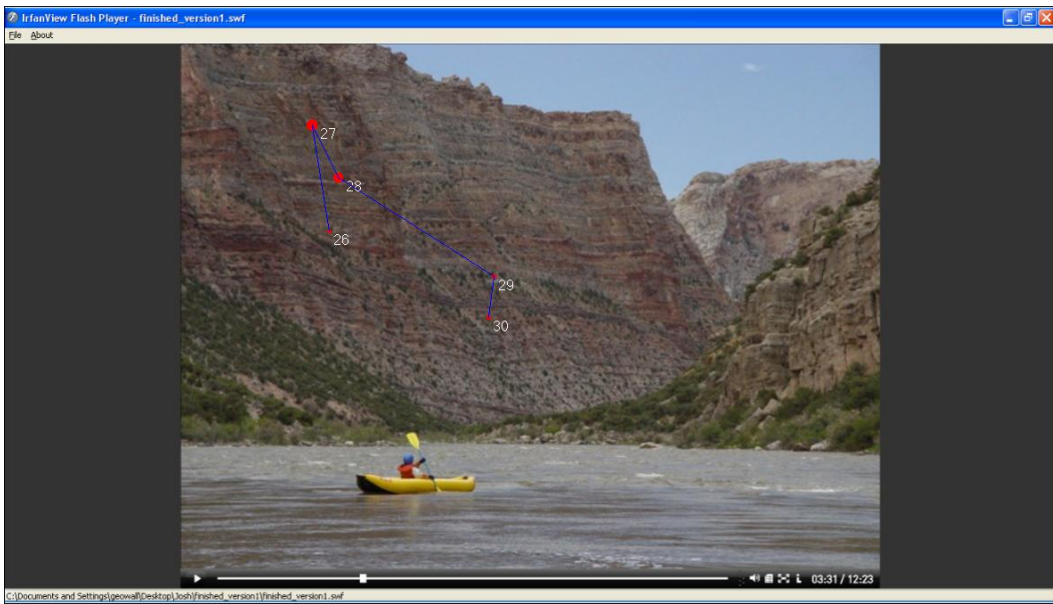


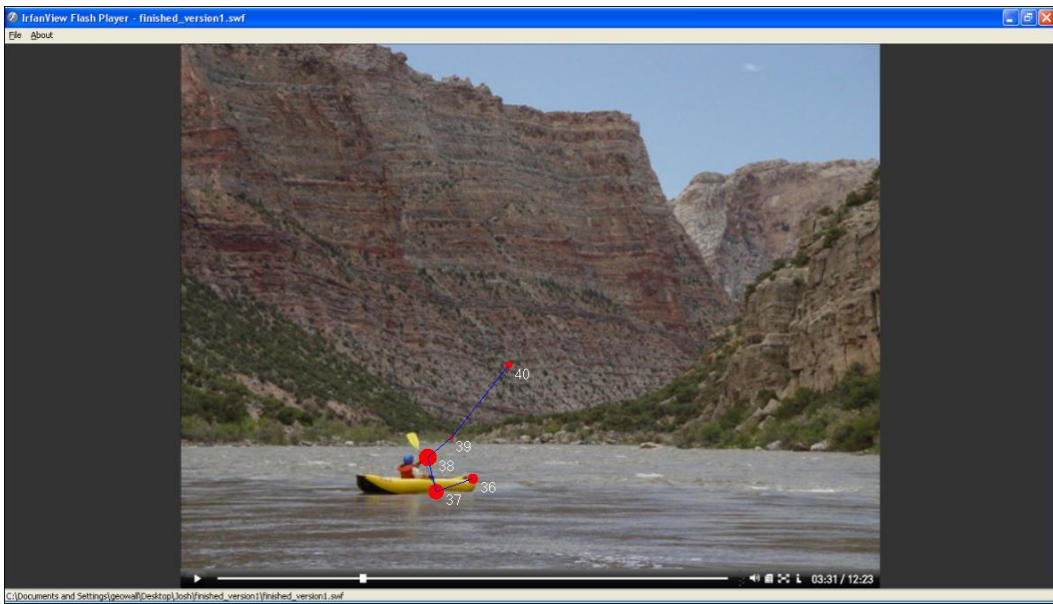
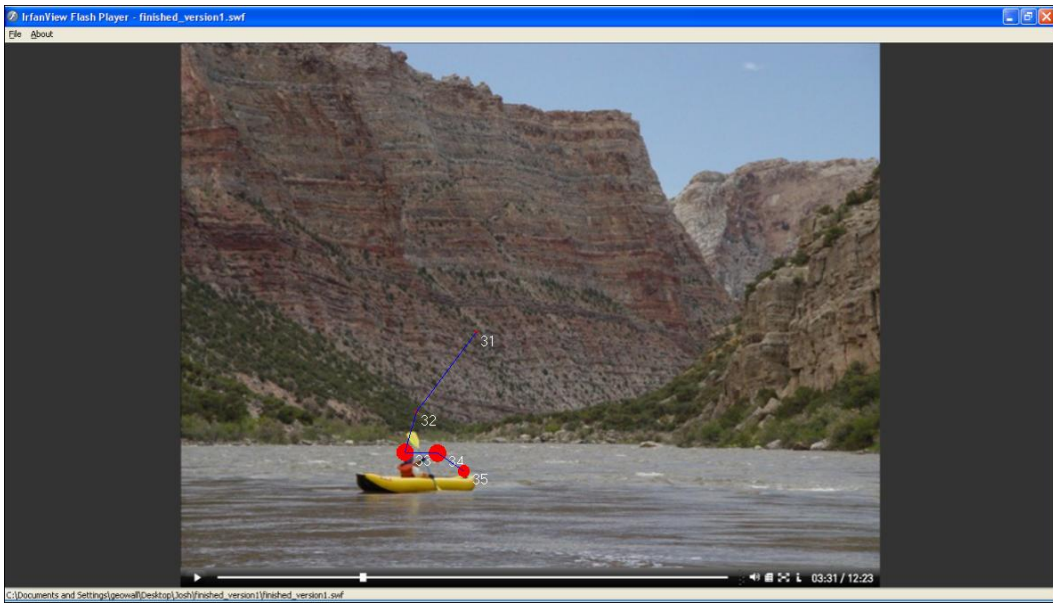


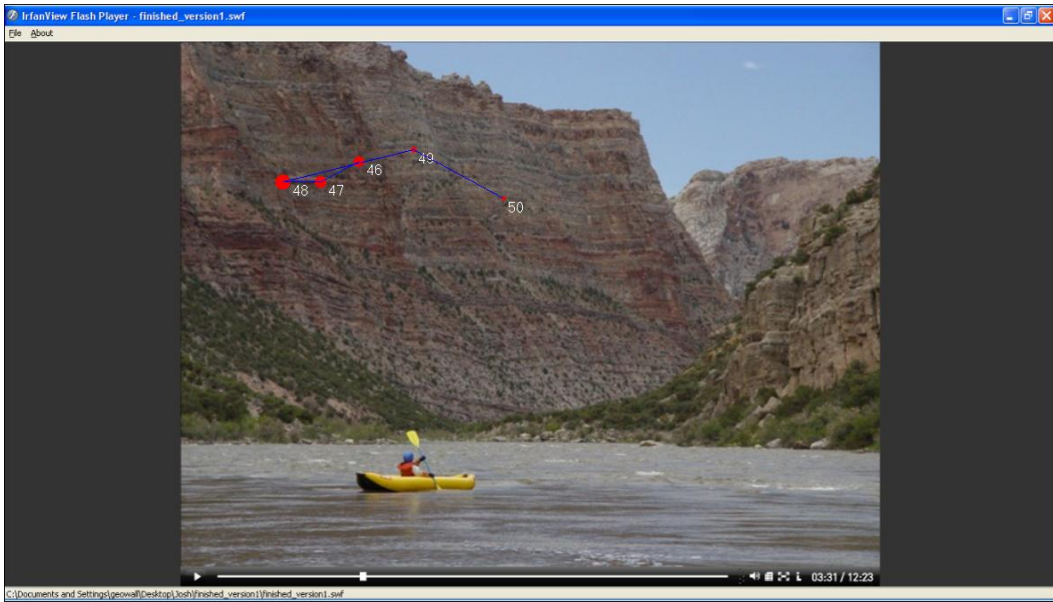
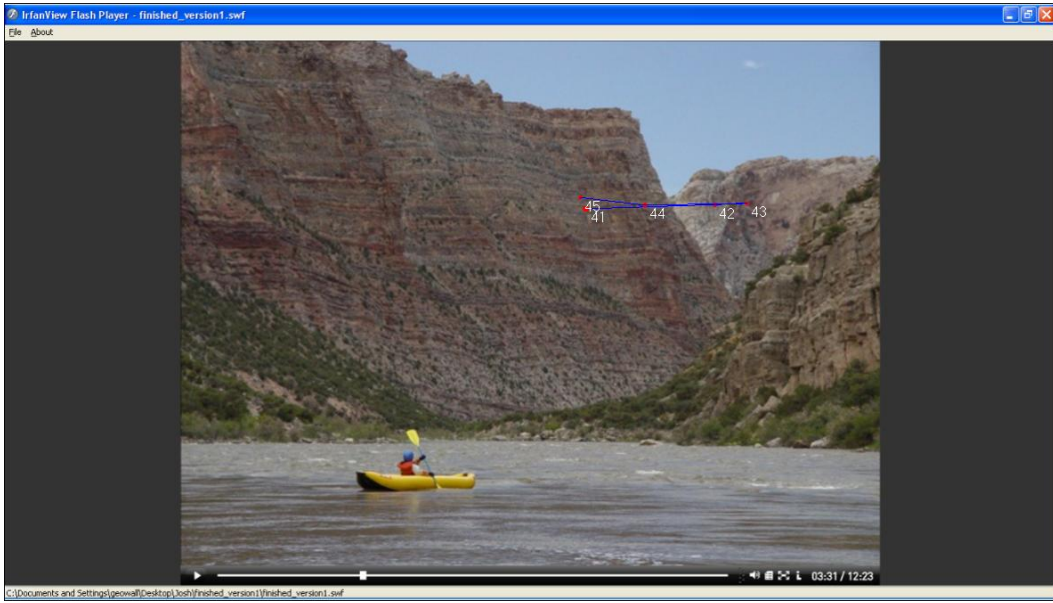
Fixation sequence diagrams for image 5 for an individual who has average distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.

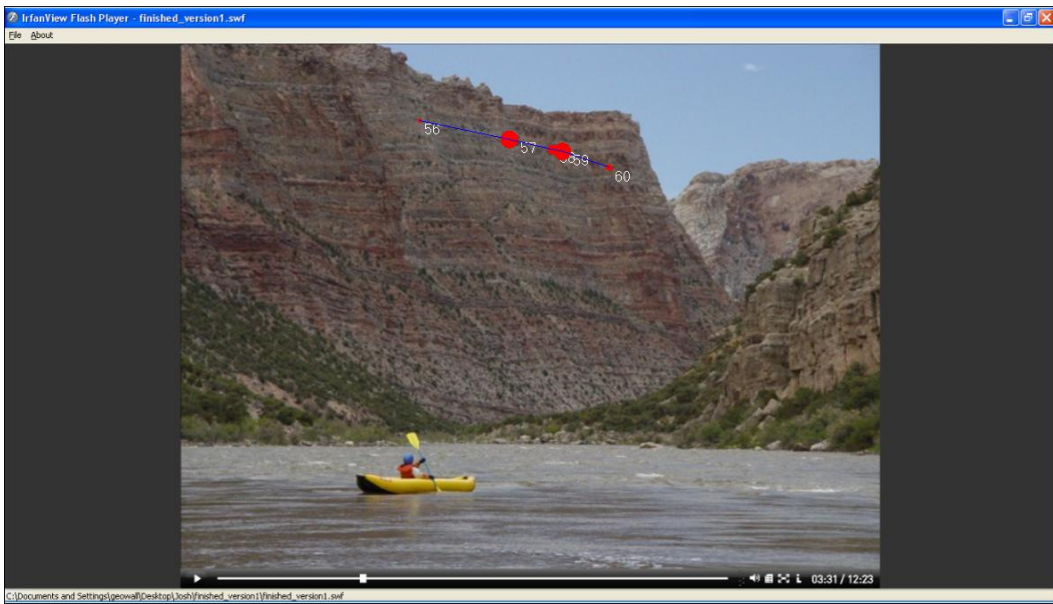
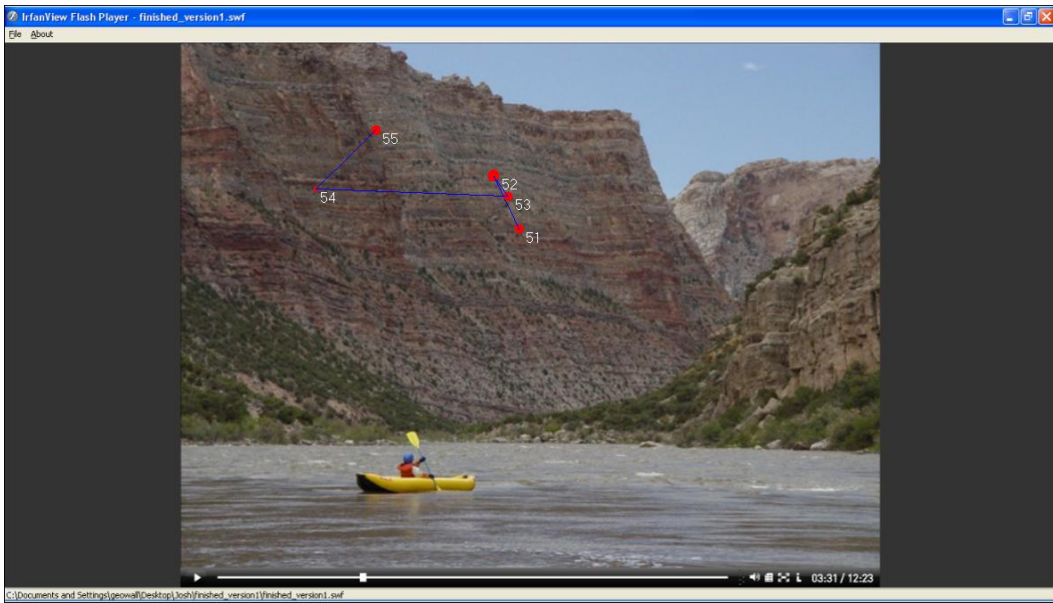


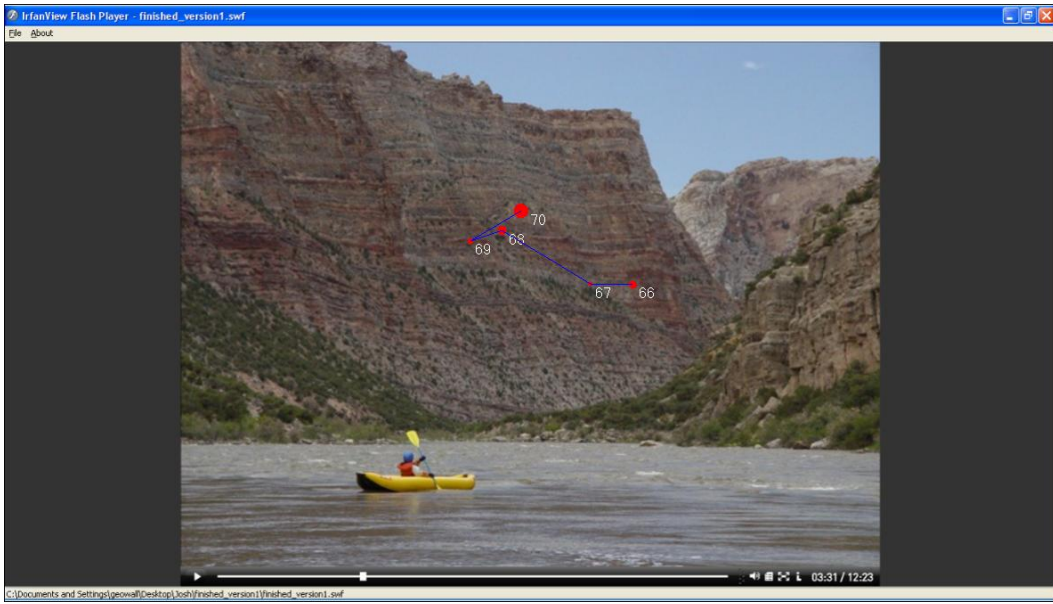
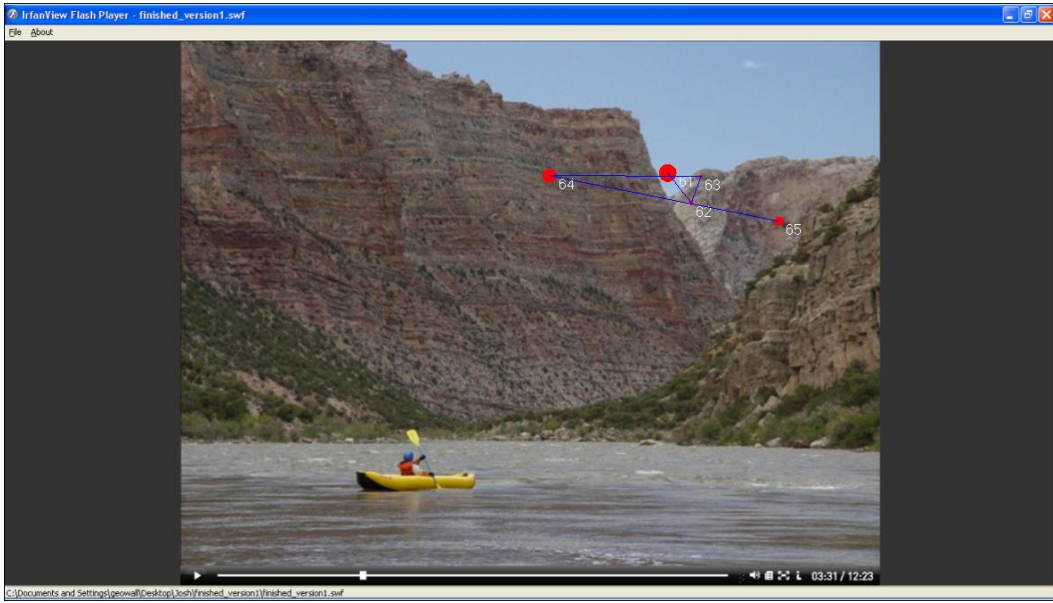


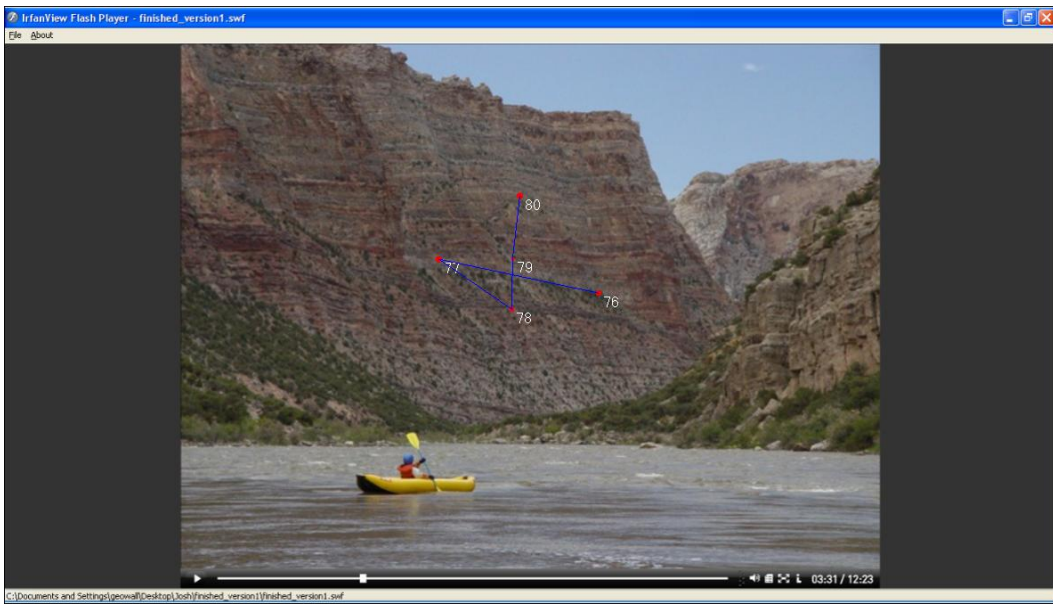
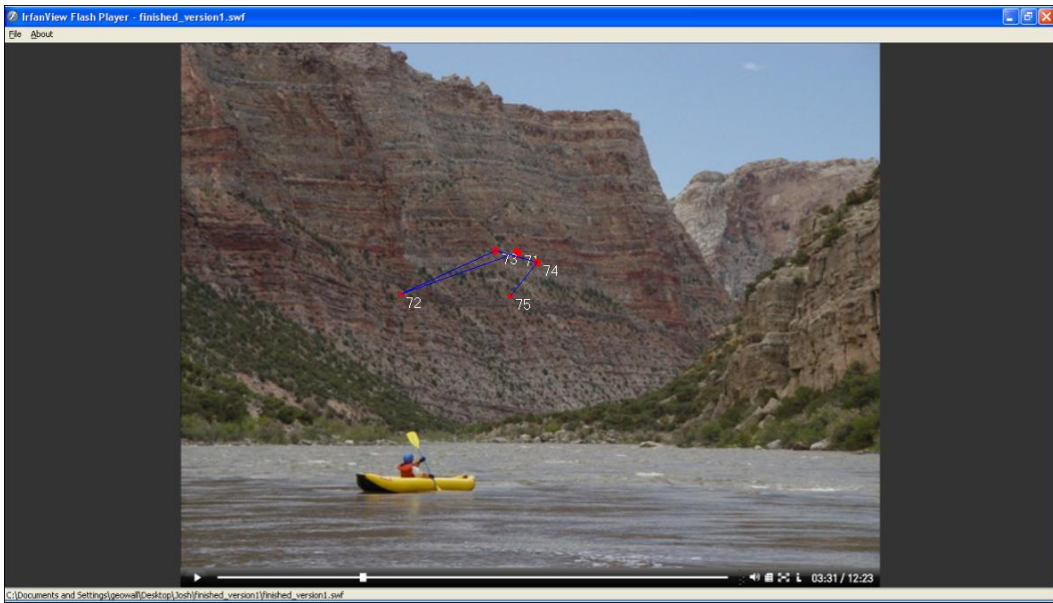


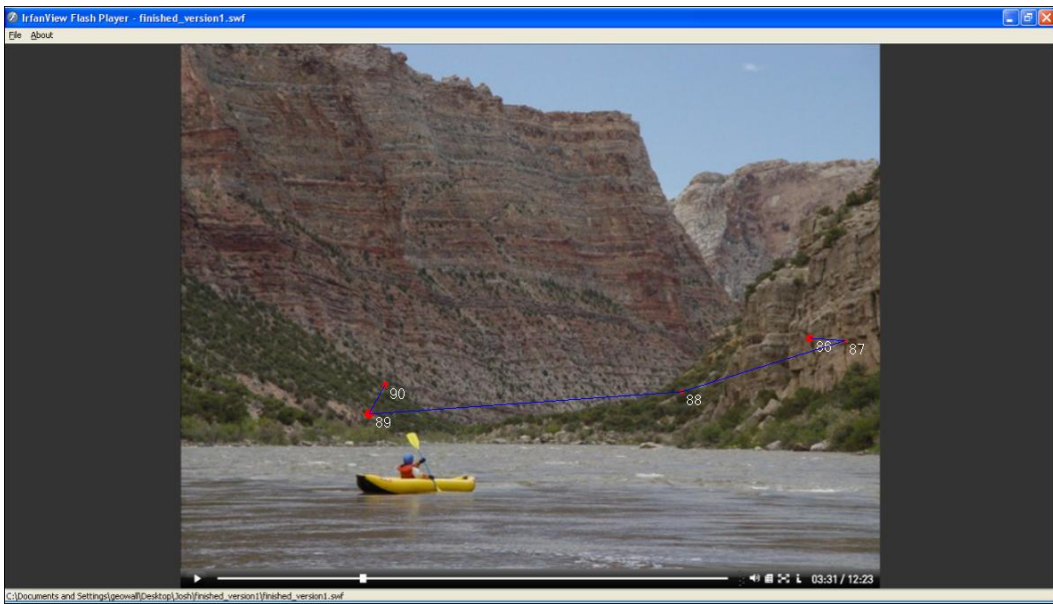
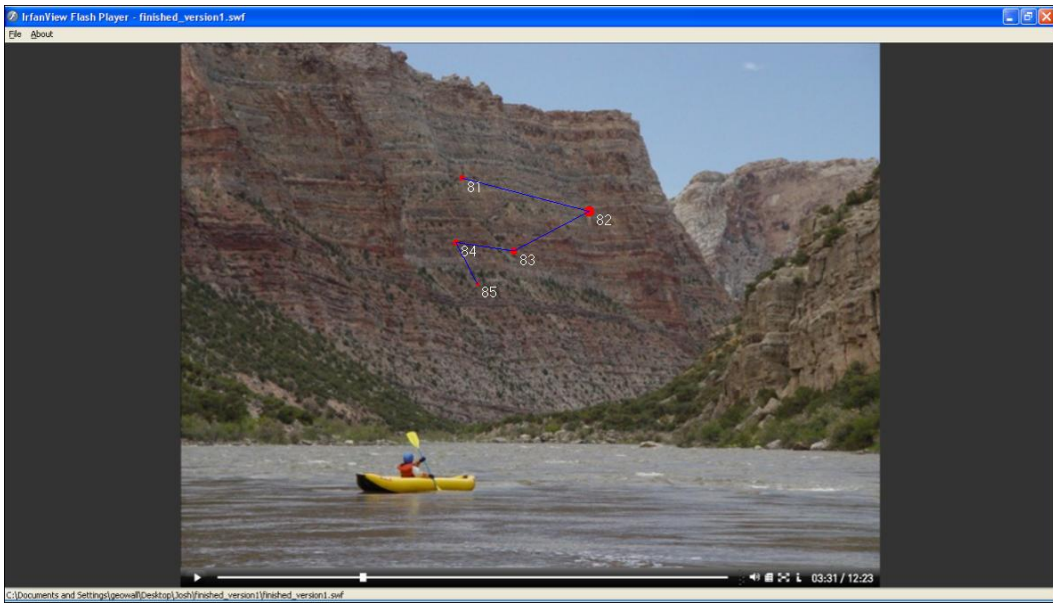


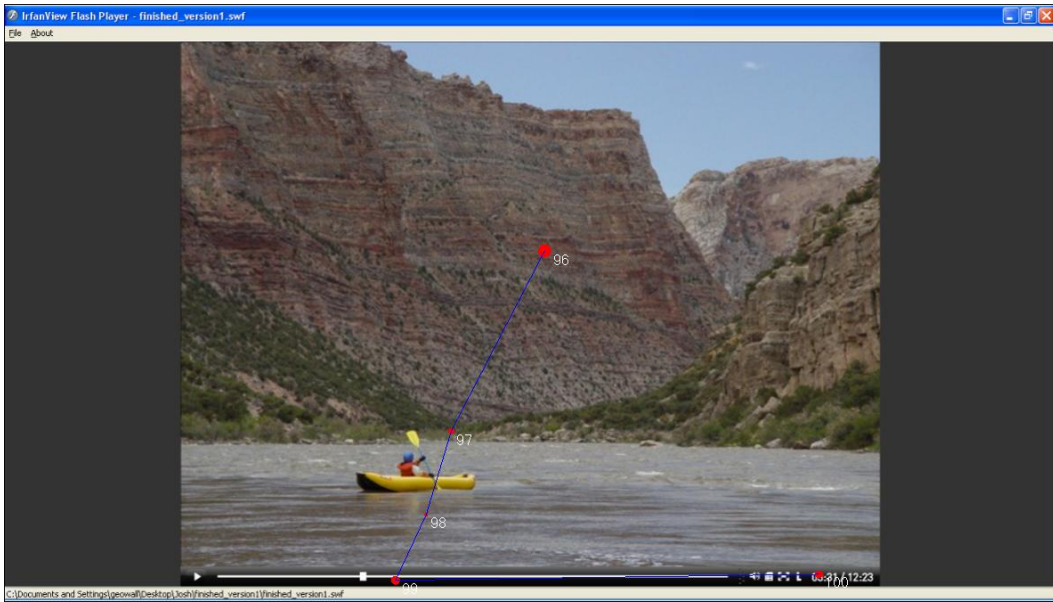
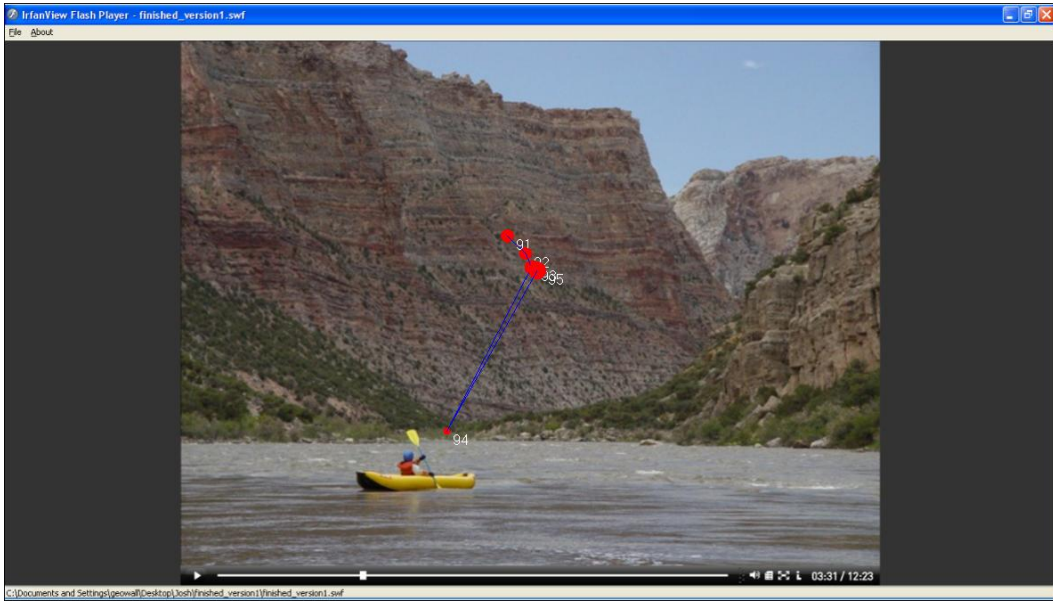


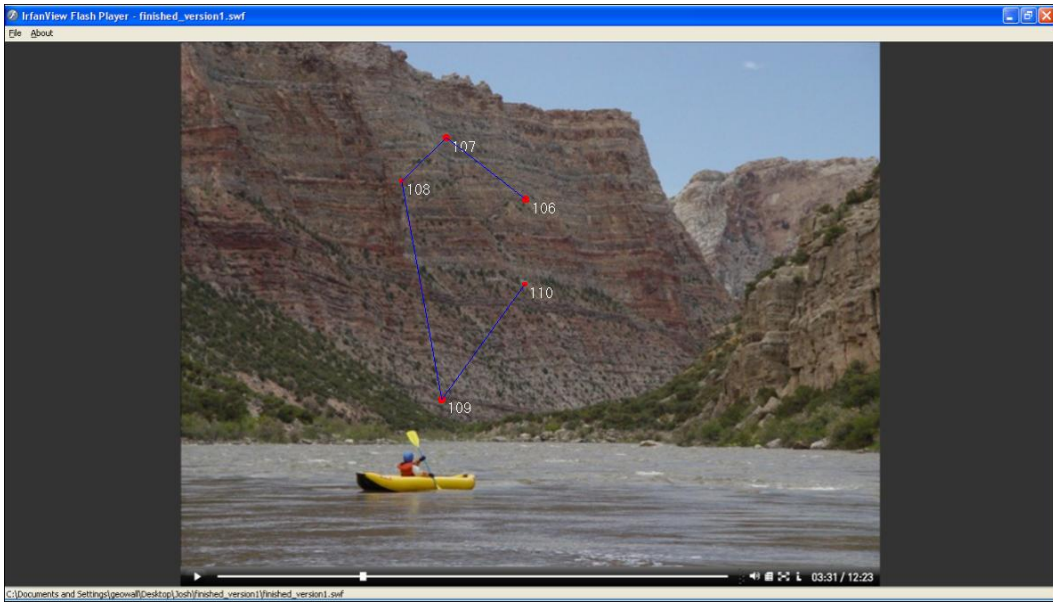
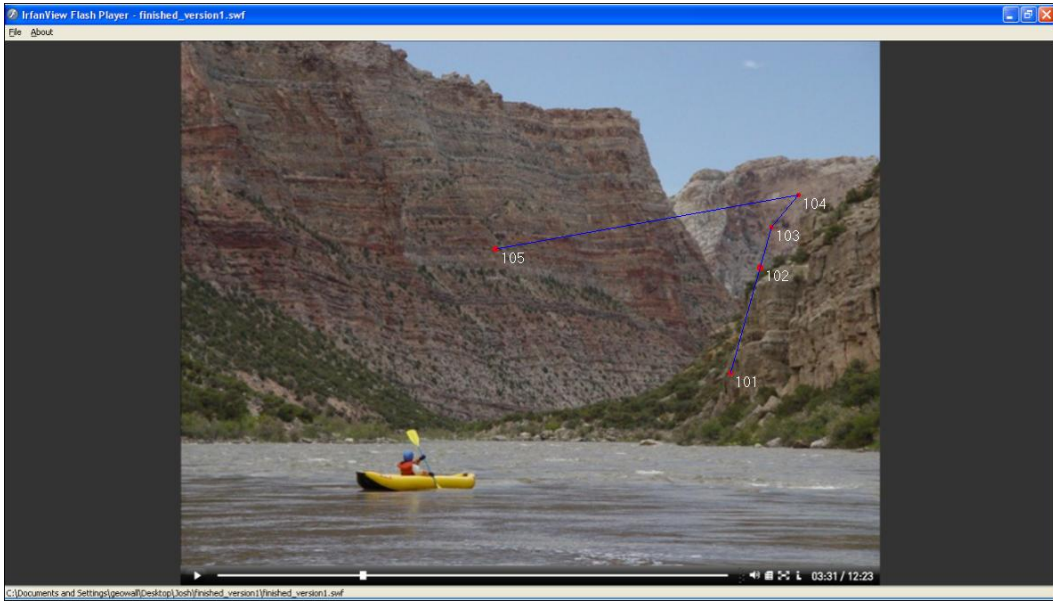


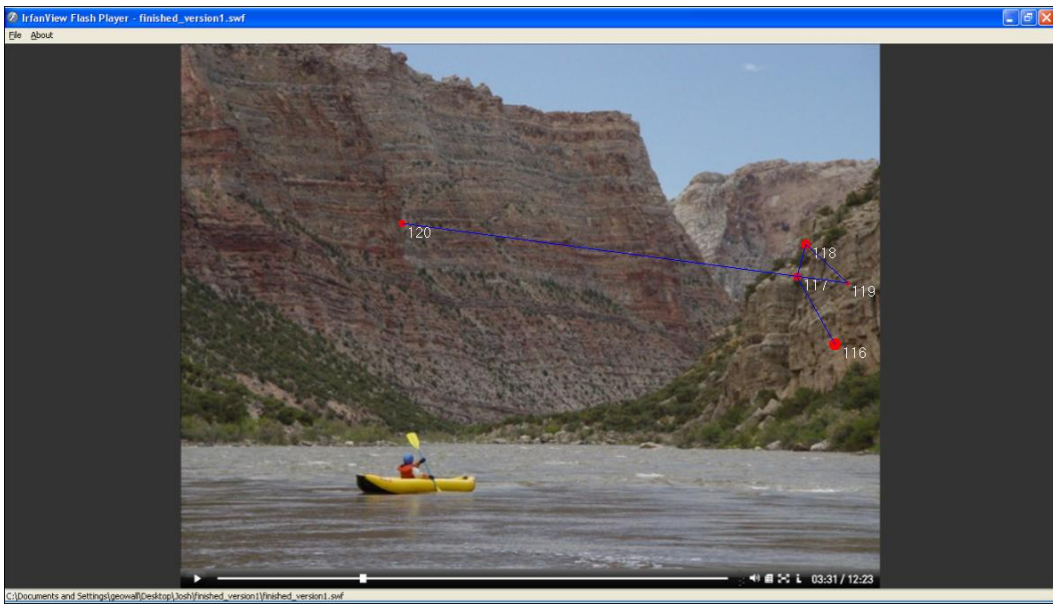


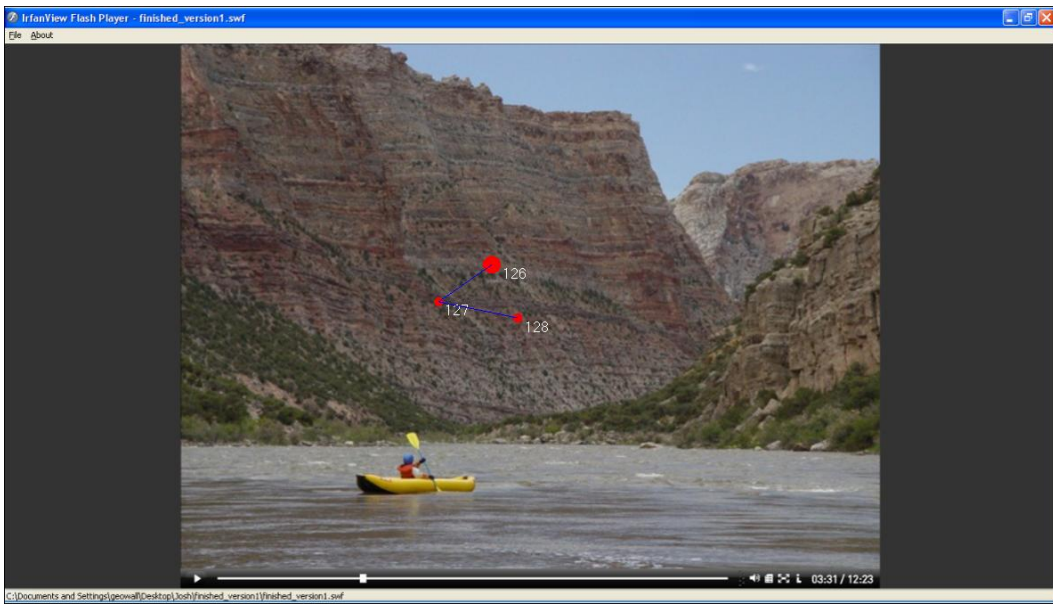
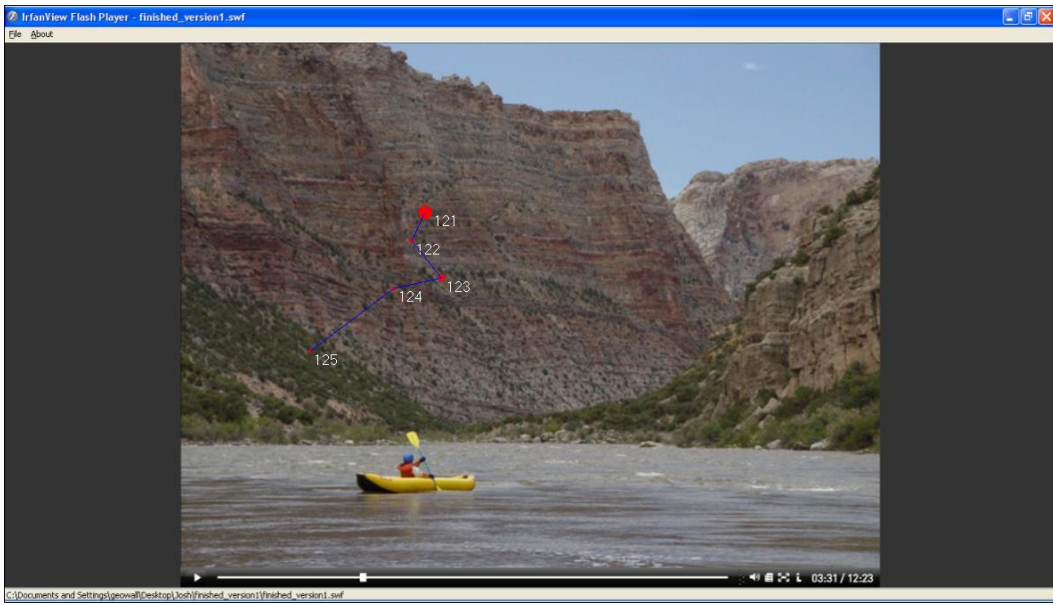




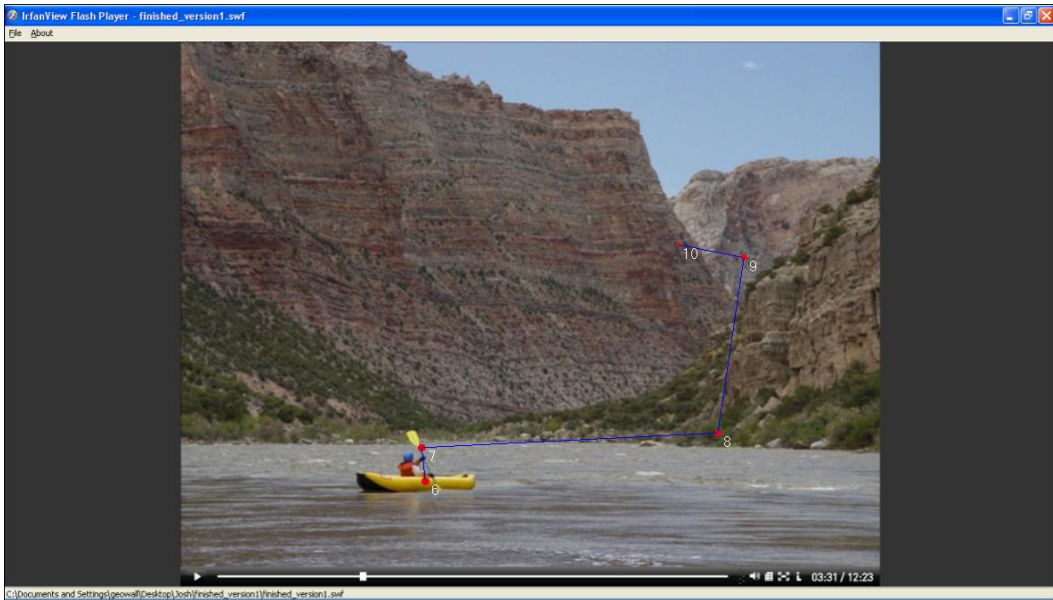
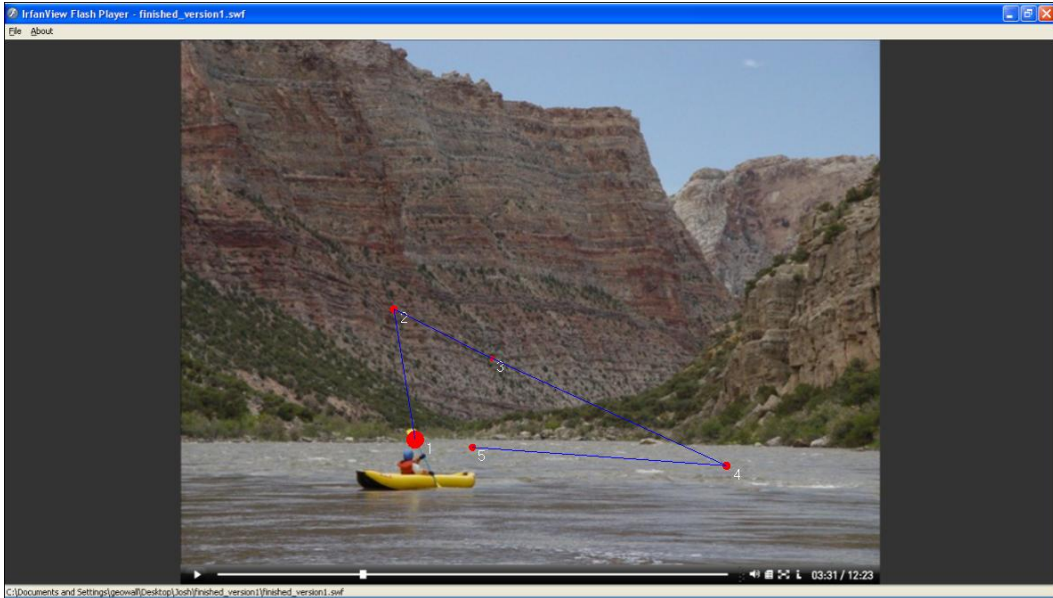




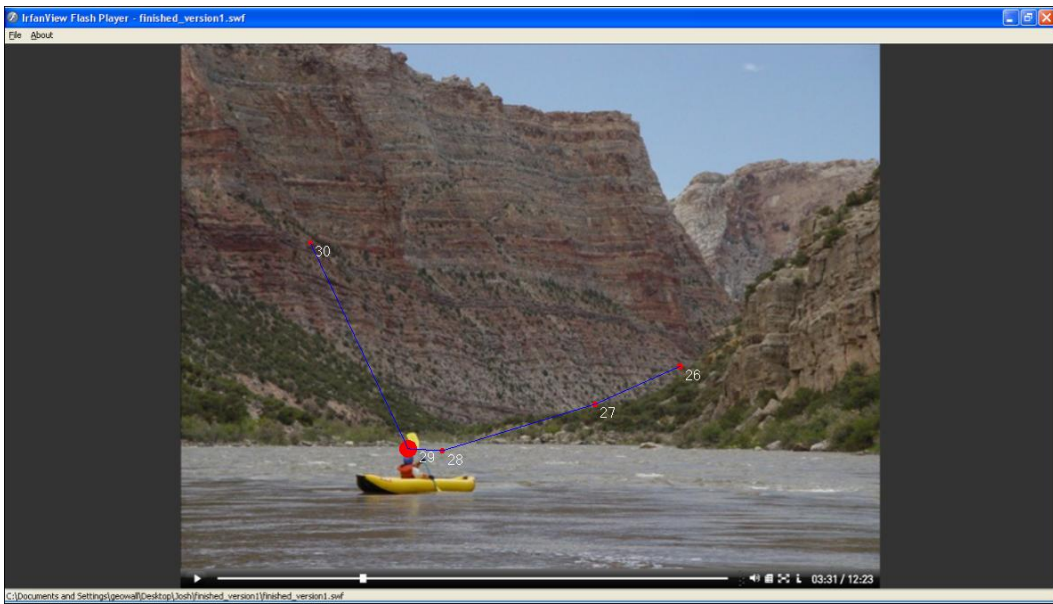


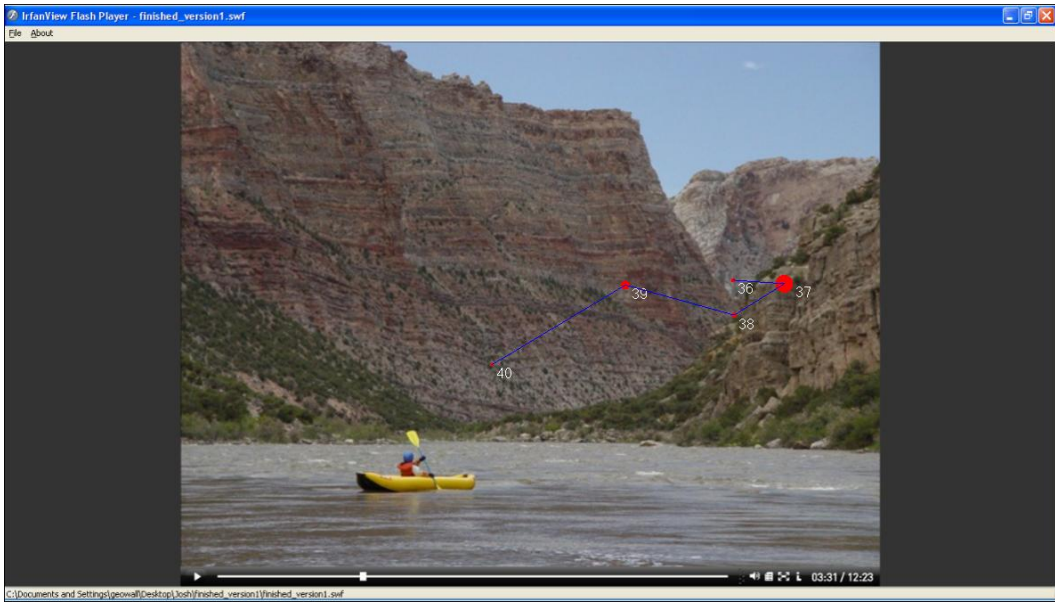
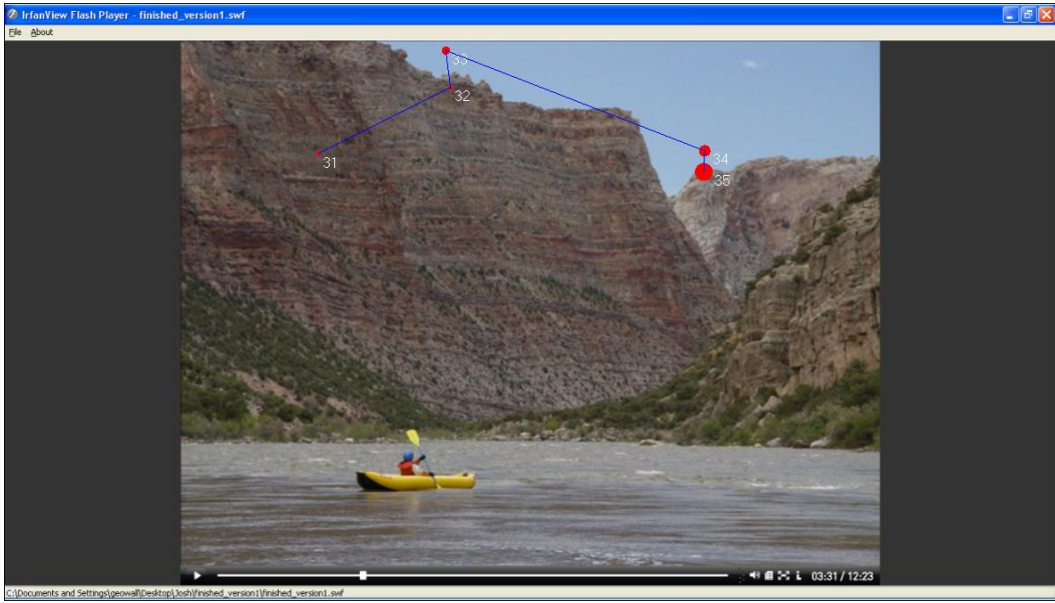


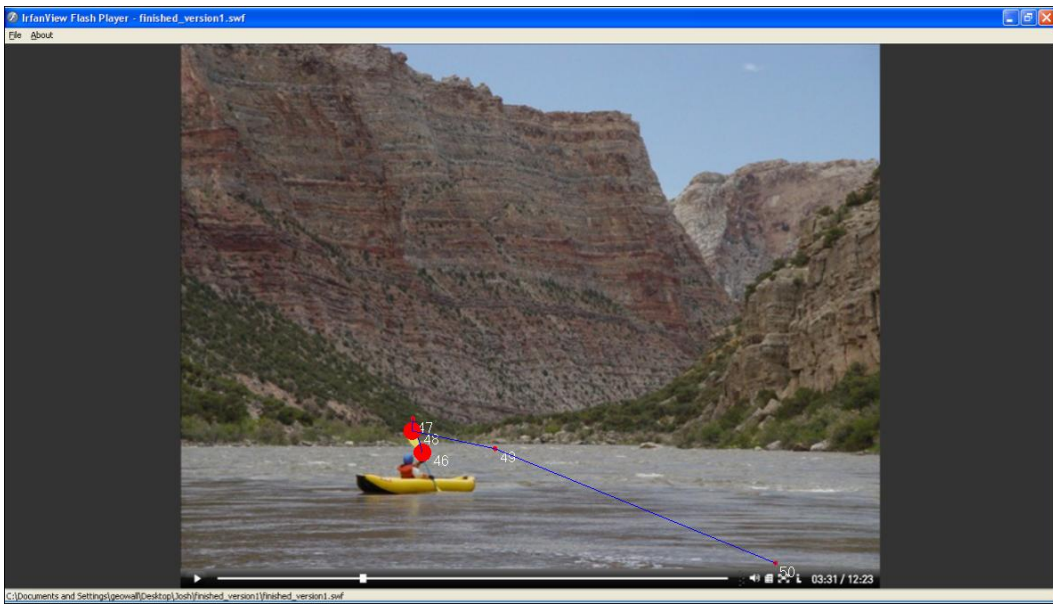
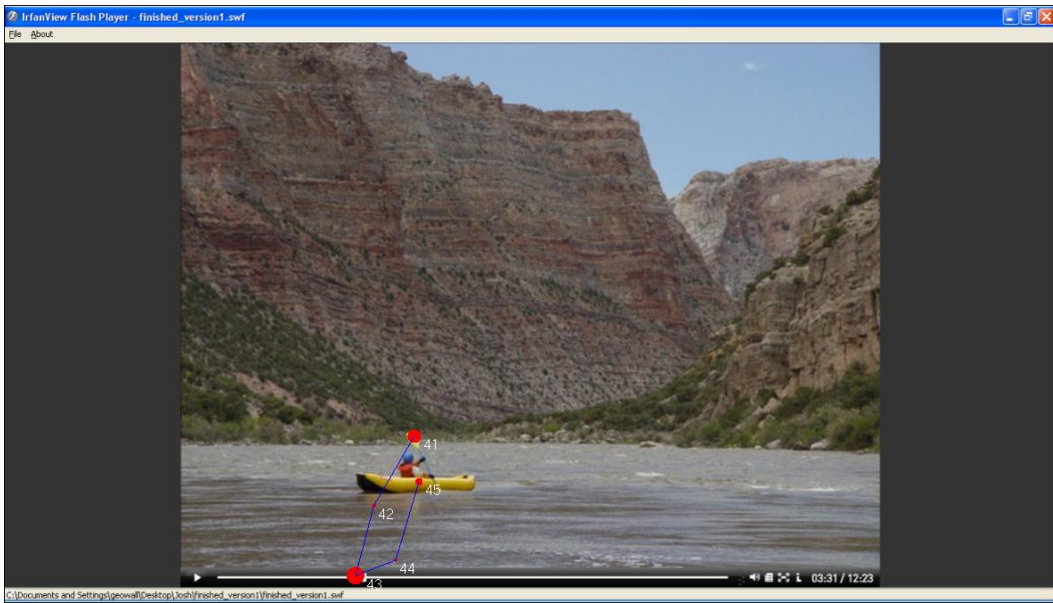
Fixation sequence diagrams for image 5 for an individual who has high distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.

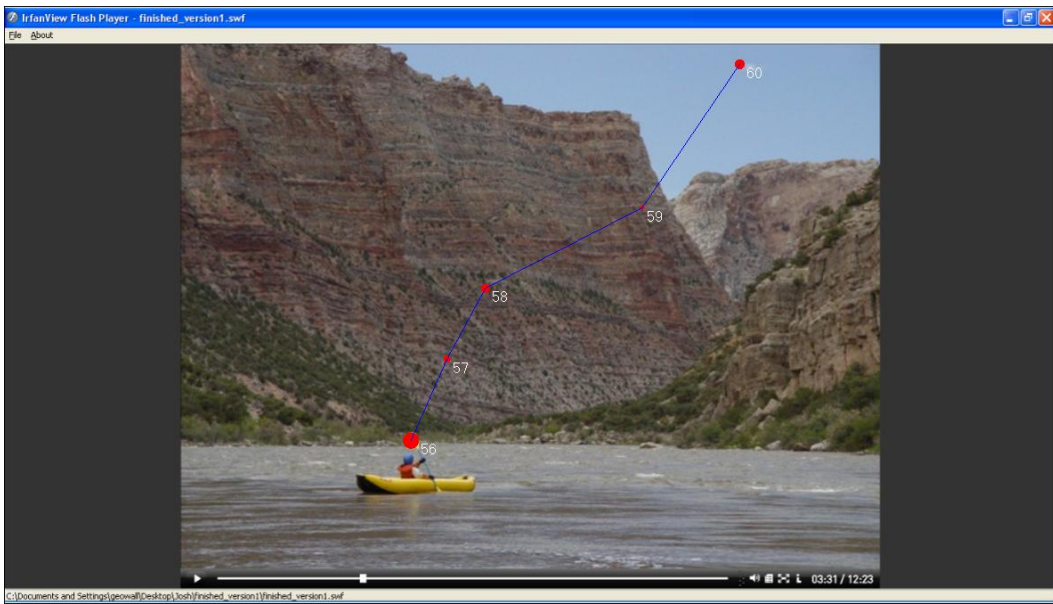
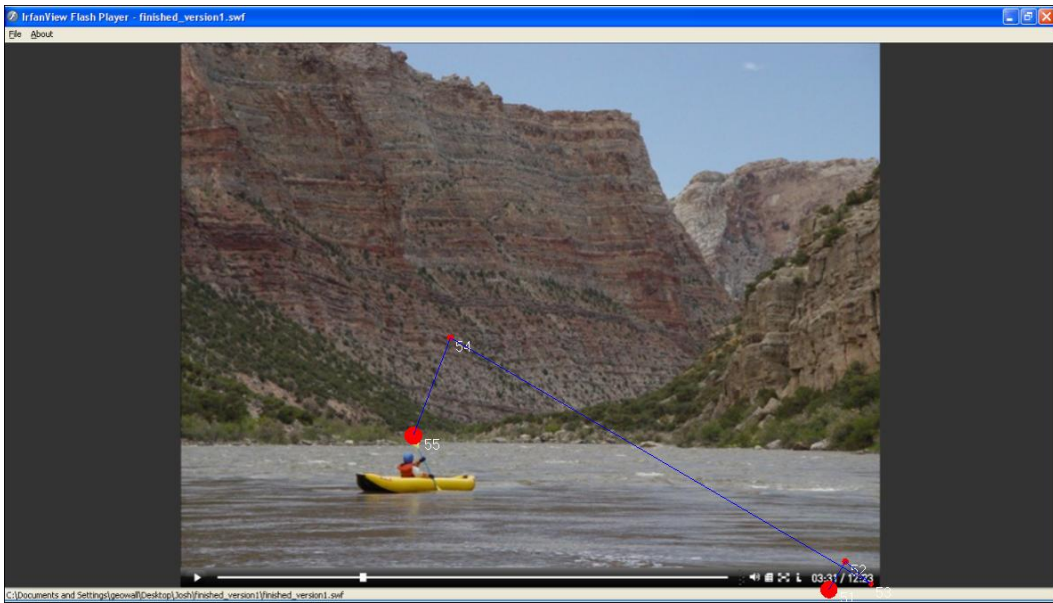


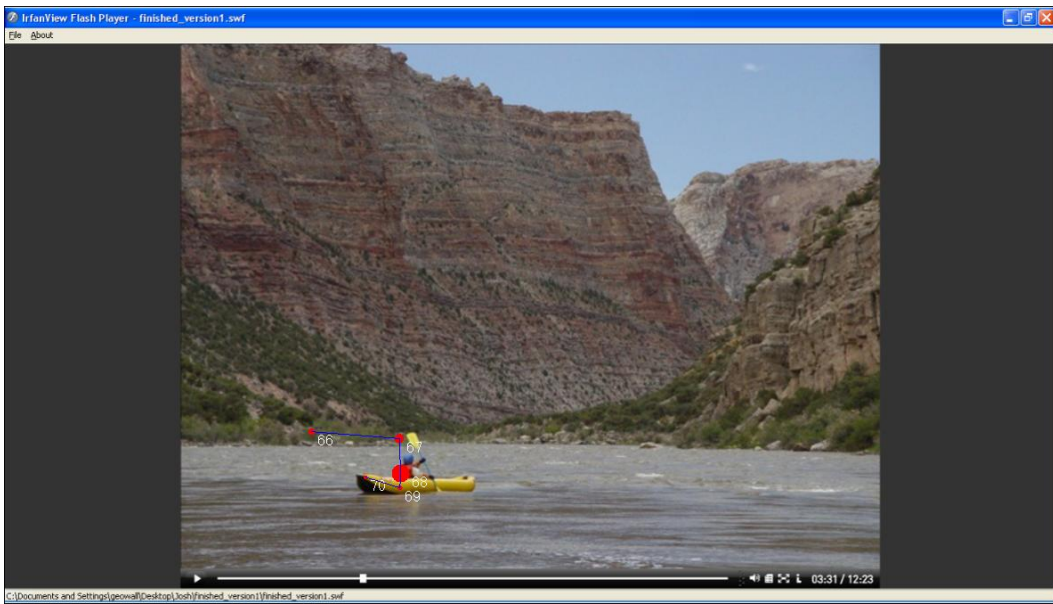
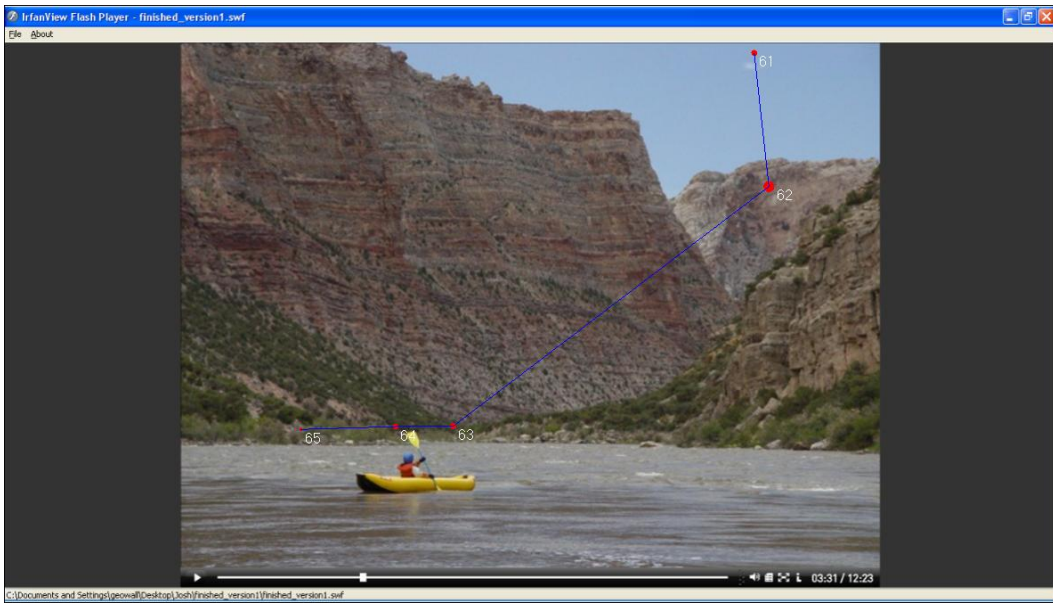


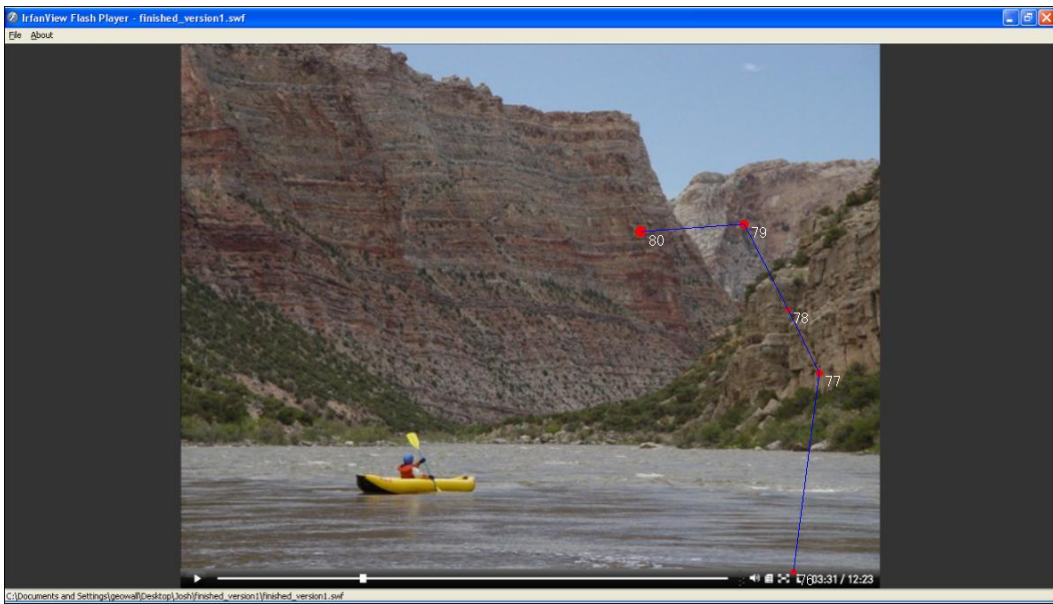
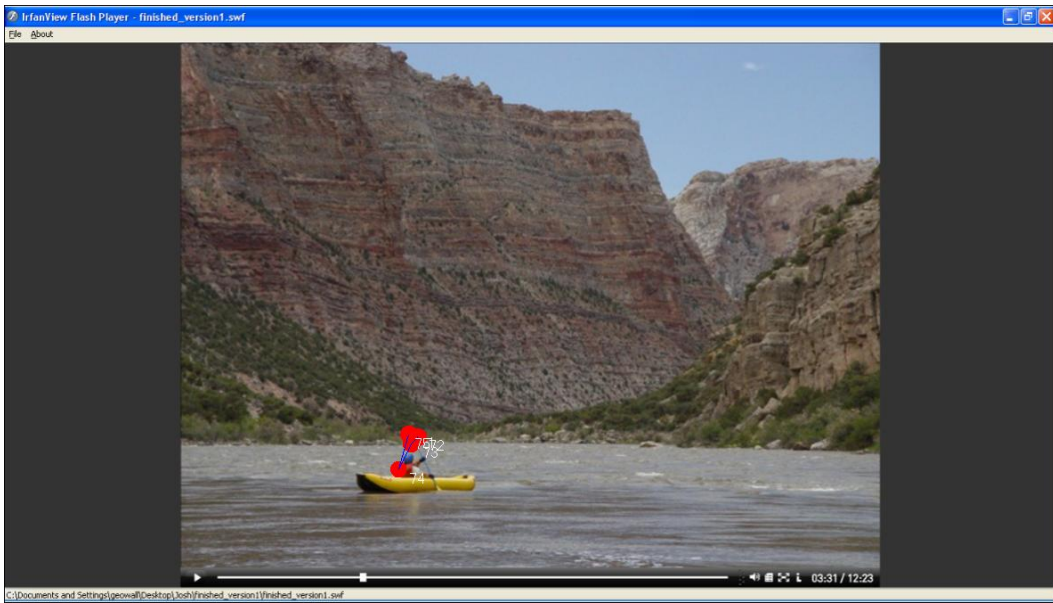


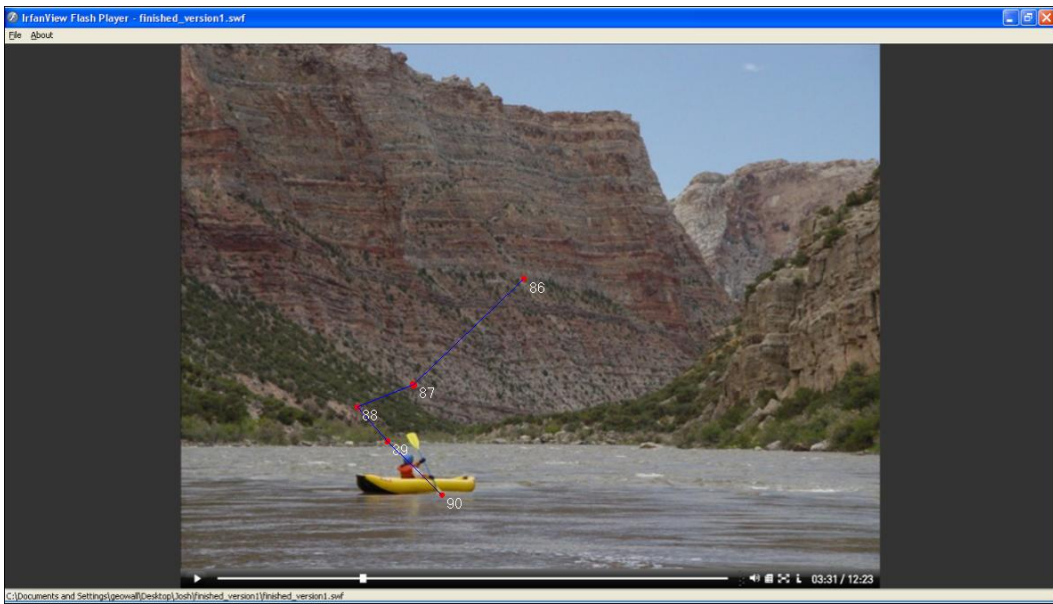
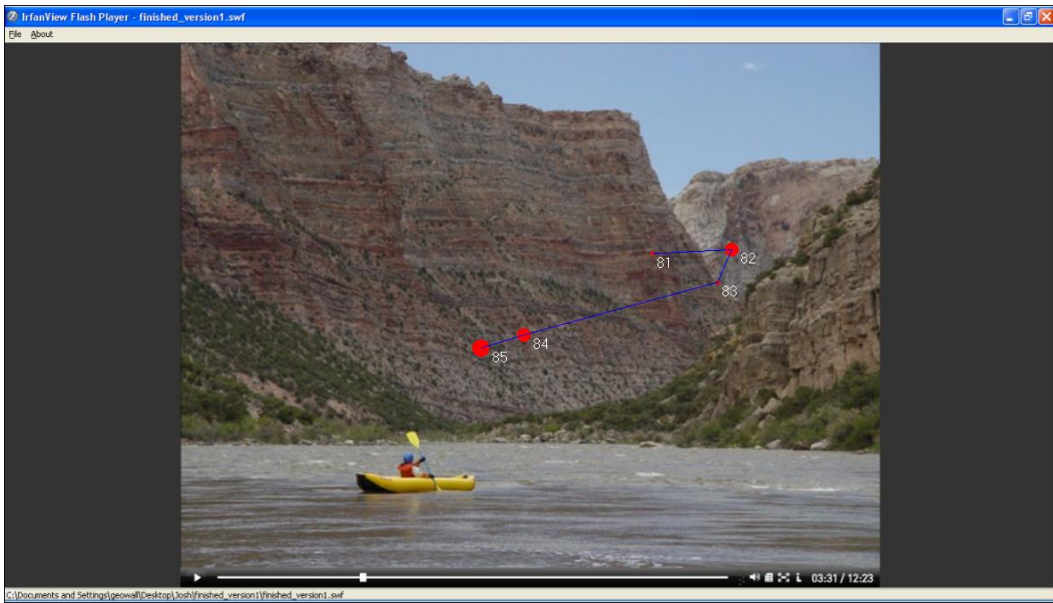


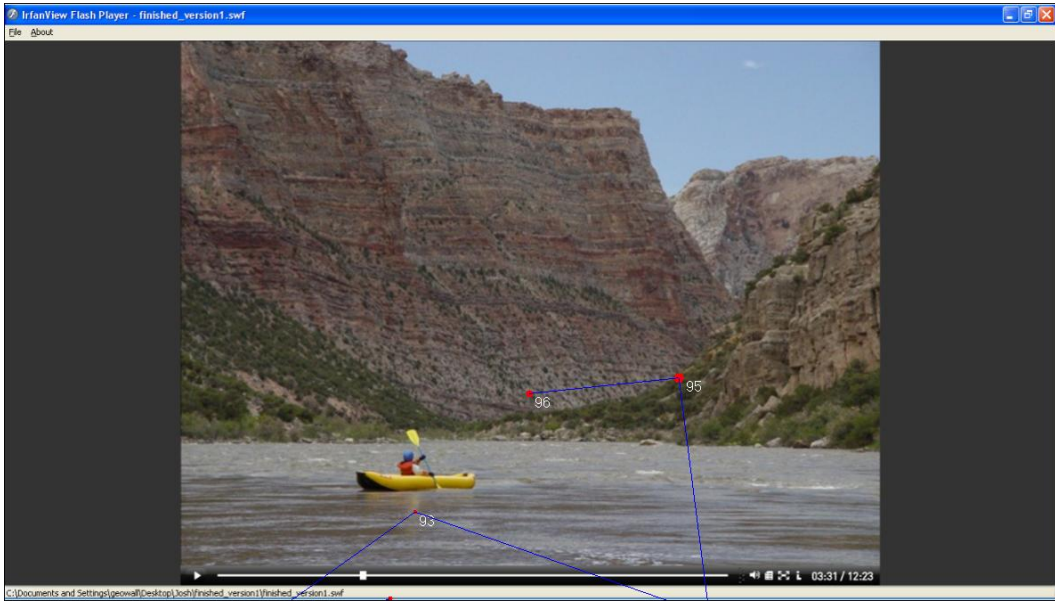






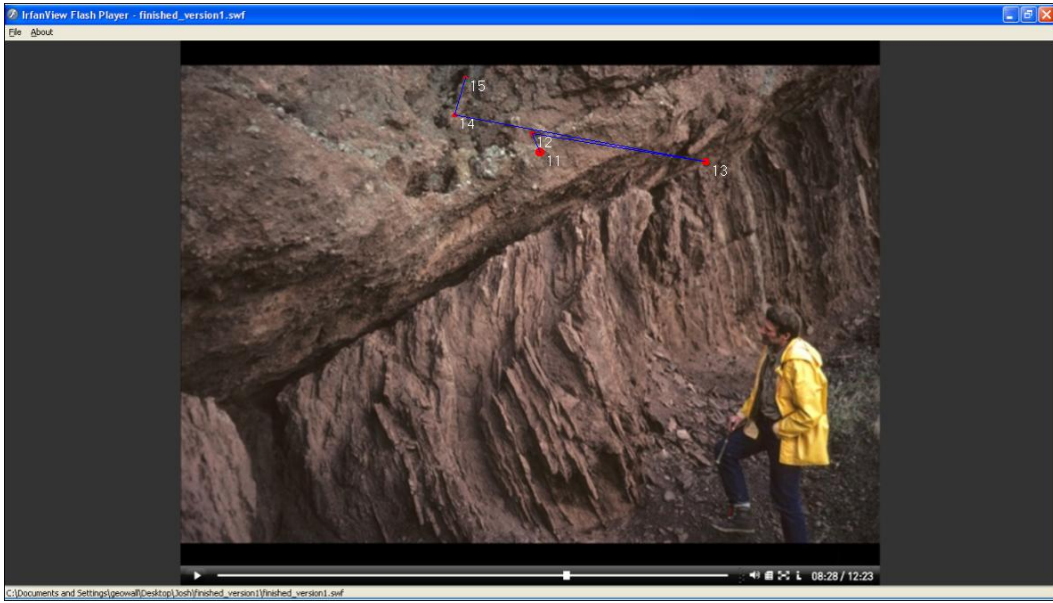


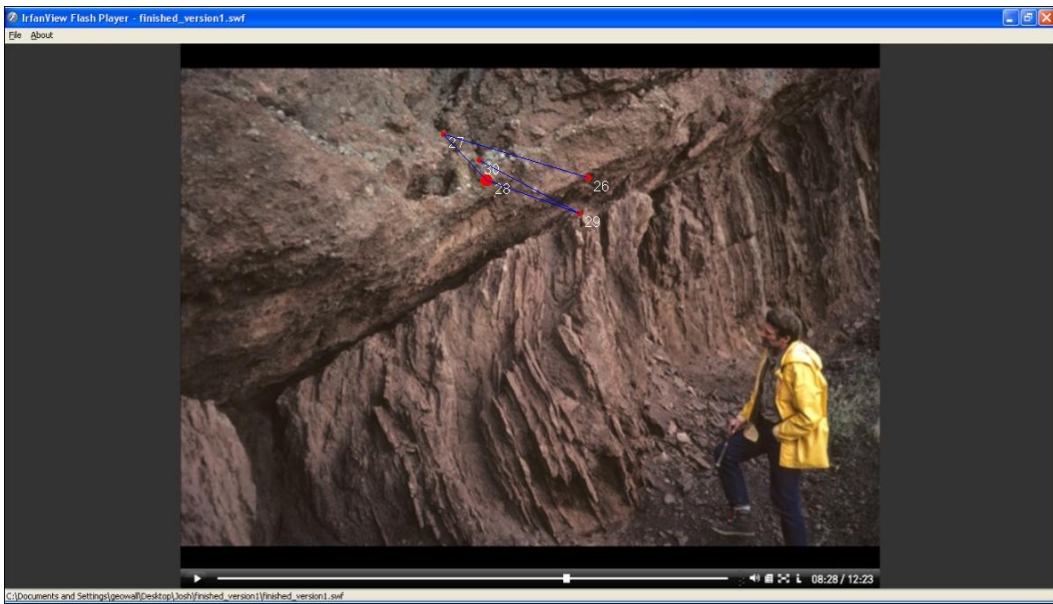
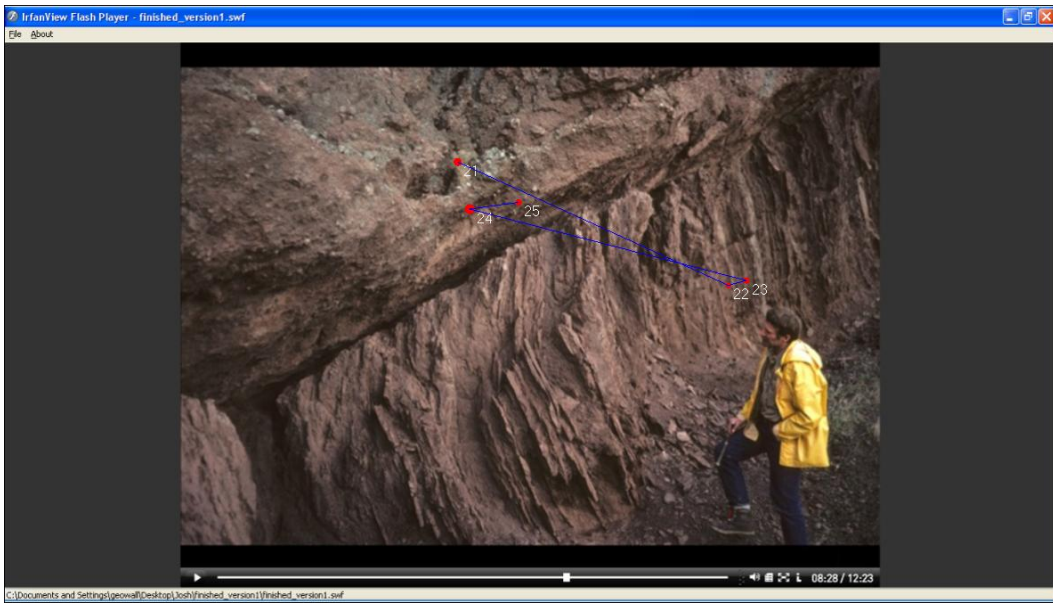


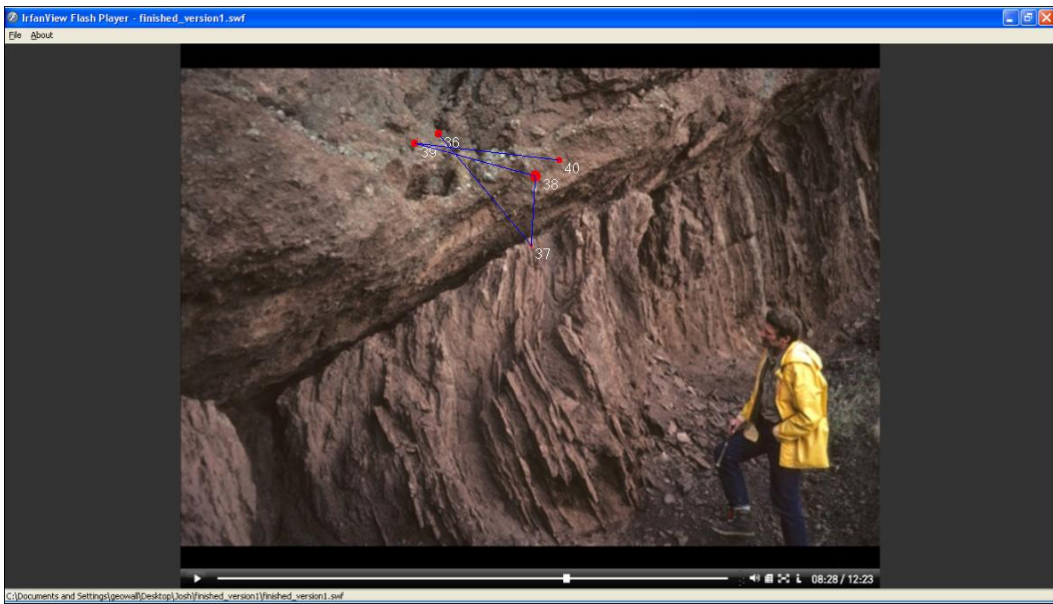
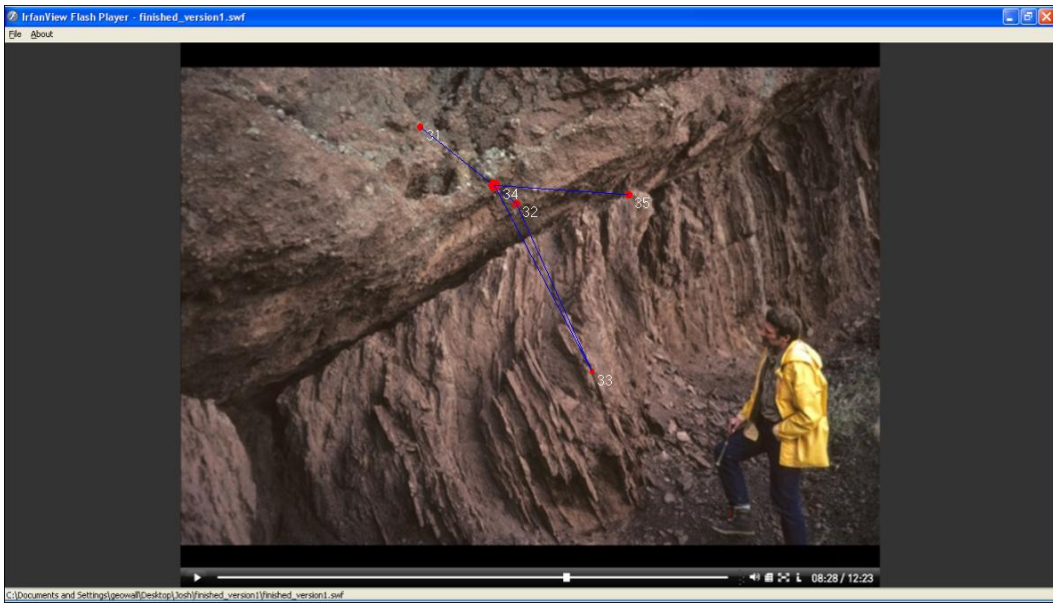


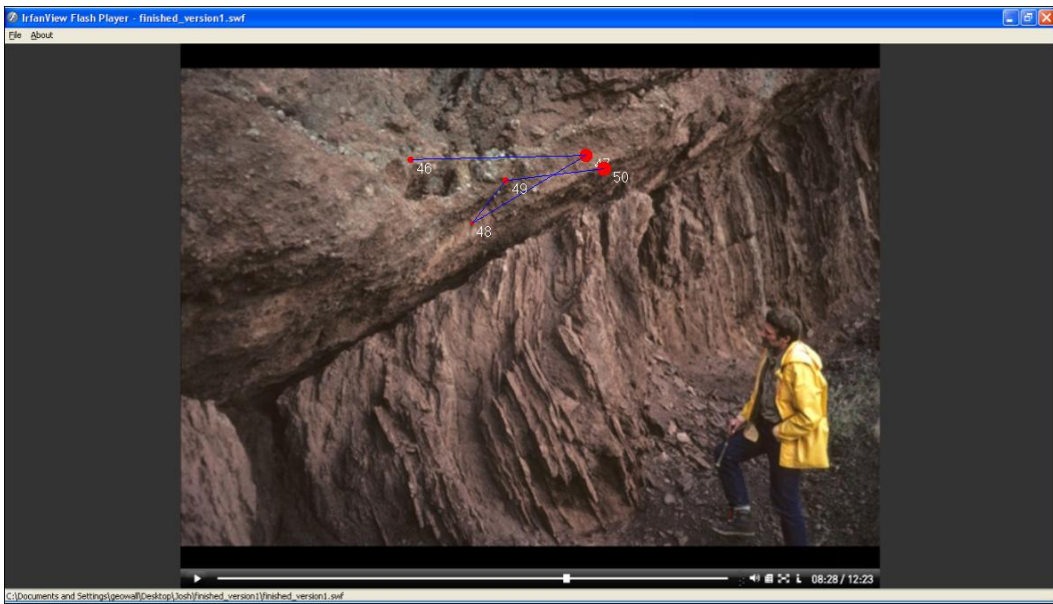
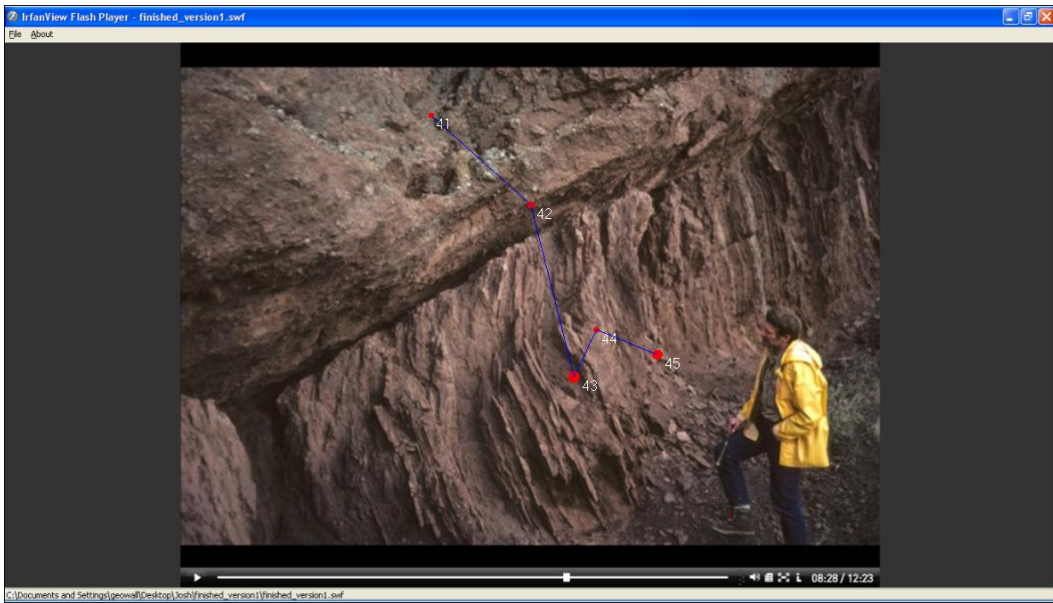
Fixation sequence diagrams for image 10 for an individual who has low distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.

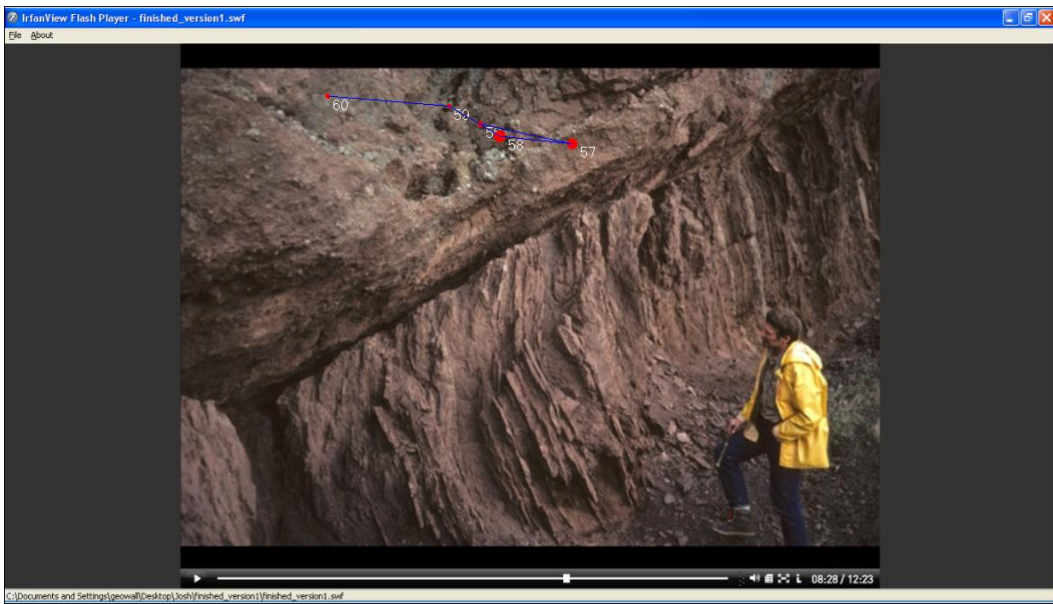
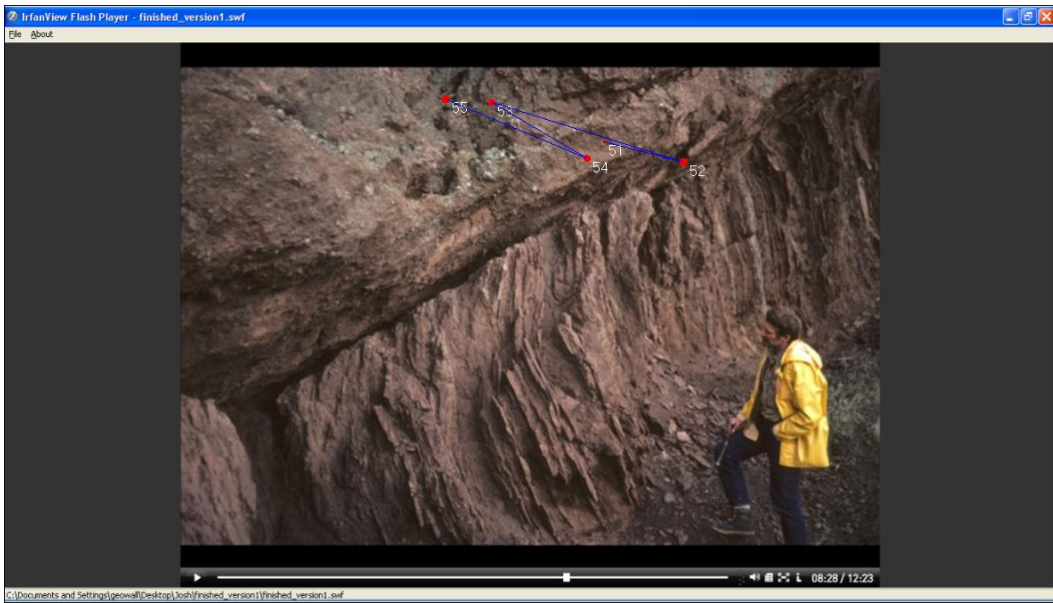


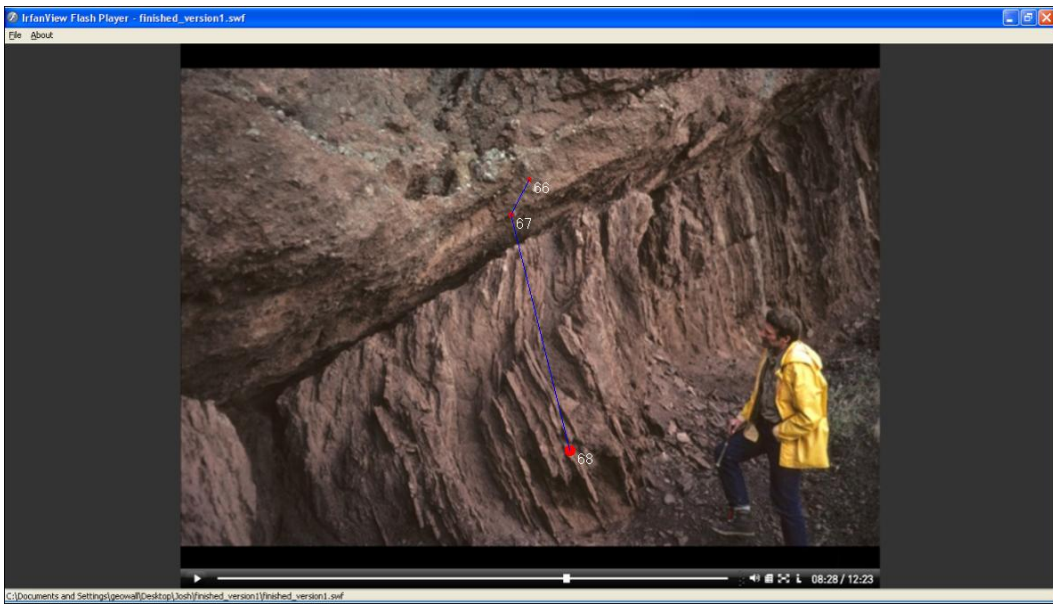
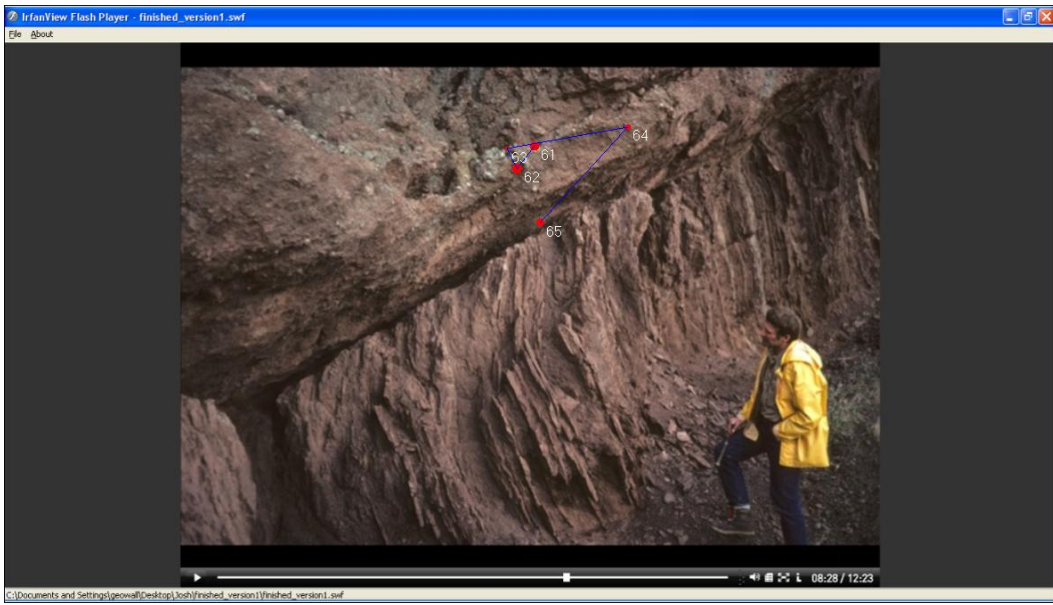




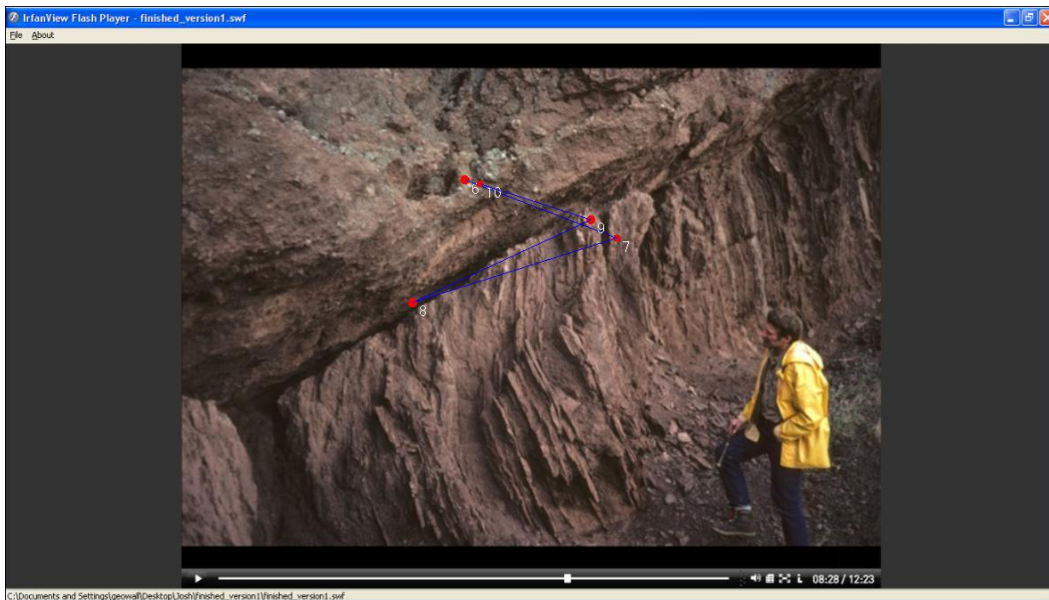
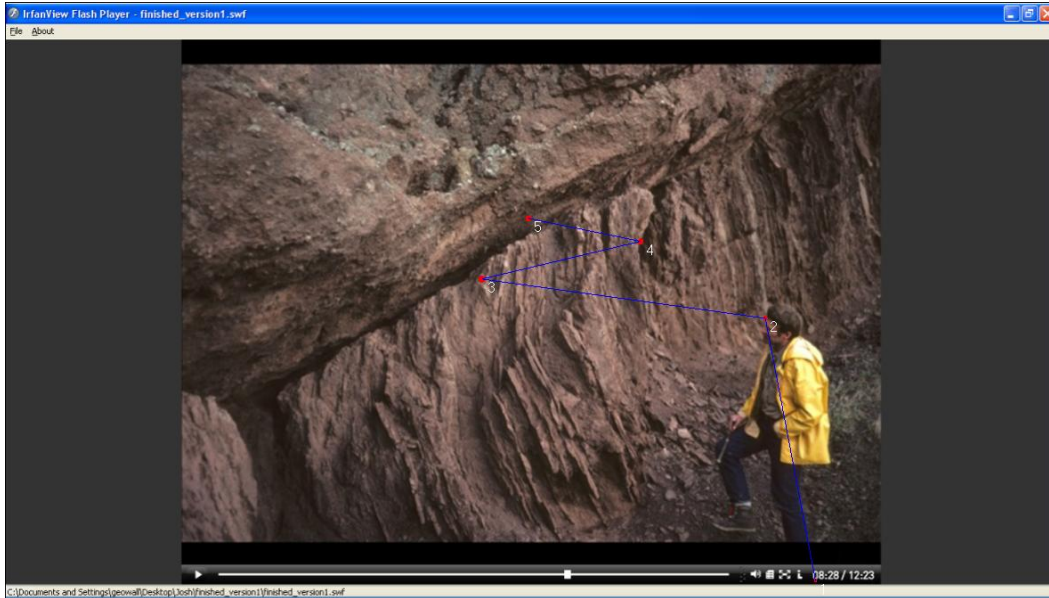


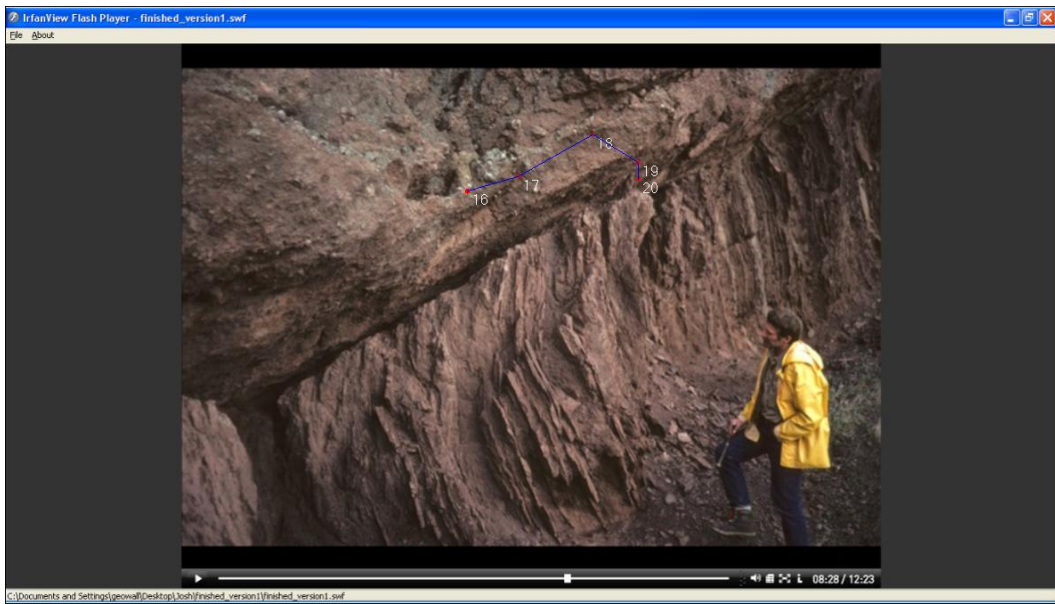
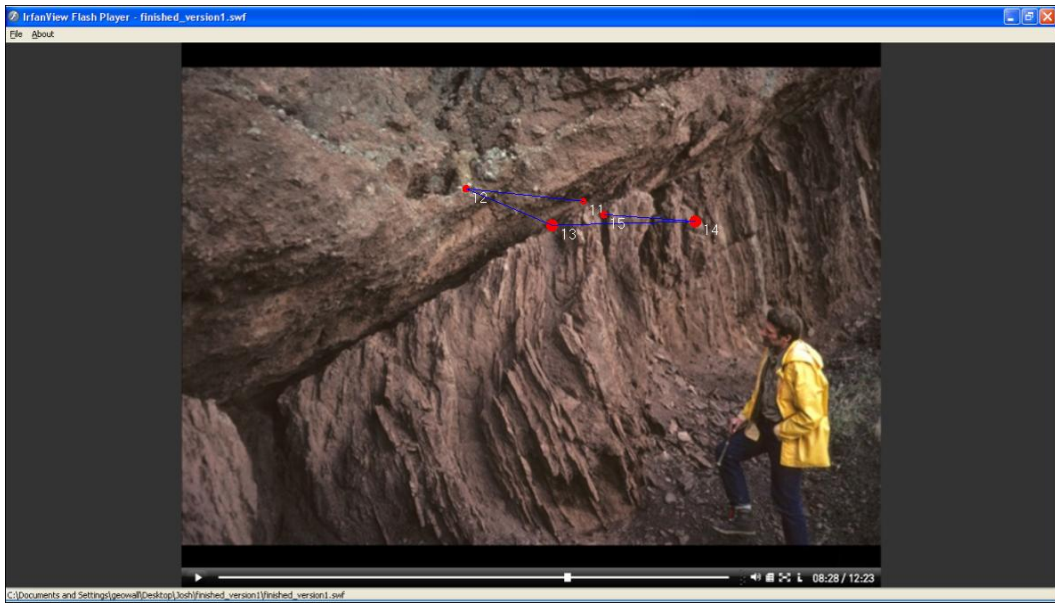


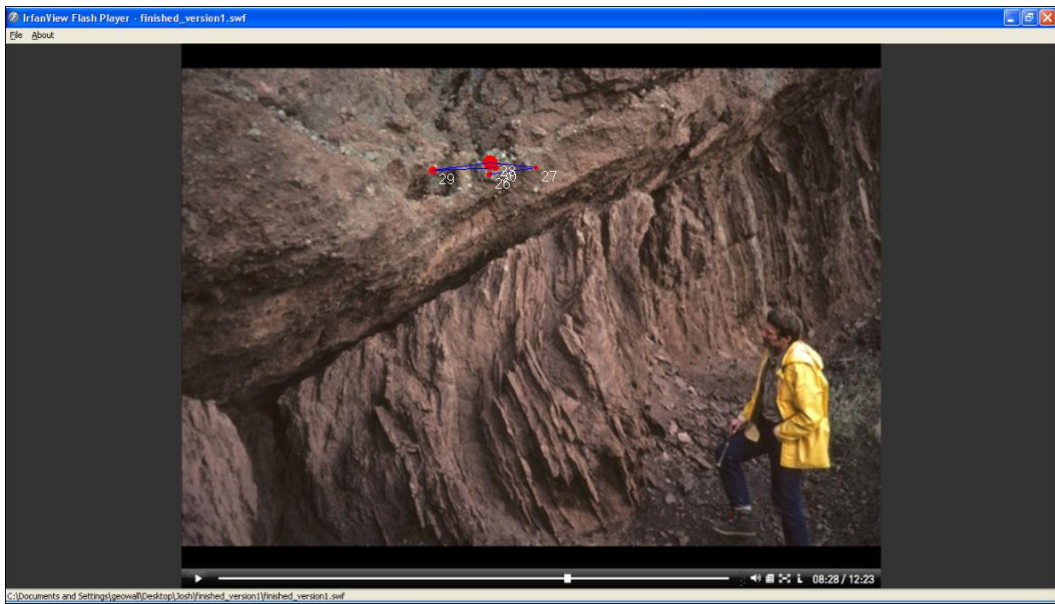


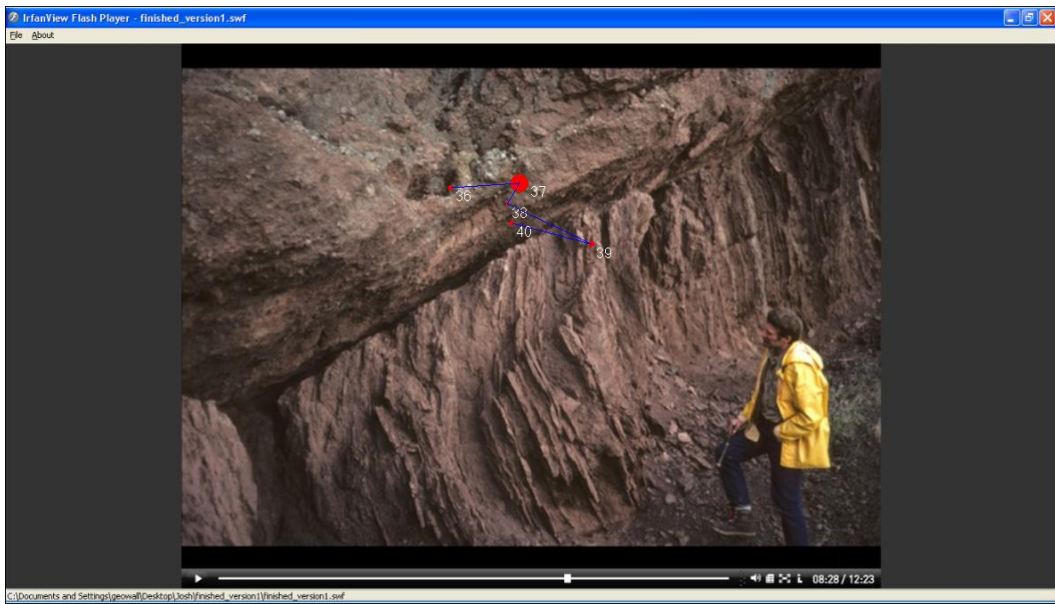


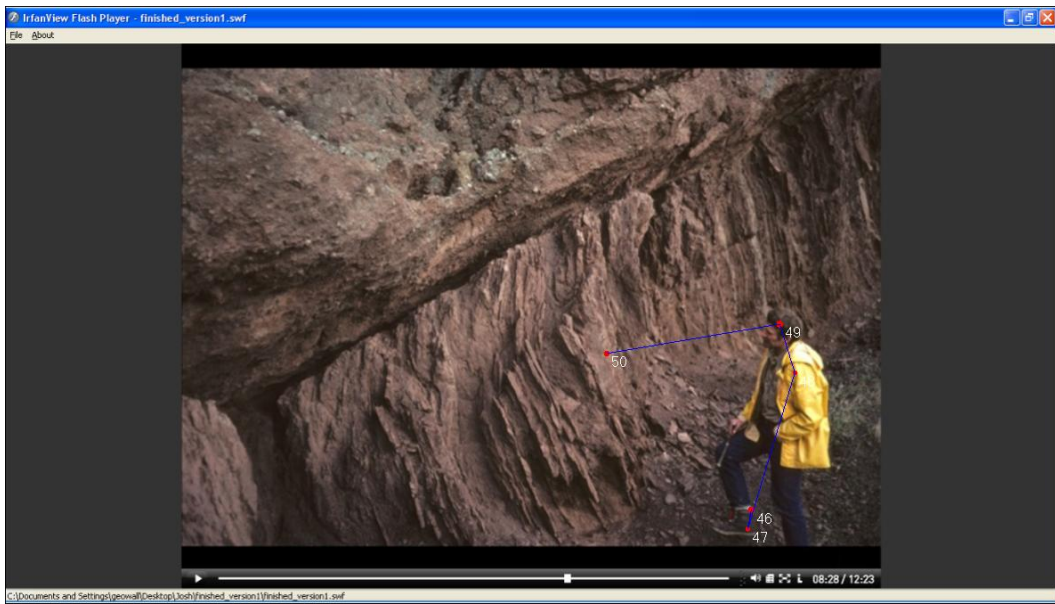
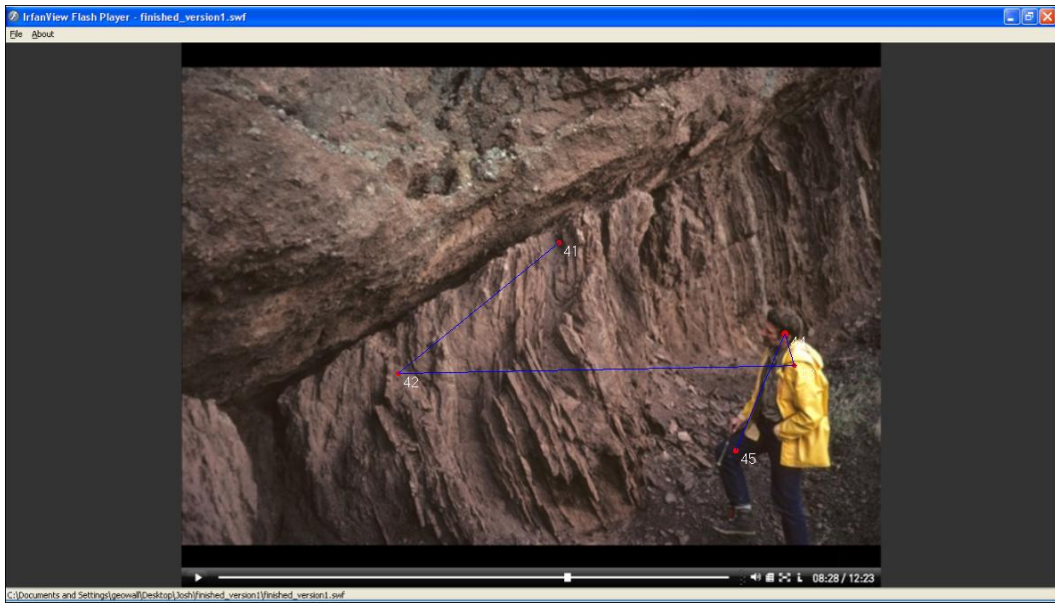
Fixation sequence diagrams for image 10 for an individual who has average distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.

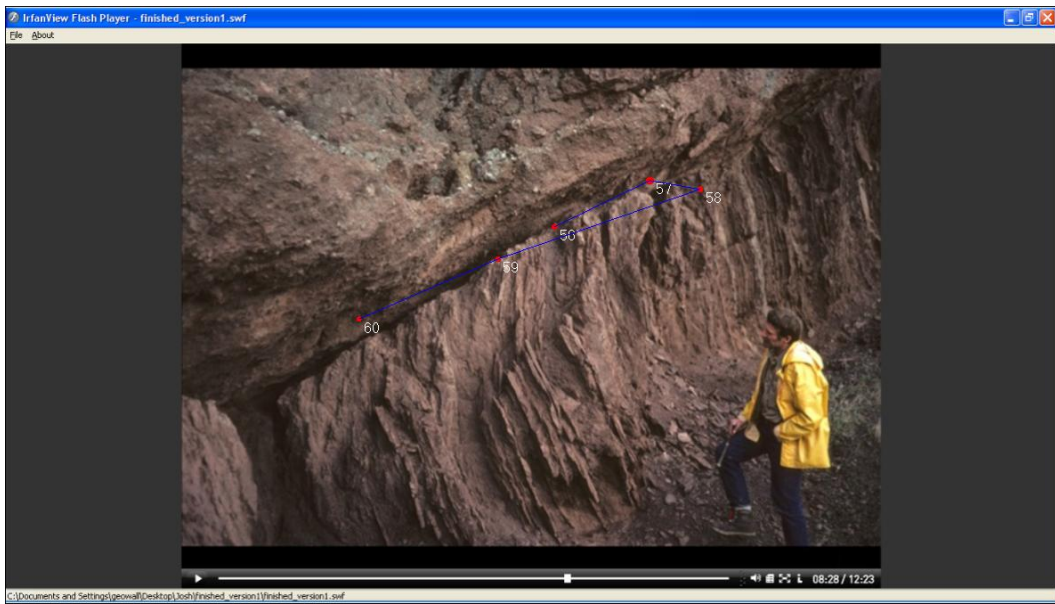
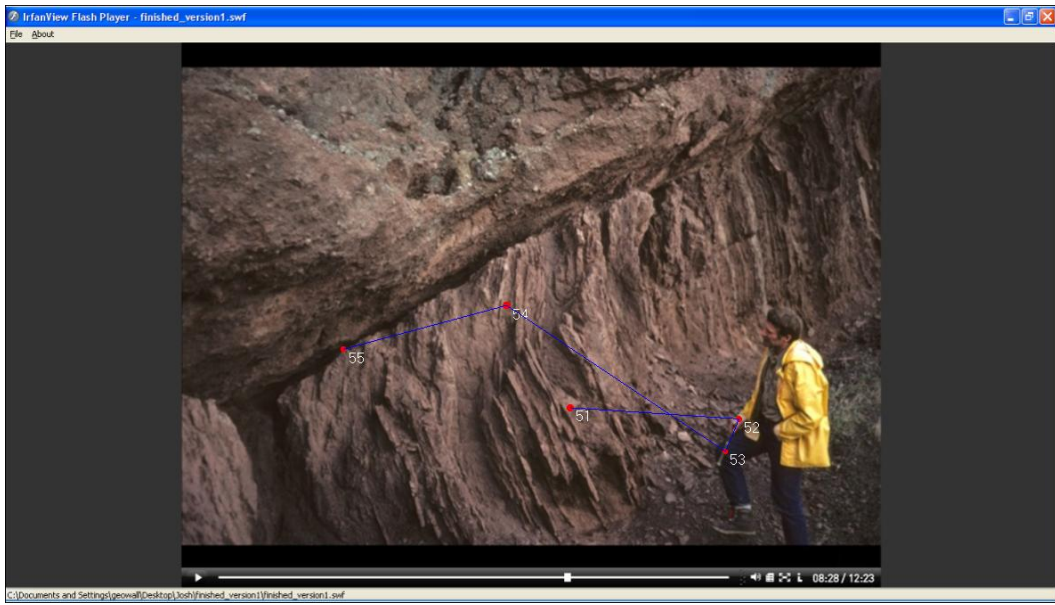




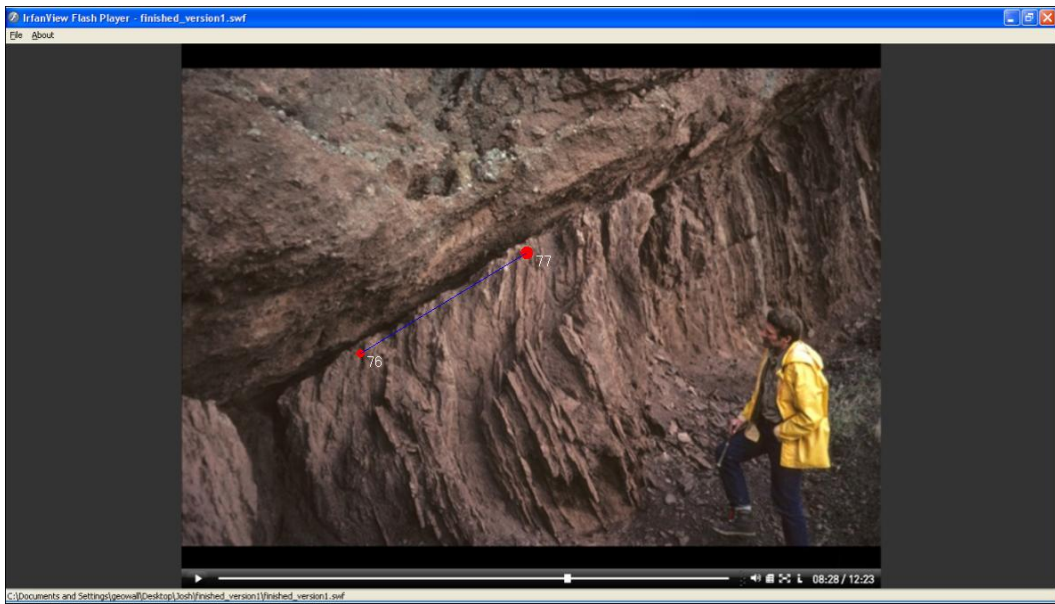
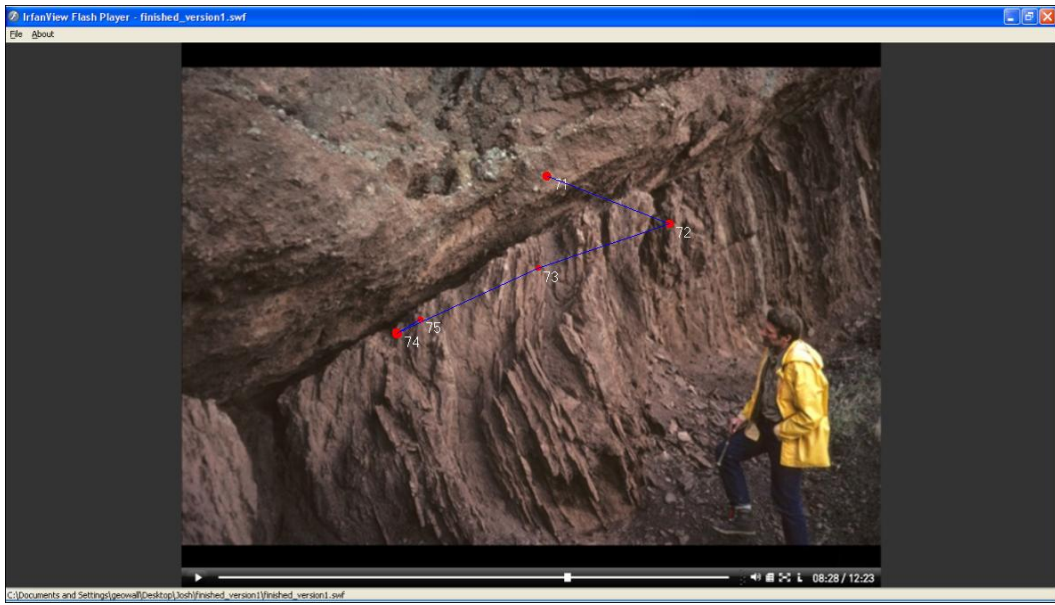




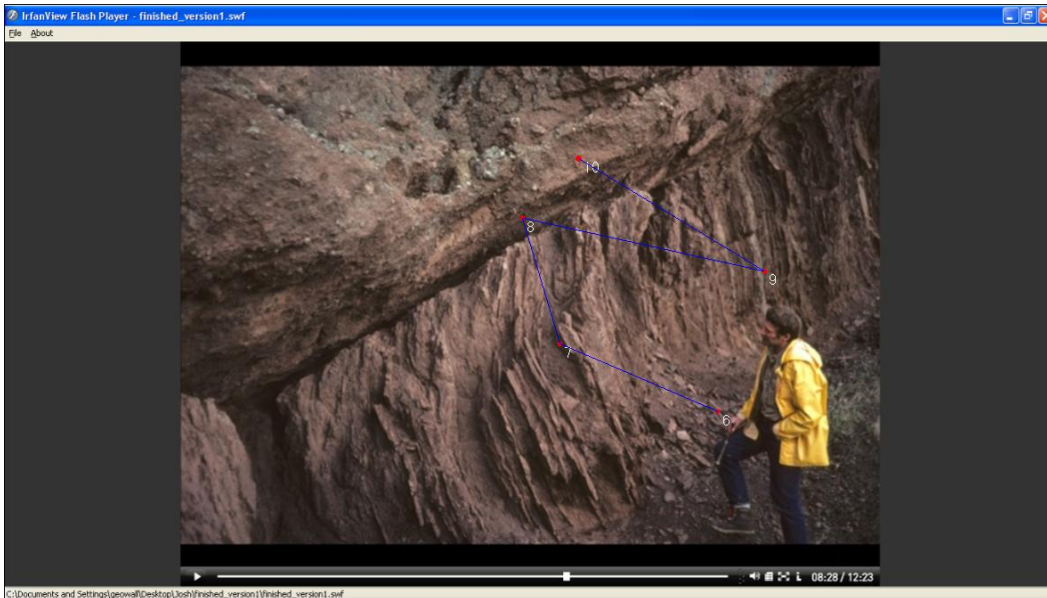
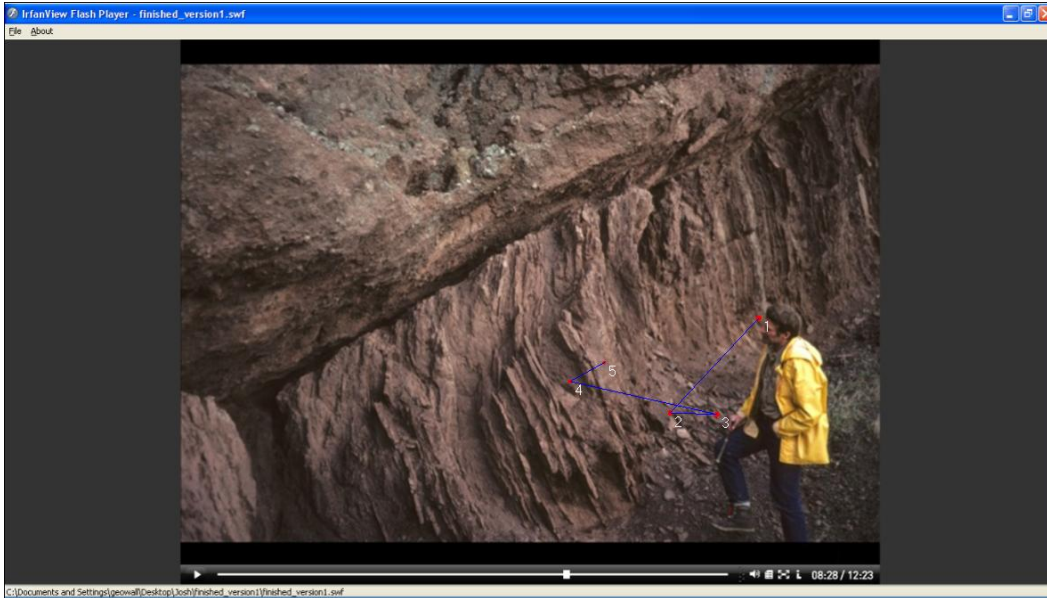


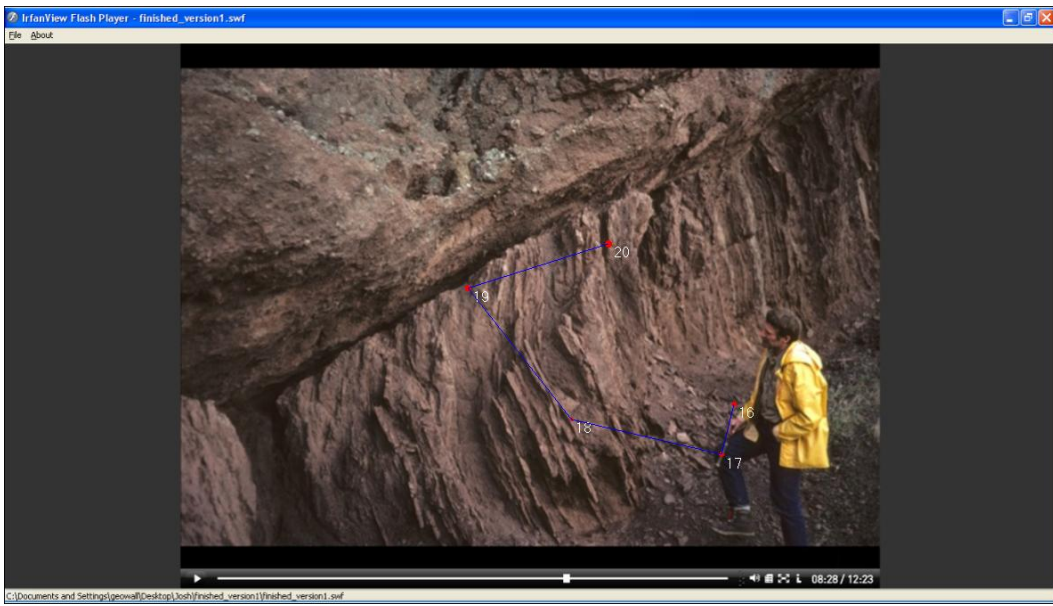
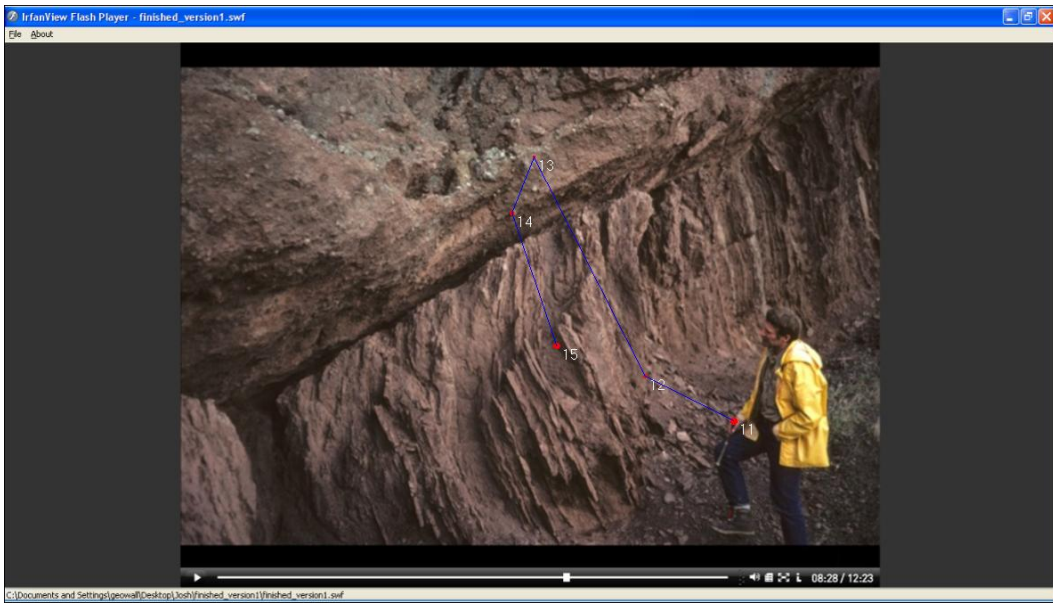


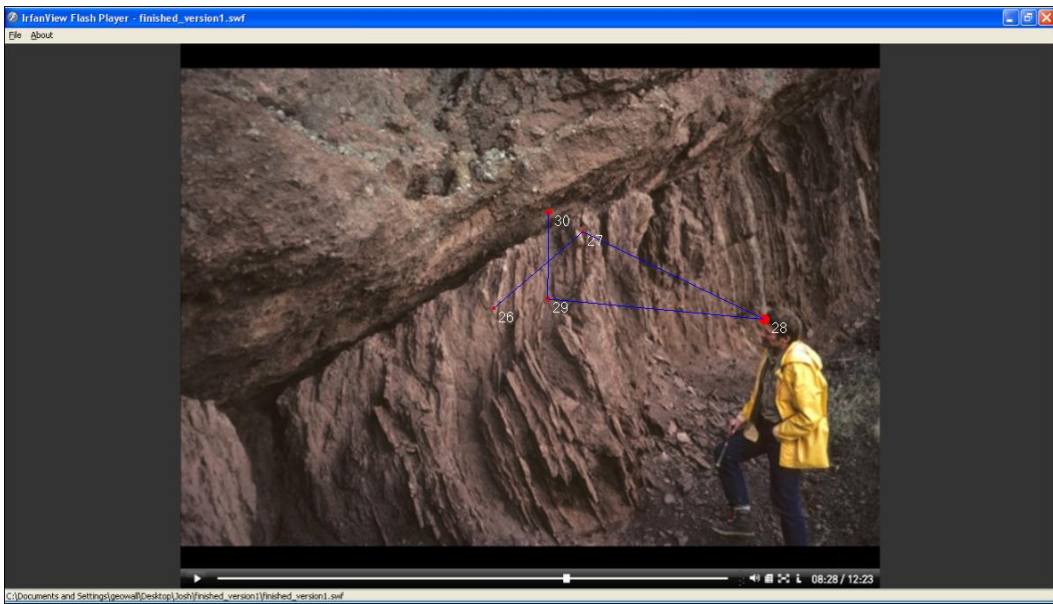
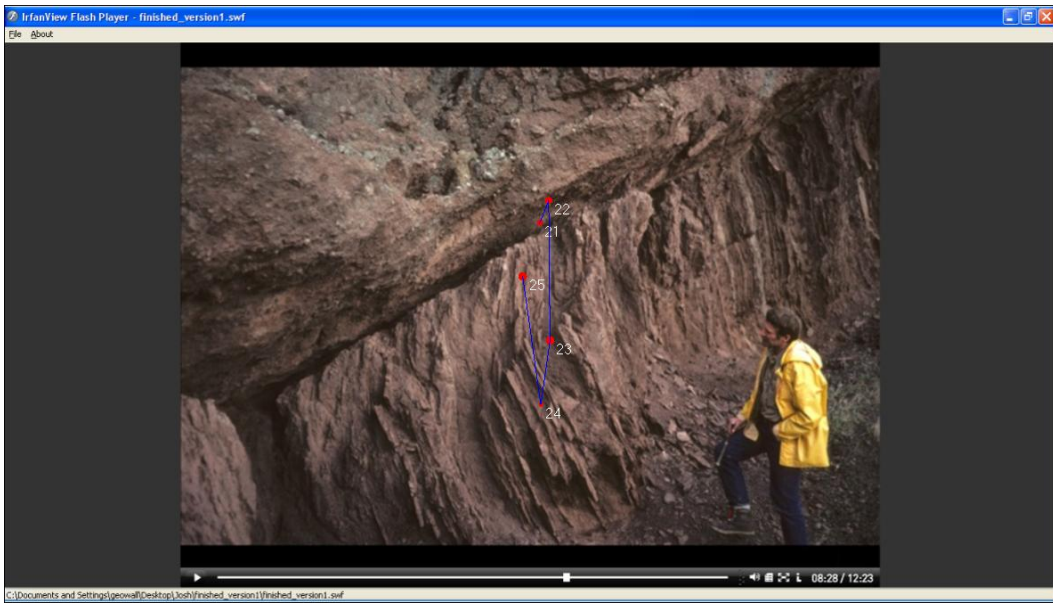


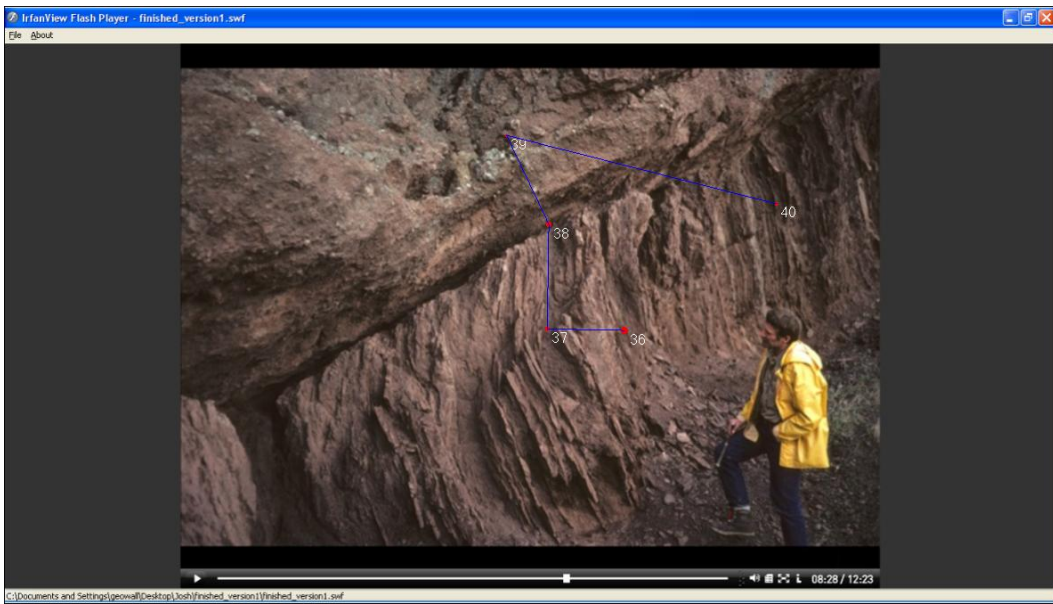
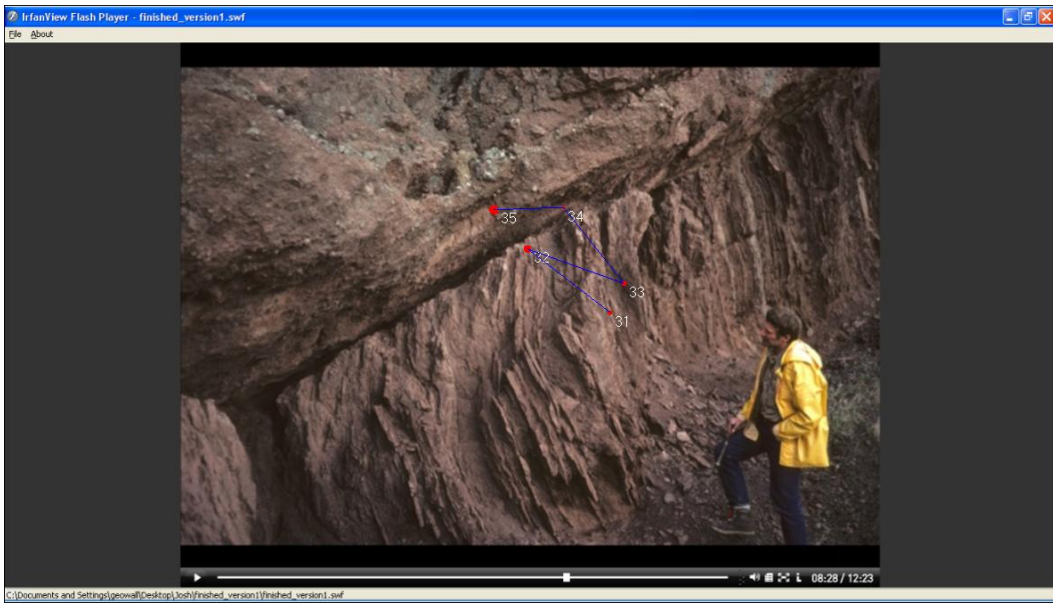


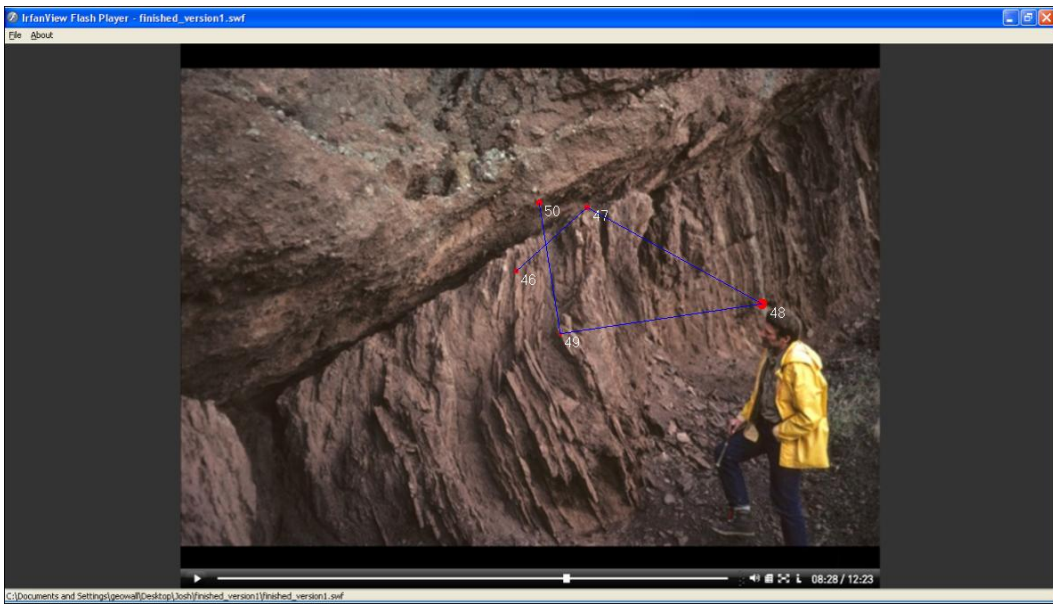
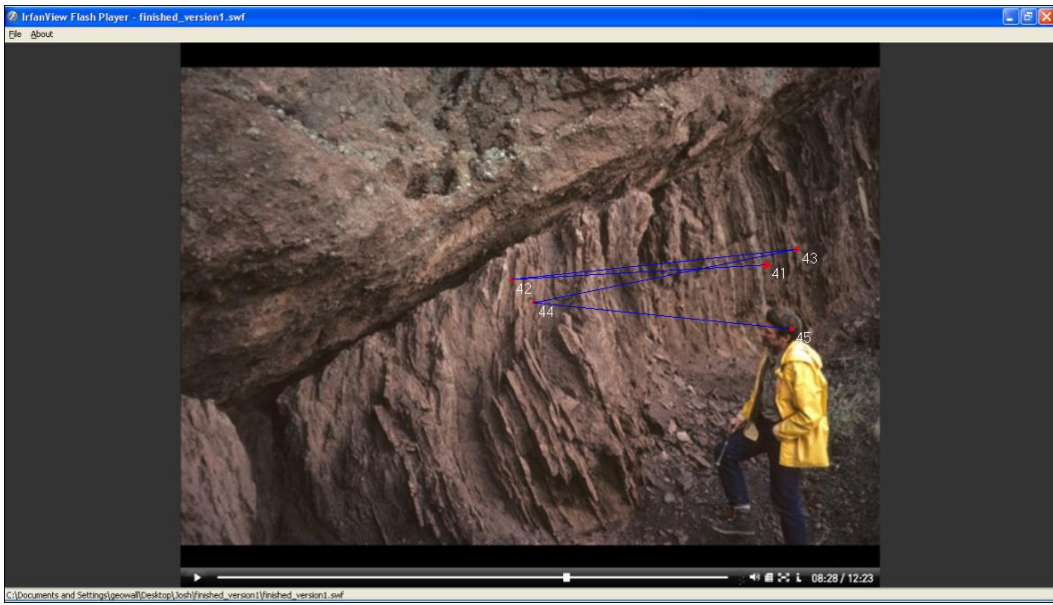
Fixation sequence diagrams for image 10 for an individual who has high distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.

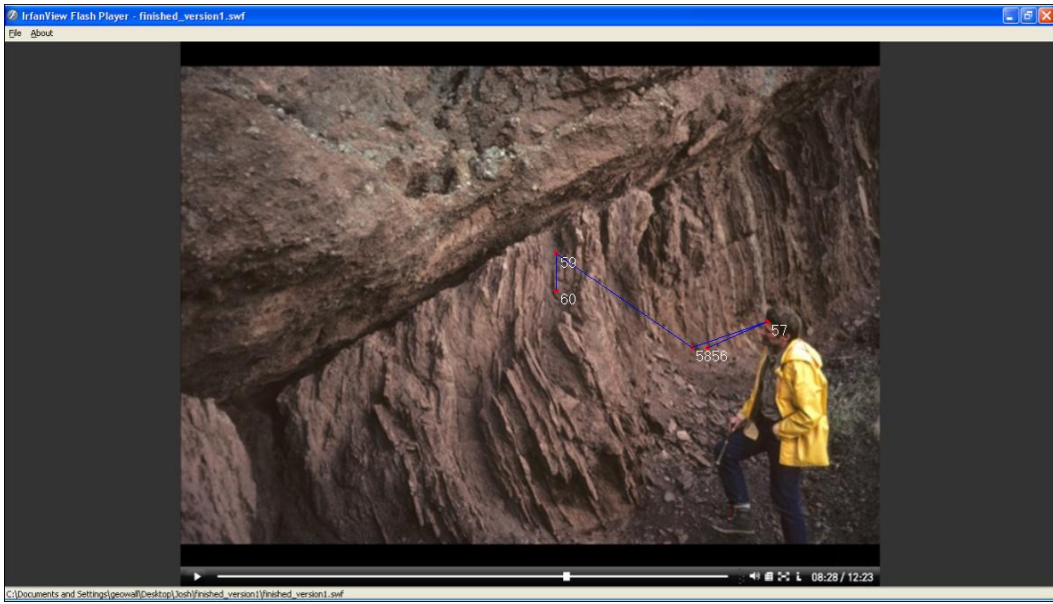
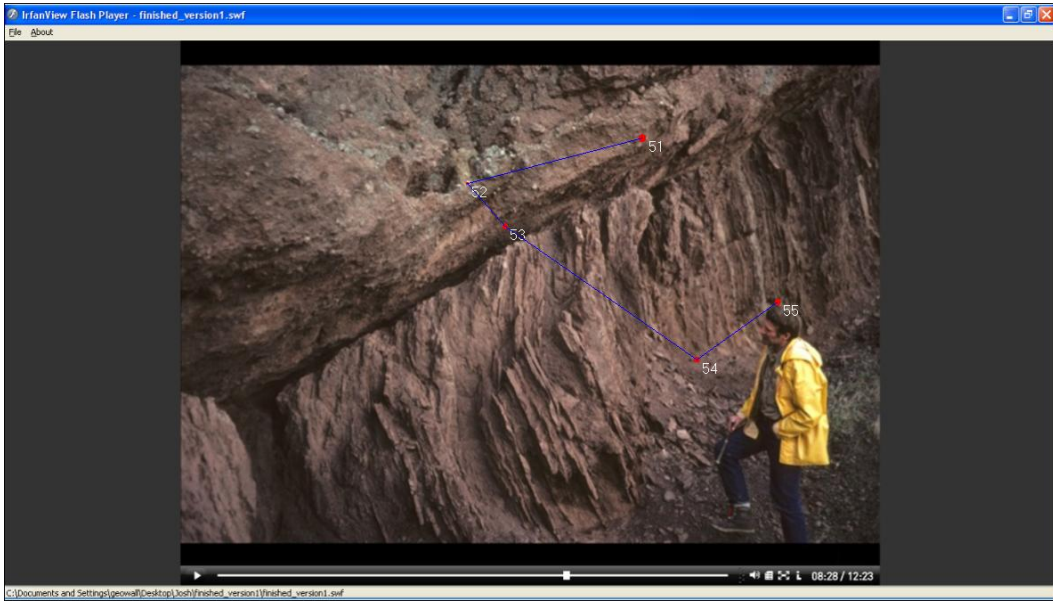


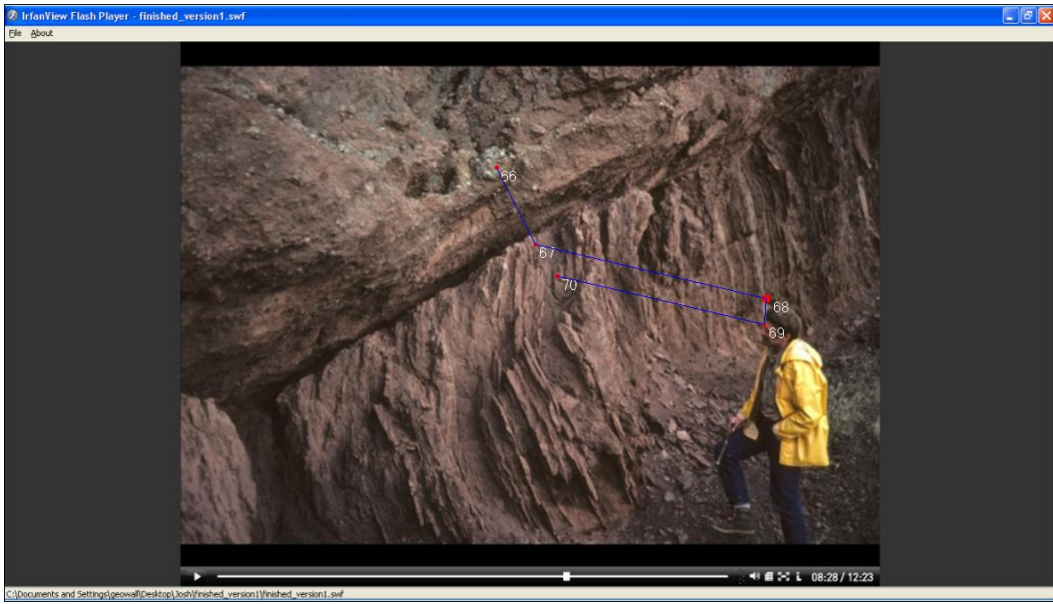
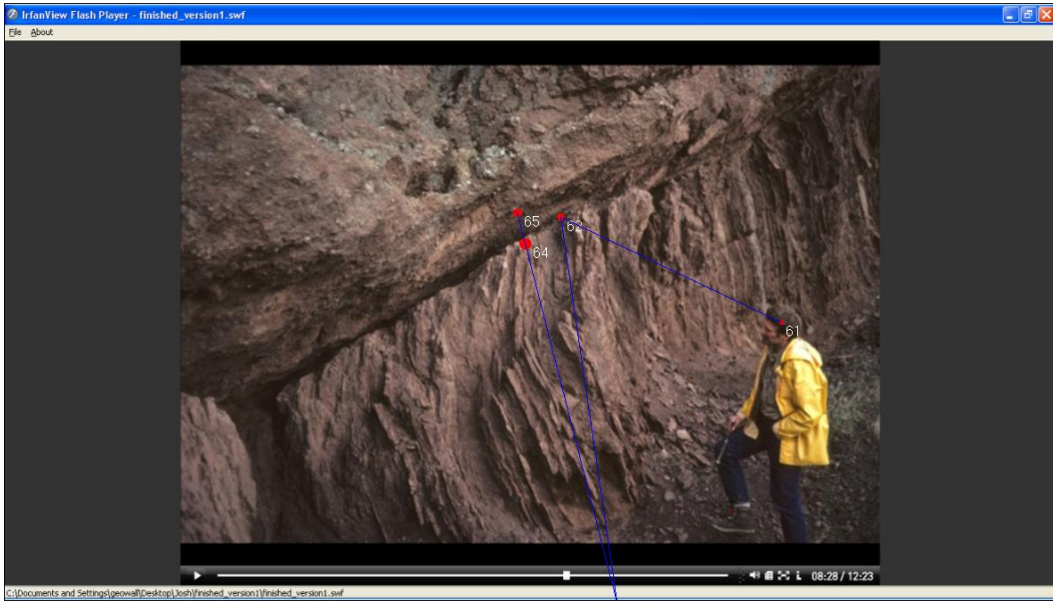


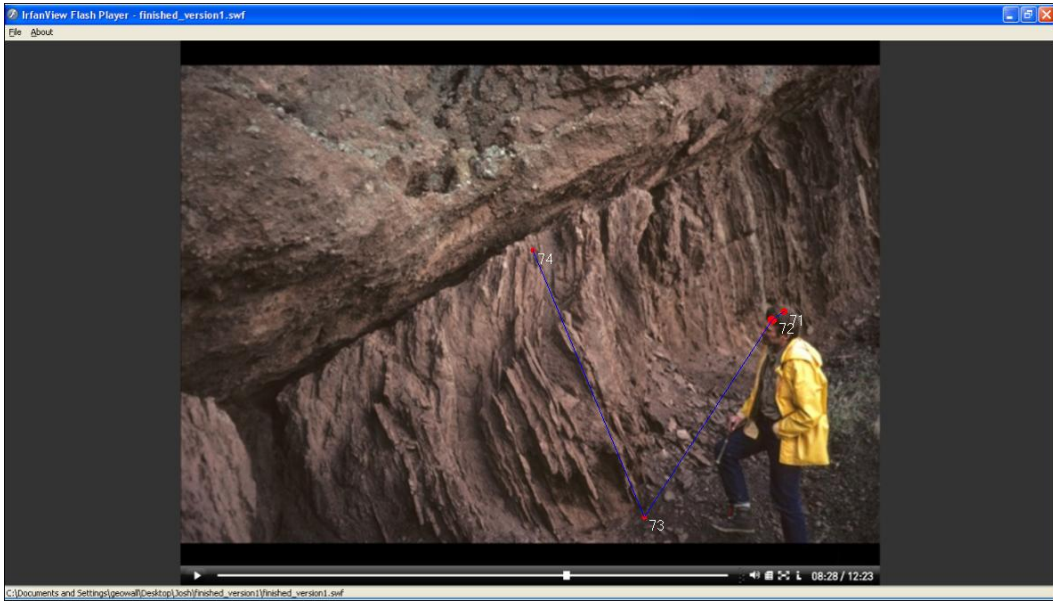








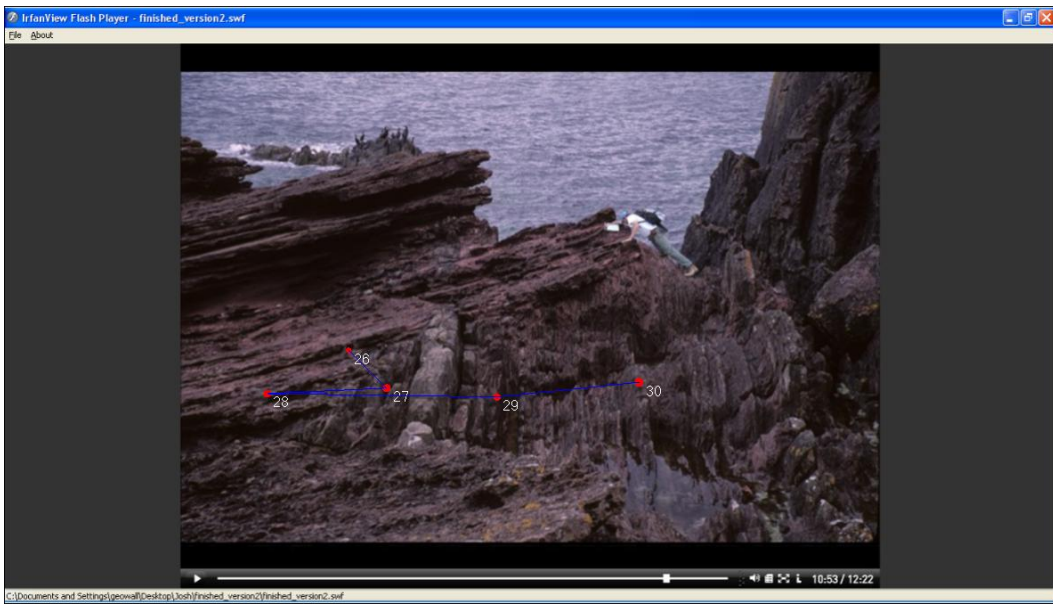


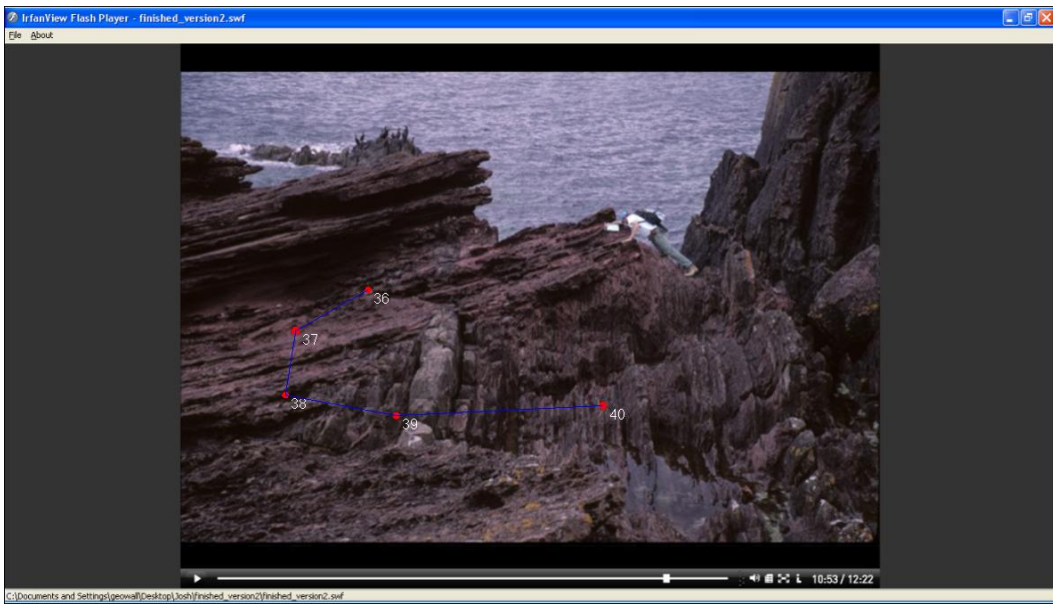


Fixation sequence diagrams for image 15 for an individual who has low distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.

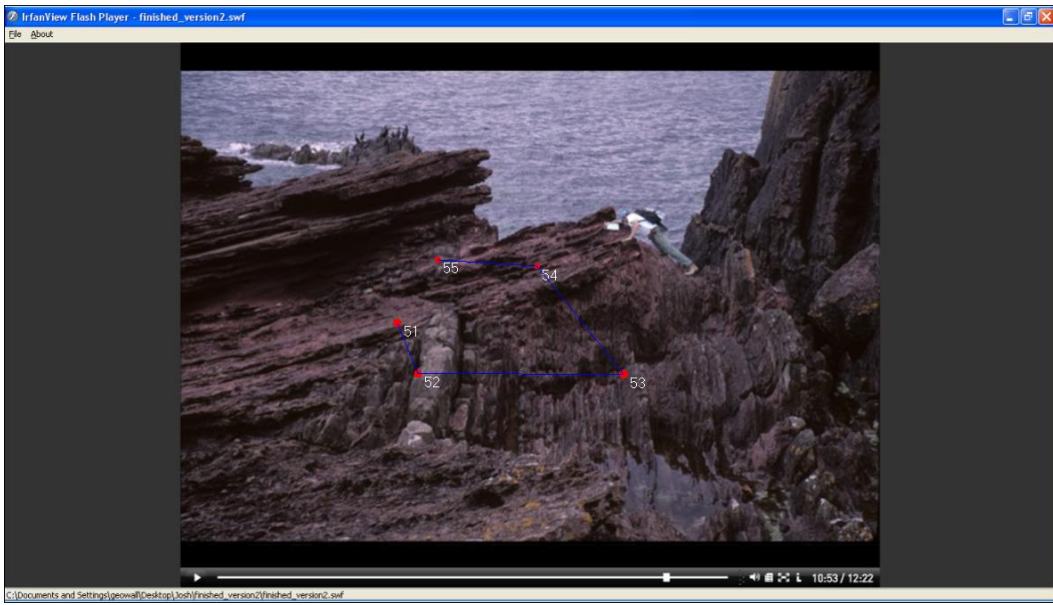


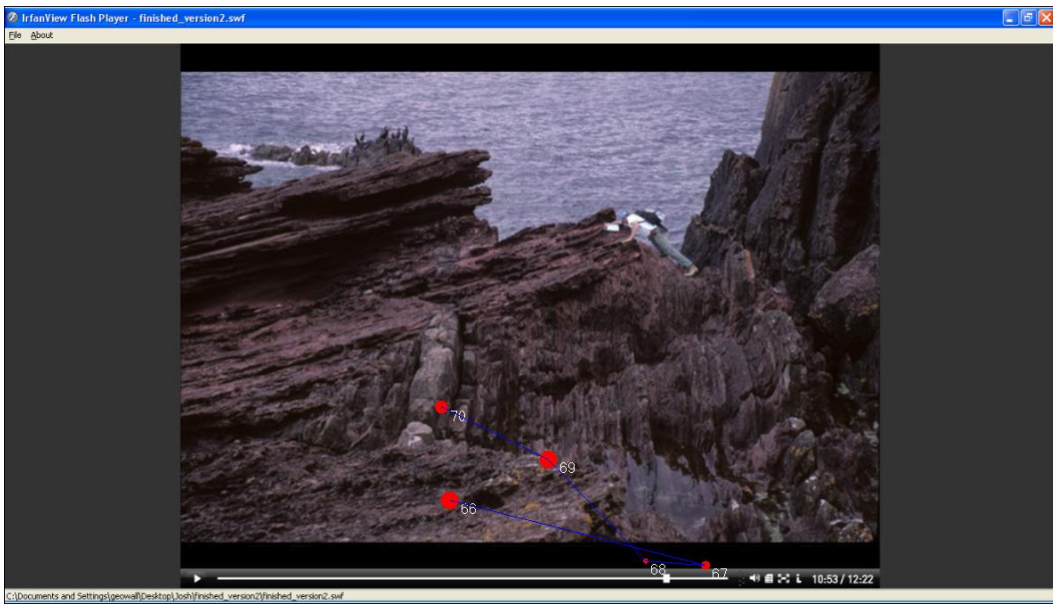
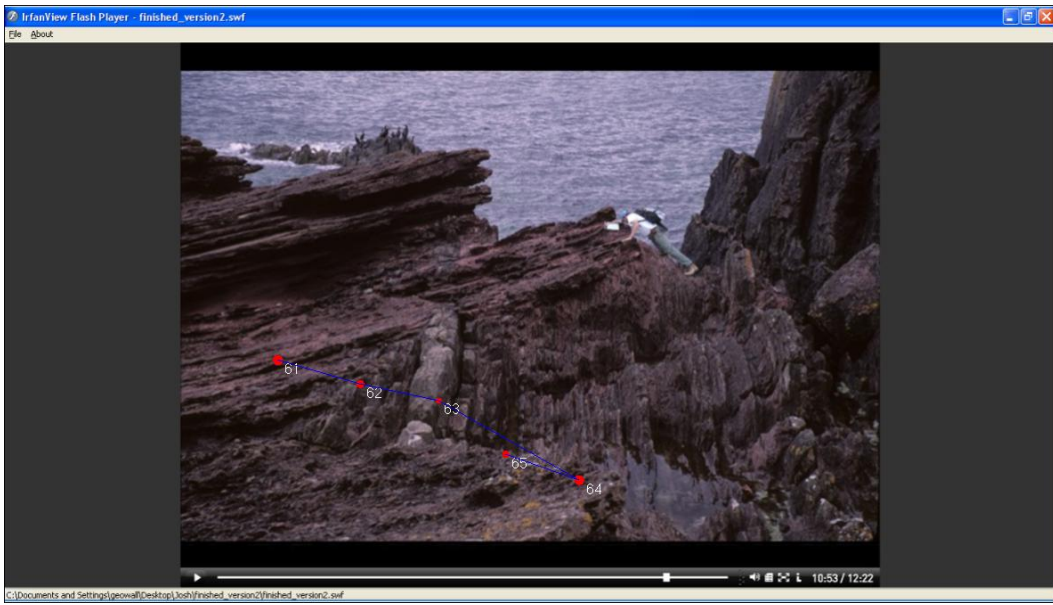


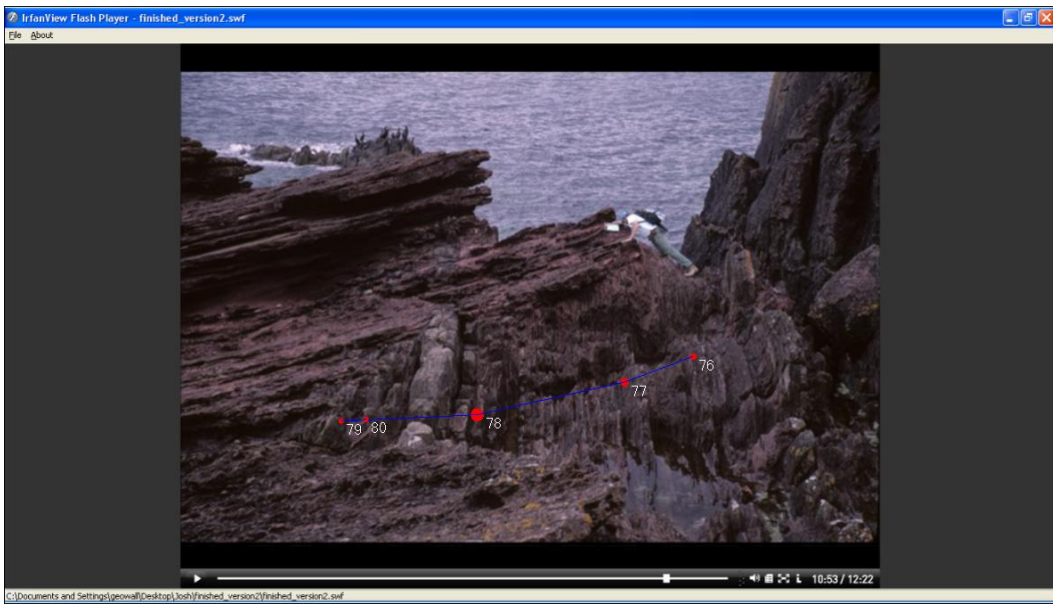
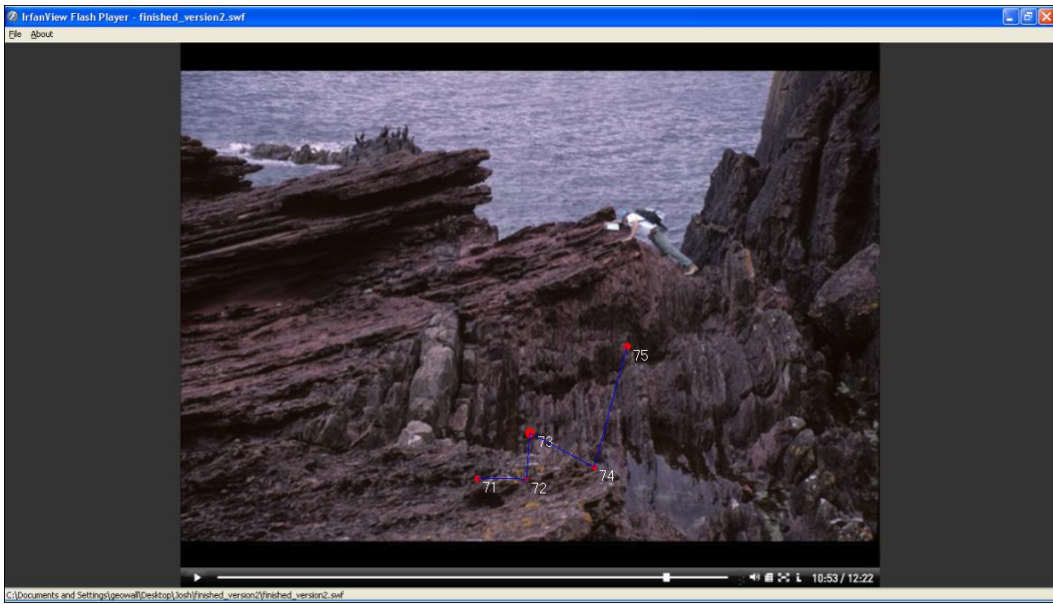






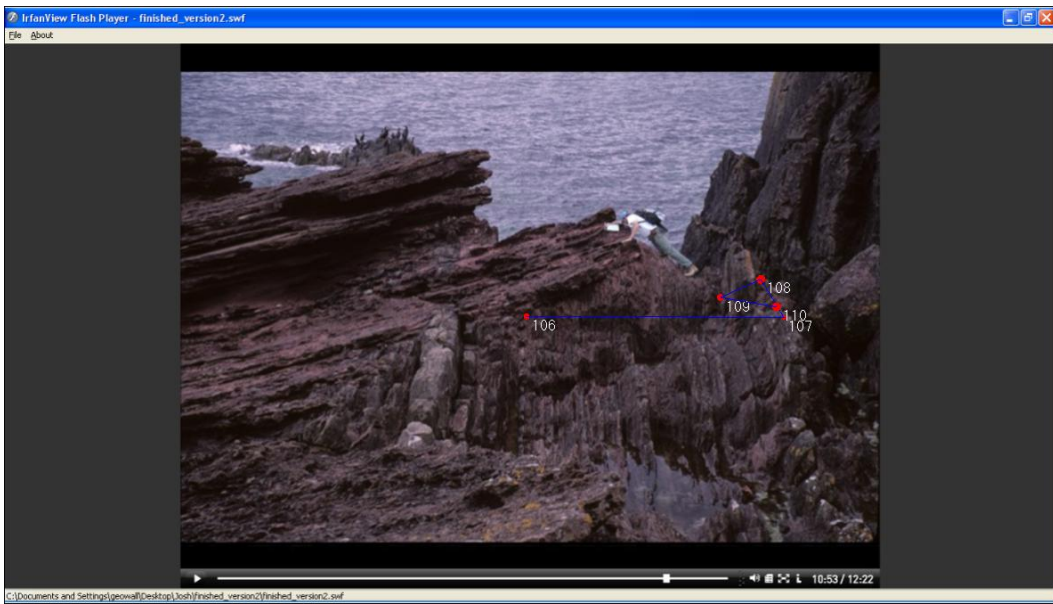










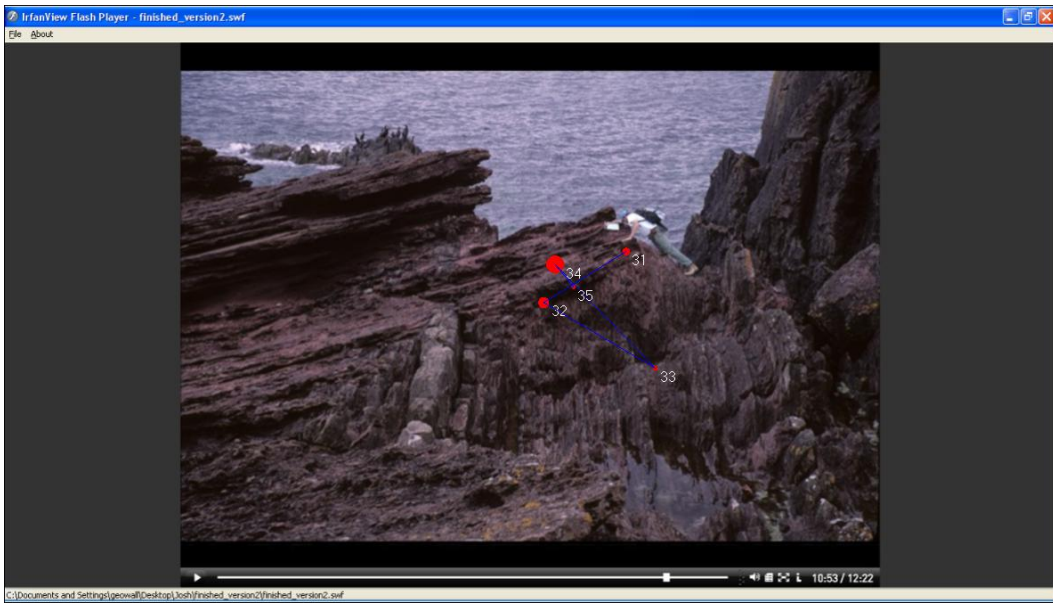


Fixation sequence diagrams for image 15 for an individual who has average distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.



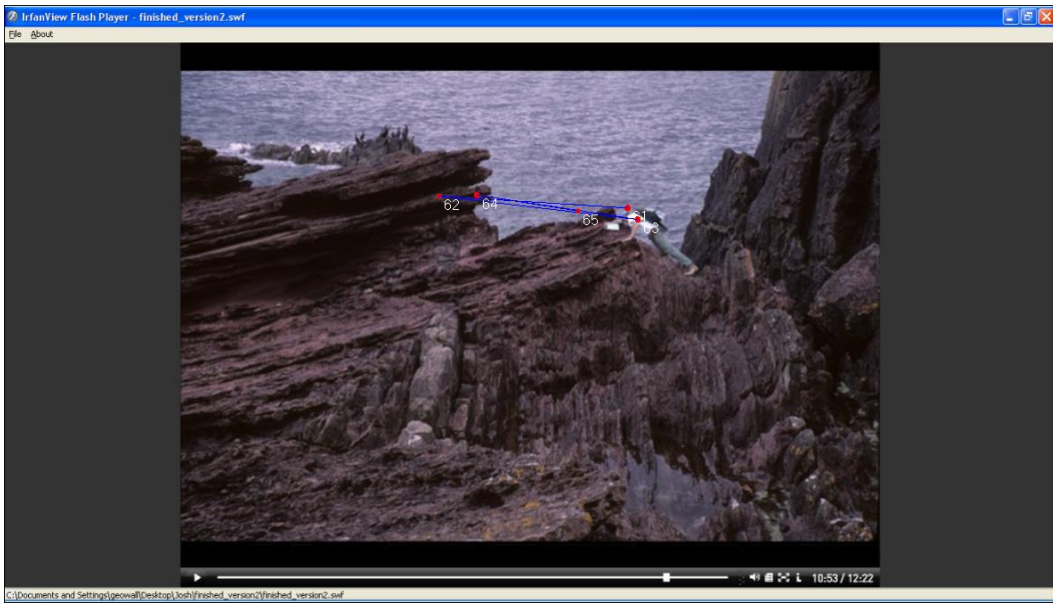


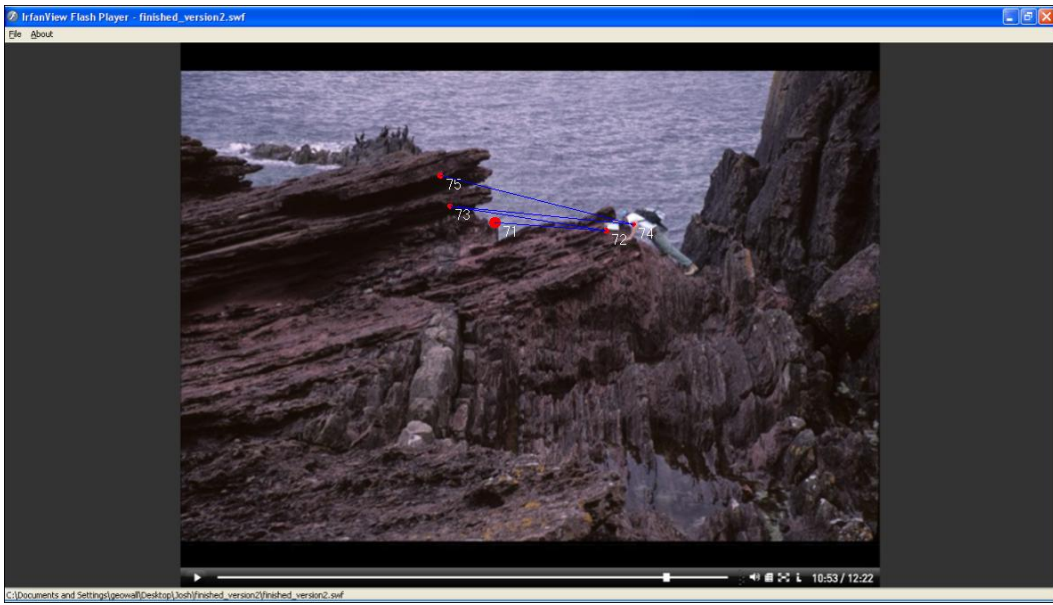


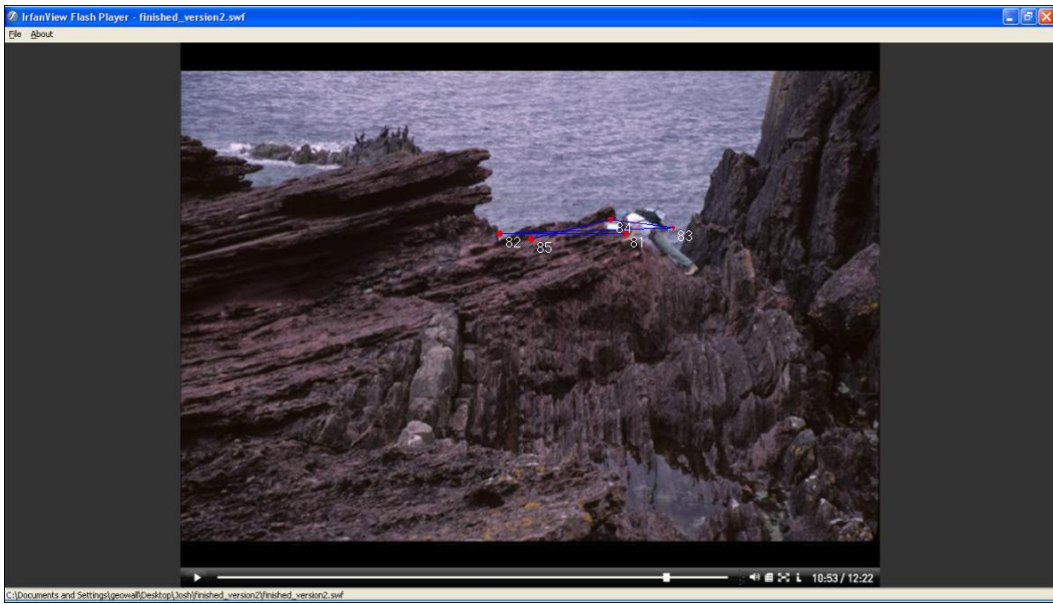








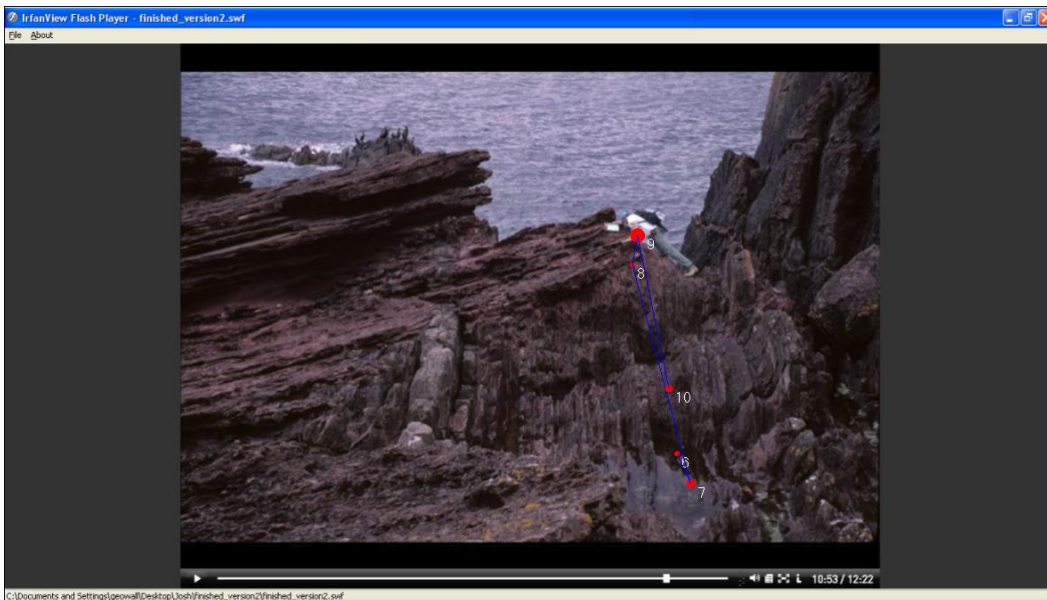




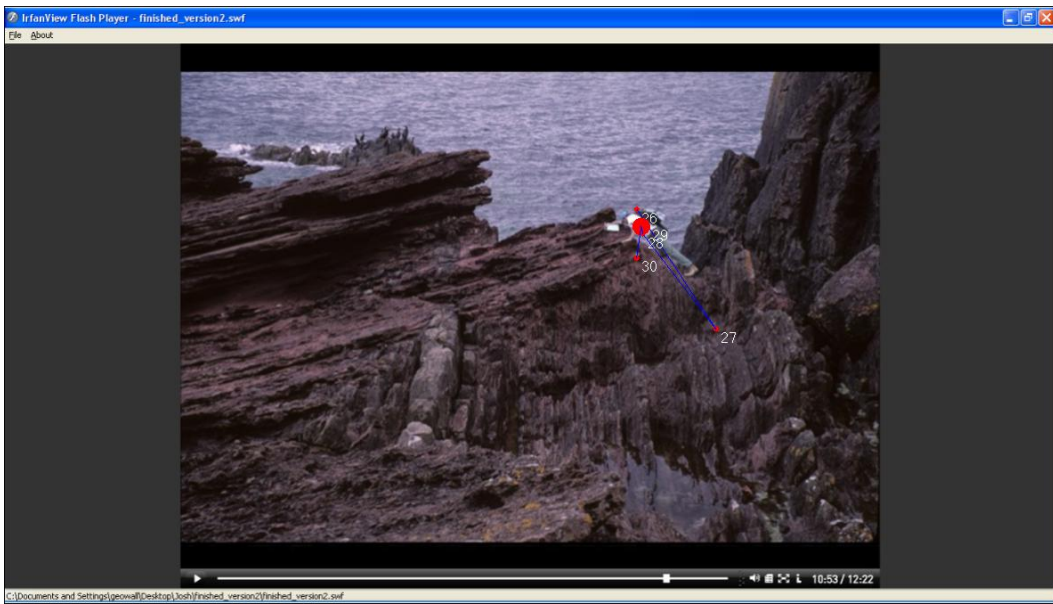




Fixation sequence diagrams for image 15 for an individual who has high distractibility. The dots are fixation locations and the lines connecting the dots are gaze paths. The number indicates the sequential fixation number as the learner viewed the image. Note, the size of the dot indicates the relative time fixating on a location, large dots indicate longer times and small dots indicate shorter times.

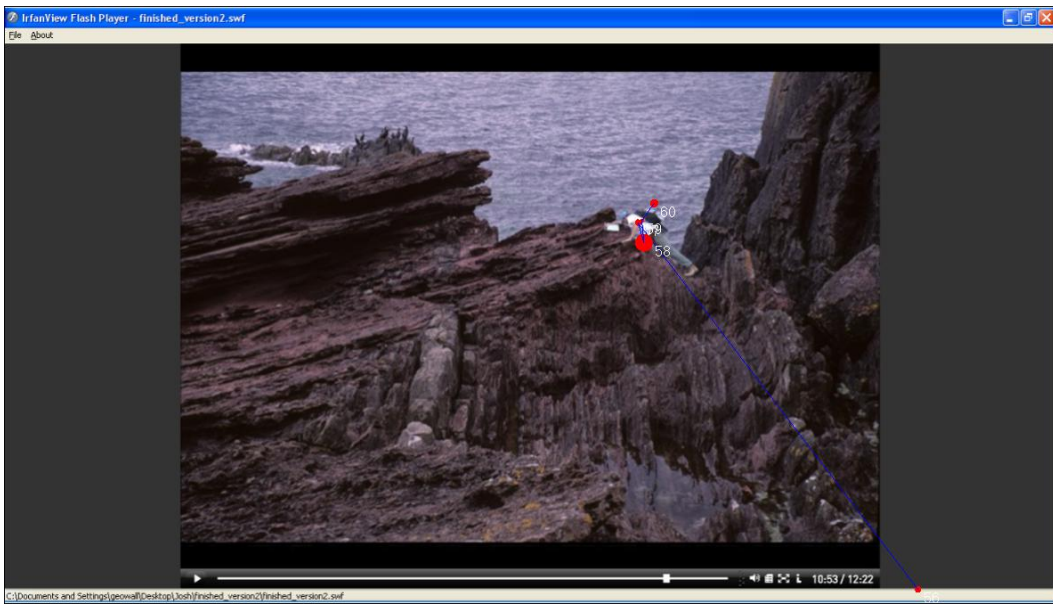


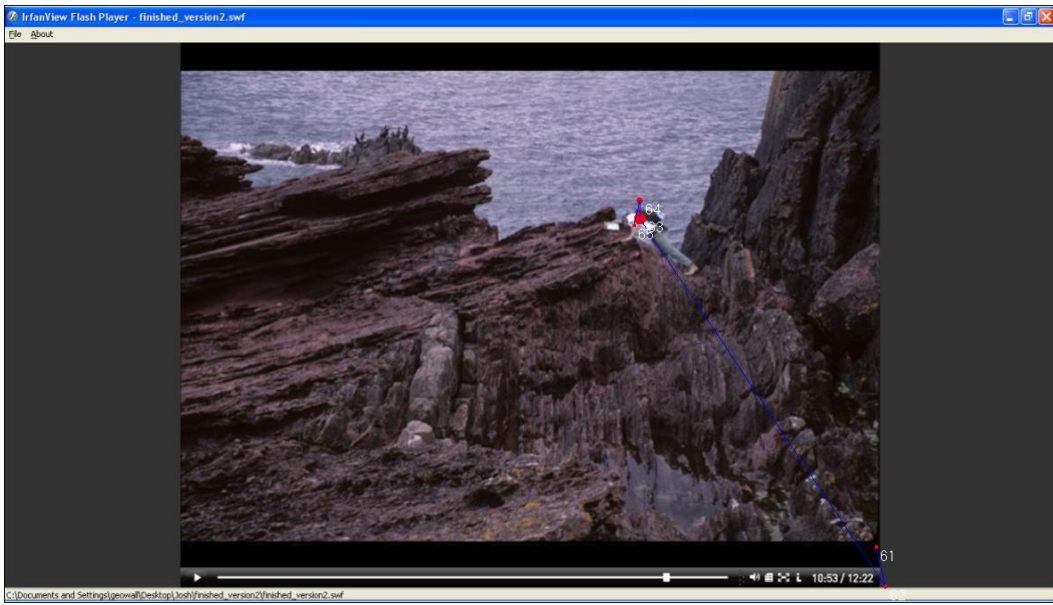








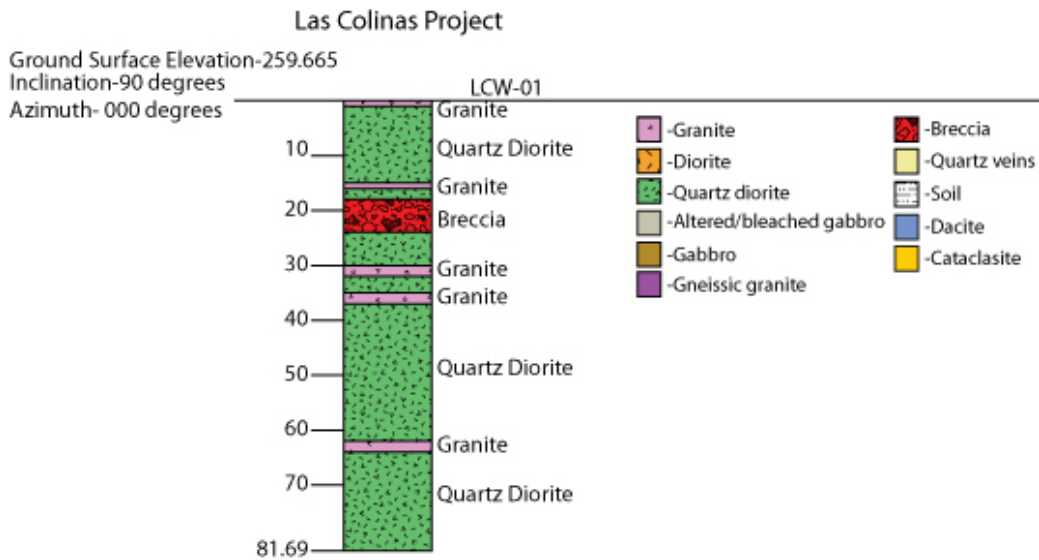




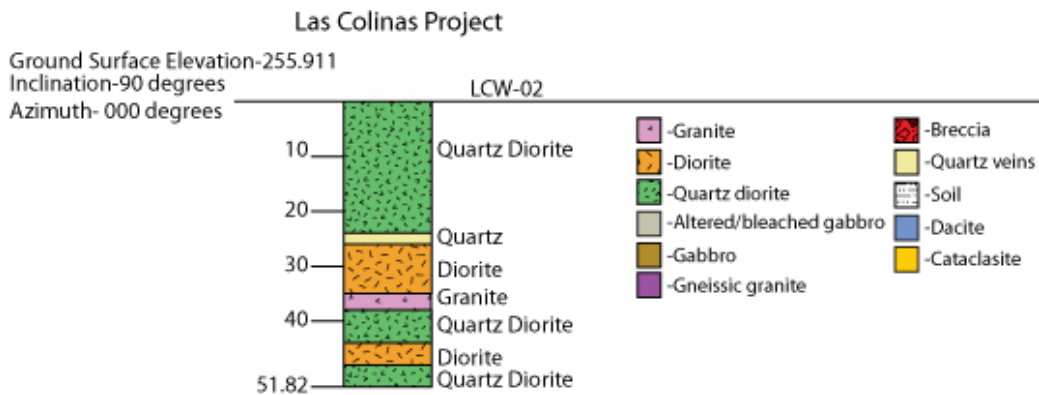


APPENDIX F

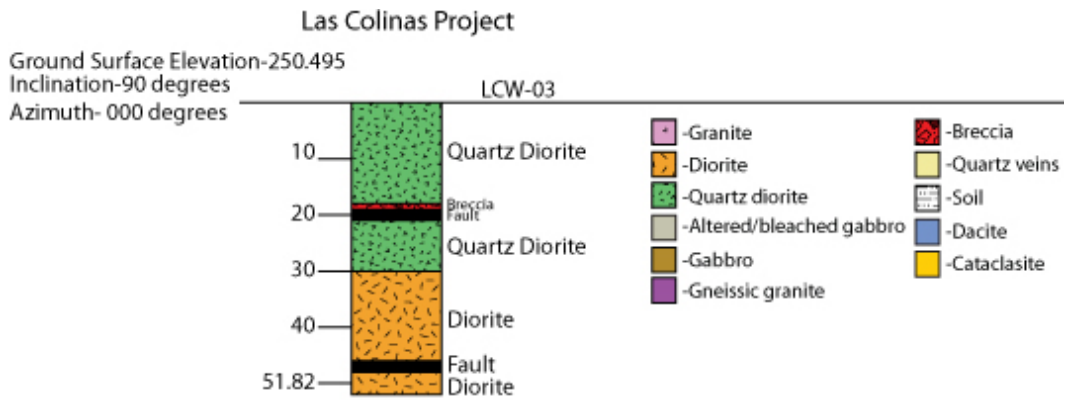
SCHEMATIC ILLUSTRATIONS OF BOREHOLE LOGS



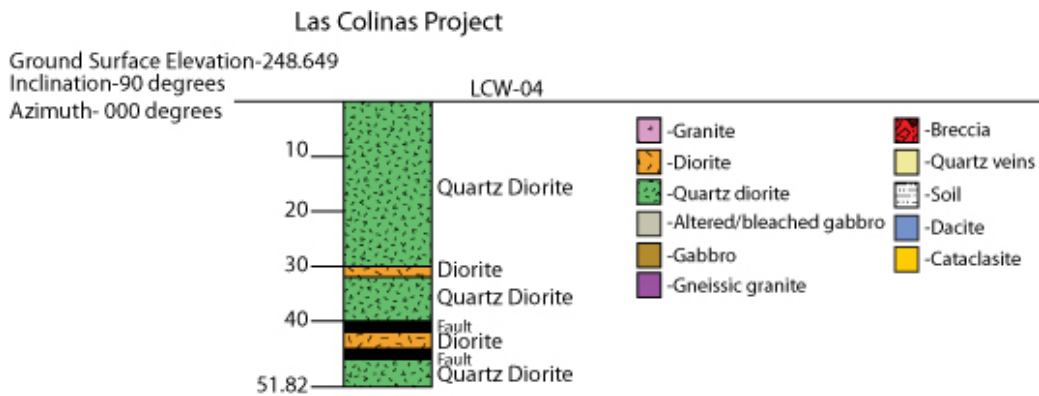
LCW-01: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



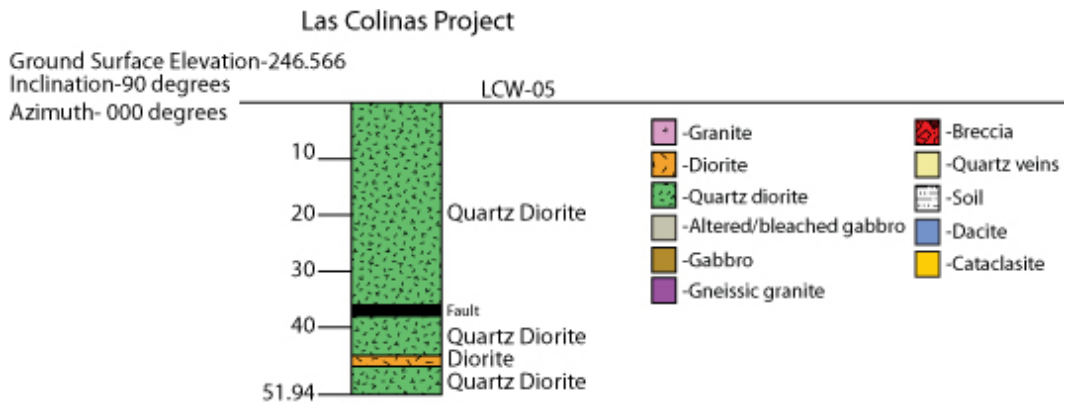
LCW-02: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



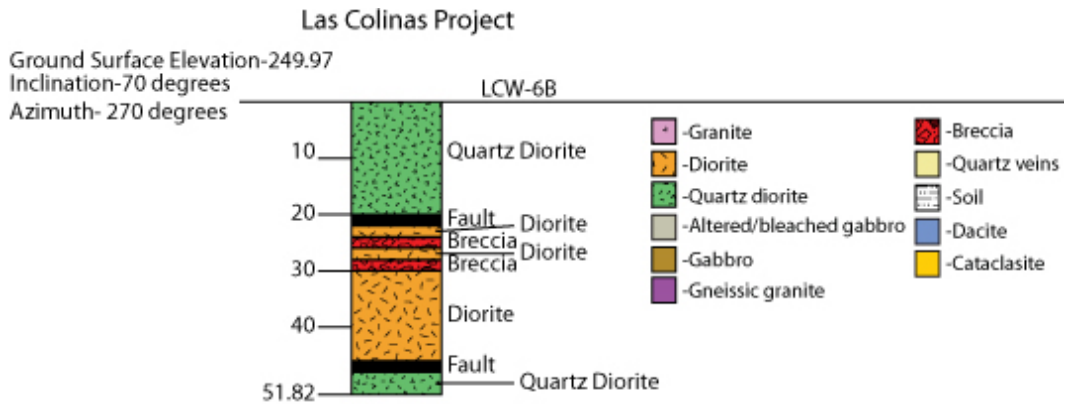
LCW-03: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



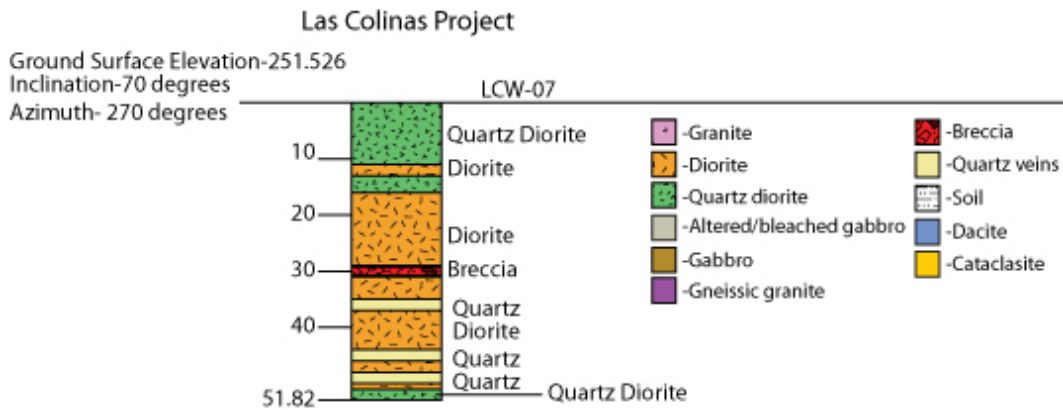
LCW-04: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



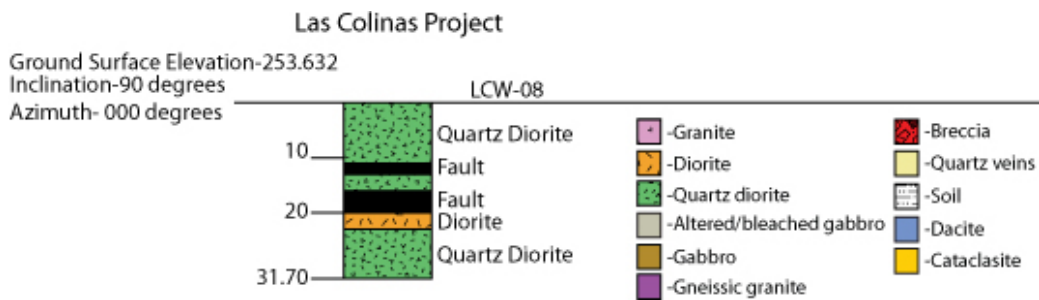
LCW-05: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



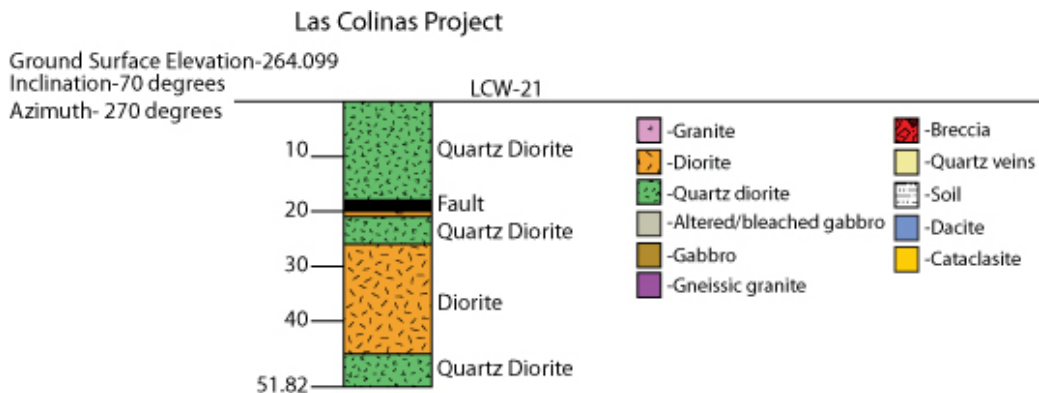
LCW-6b: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



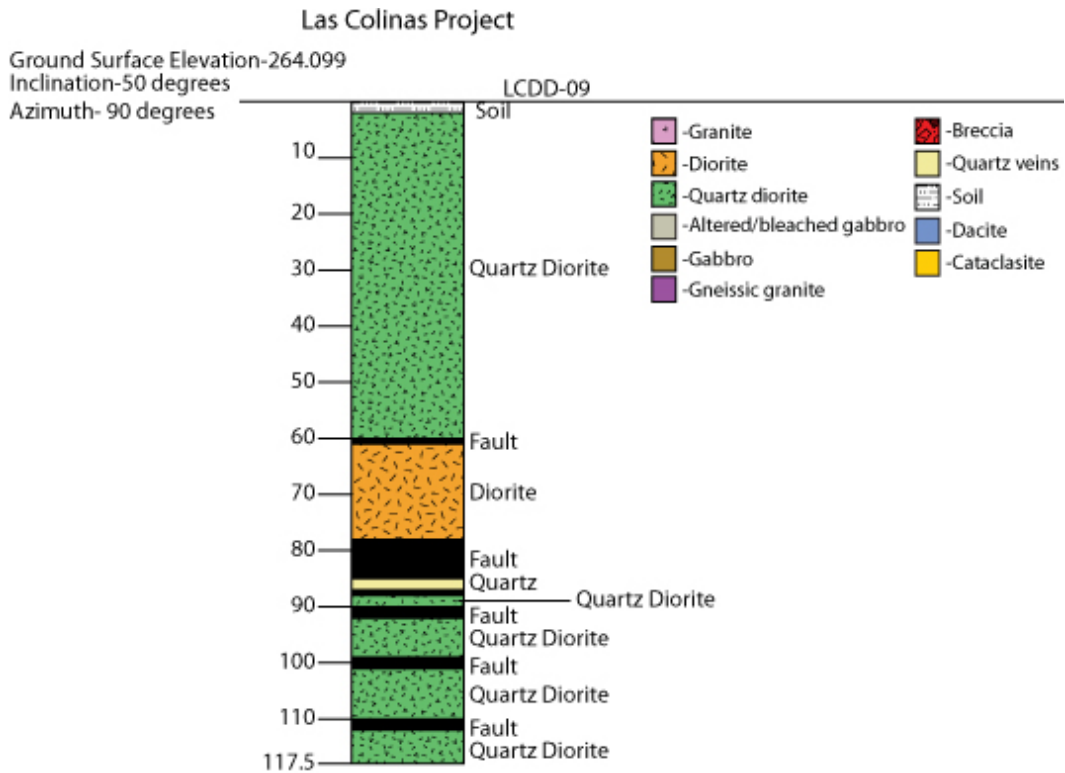
LCW-07: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



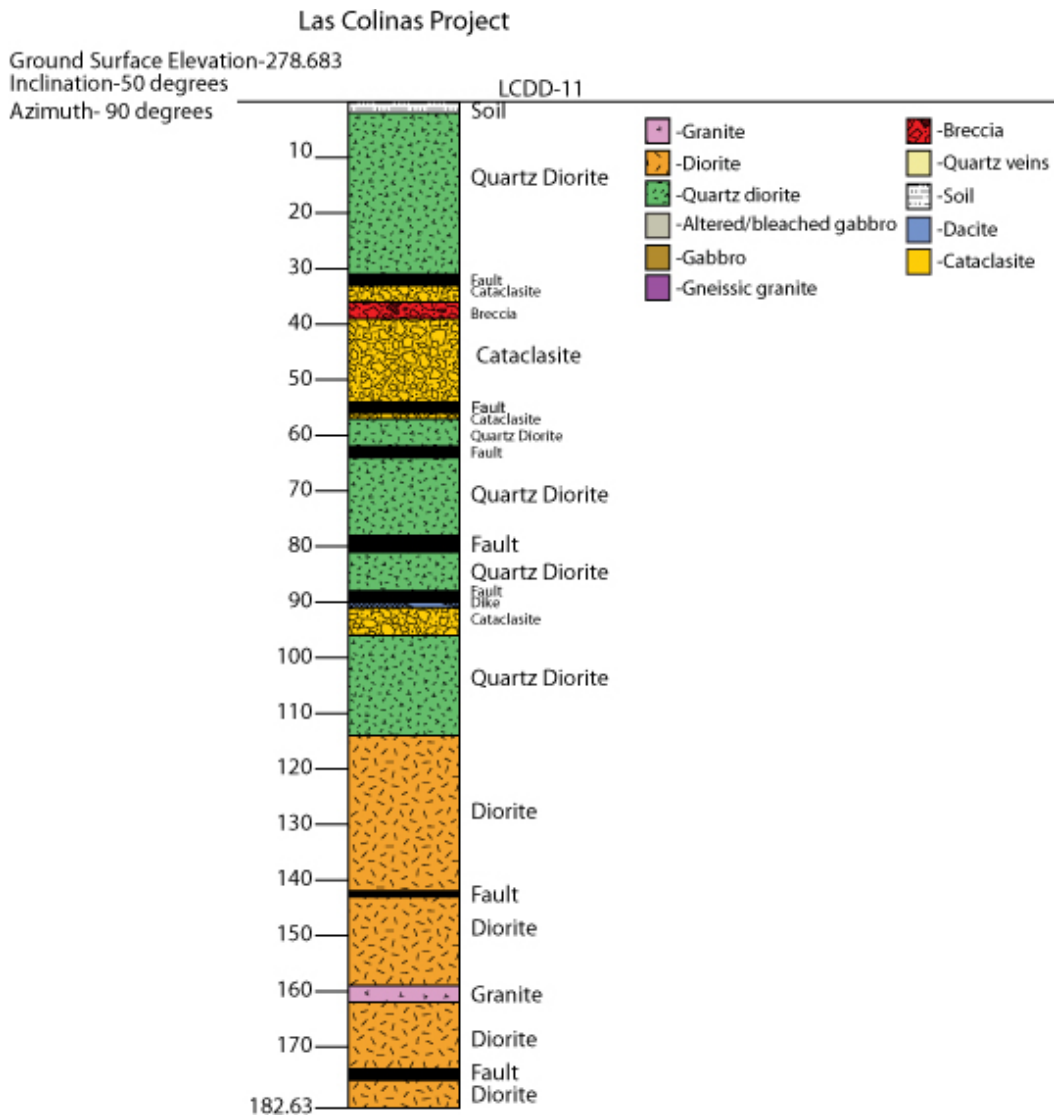
LCW-08: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



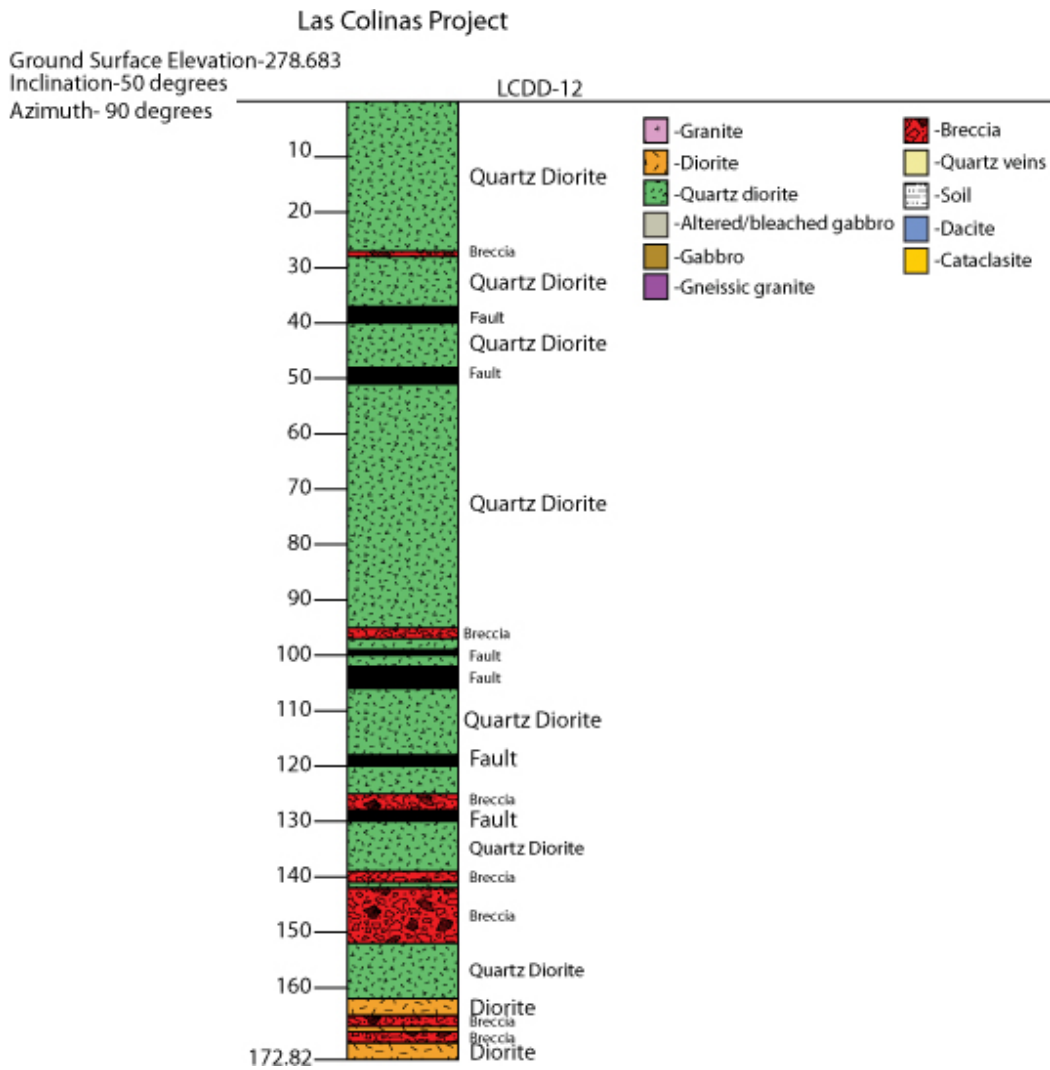
LCW-21: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



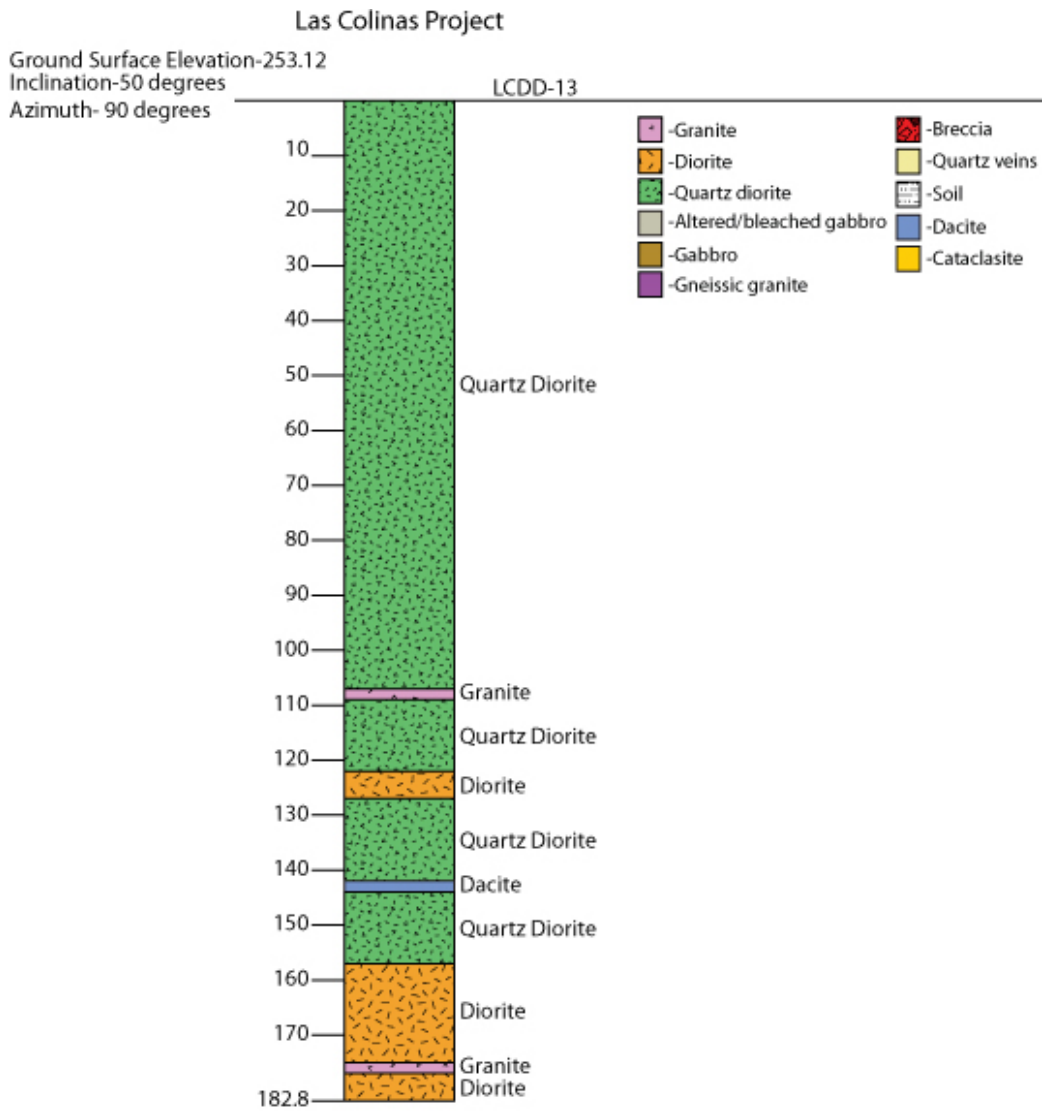
LCDD-09: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



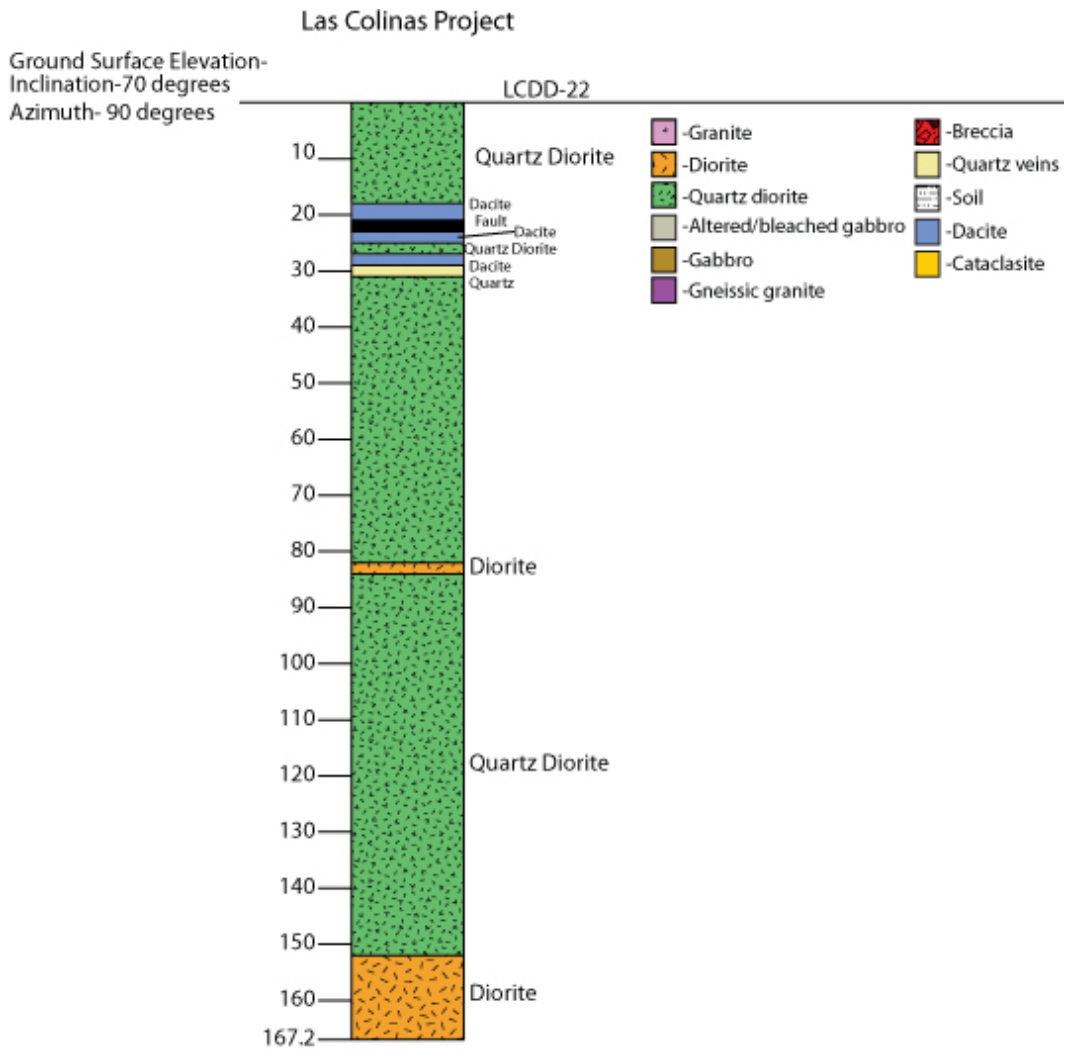
LCDD-11: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



LCDD-12: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



LCDD-13: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.



LCDD-22: Schematic illustrations of borehole logs were constructed by translating logs from Compañía Minera Pitalla.