INCREASING GEOSPATIAL LITERACY WITH GEOSPATIAL TECHNOLOGIES

TO IMPROVE GEOSCIENCE EDUCATION

by

Daniel J. Foley

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Department of Geography, Planning and Recreation

Northern Arizona University

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Committee Members:

Mark Manone (Chairperson)

Erik Schiefer

Corryn Smith

Contents:

Abstract:

Geospatial thinking integrated with the use of Geographic Information System (GIS) and other geospatial technologies is critical for geoscience education. However, in most geoscience curriculum, geospatial thinking and technology does not play a direct focus in learning objectives through practical applications. This poses a problem as students may graduate without the technological skills to be competitive in a 21st century geoscience career. Therefore, the objective of this Practicum is to provide a framework to increase geospatial literacy for geoscientists by integrating geospatial technology directly into geoscience education beginning in introductory college level geoscience courses. This is designed to give students the ability to take major geoscience concepts taught in two-dimensions and then apply that to three-dimensional space while developing a new way of geospatial thinking to form geospatial literacy. A goal of this study is to provide students the skills to develop enhanced geospatial thinking awareness and improved skills in geospatial technology by taking a constructivist learning approach. To train the next generation of geoscientists it is important to provide students with a better understanding of geospatial literacy through geospatial technology. To advance geoscience education it is suggested to use ArcGIS Pro, the most up to date version of ESRI GIS software implemented into geoscience education.

Abbreviation	Full Name
2D	Two-dimensional
3D	Three-dimensional
API	Application Programming Interface
ASU	Arizona State University
CCT	Cubes Comparison Test
CGIS	Canada Geographic Information System
CLI	Canada Land Inventory
CU	University of Colorado Boulder
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
GPS	Global Positioning systems
GRASS	Geographic Resources Analysis Support System
GST	Geospatial Technologies
GUI	Graphical User Interface
MOOC	Massive Online Open Course
NASB	Northern Arizona Seismic Belt
NAU	Northern Arizona University
NRC	National Research Council
QGIS	Quantum GIS
SAGA	System for Automated Geoscientific Analyses
SDT	Surface Development Test
STEM	Science, Technology, Engineering and Mathematics
TIN	Triangulated Irregular Network
UA	The University of Arizona
USNWR	U.S. News and World Report

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Introduction:

Geoscience instructors have a daunting task teaching introductory college level students about global earth processes, geologic hazards, and environmental science. On top of that, introducing Geographic Information Systems (GIS,) considered to be the single biggest contribution geographers have made to society and the economy since the Age of Discovery (Wiegand, 2001), poses an even greater challenge and often goes unlearned in geoscience education. However, the critical thinking, problem solving, and ability to communicate complex ideas developed with Geospatial Technologies (GST) are widely regarded by students and employers as critical competencies (Murphy, 2007). Therefore, it is suggested that modern educators adapt their curriculum and teaching to keep up with technological development and advancement for modern geoscience careers.

The education and training of undergraduate students is arguably the most important activity in any college or university department. In a world that is increasingly complex, having students move on from a geoscience course only having memorized factual content without learning critical geospatial thinking and the ability to communicate complex ideas would be a disservice to students. GIS and GST have great potential for improving students' skills in problem solving, analysis, and spatial visualization. However, they have often been fragmented or separate from traditional geoscience courses. This has left a gap of teaching GIS and GST in geoscience. Instead of a geoscience undergraduate having to take an upper division or graduate level GIS course in a separate department as they are about to graduate, findings from this study suggest integrating GIS directly into introductory geoscience education earlier in students' academic pursuit. As it can be difficult for an introductory level undergraduate student to have to figure out how to apply GIS to geoscience or geoscience to GIS, this study promotes using GIS learning modules as part of a geoscience course in which examples are provided in Appendix 1 and 2. The objective of this research is to provide a framework to implement geoscience with GST to produce better geoscientists by providing more competence in Geospatial Literacy

Geology and physical geography integration in geoscience:

The concepts discussed in this study are designed to be applicable for lower division college level science educators within a geological or geographic sciences department. Geographers study the land, its features, the inhabitants, and other physical, social, and demographic phenomena of the Earth. This is sometimes referred to as "the world discipline" with geography being labeled as a bridge between humans and the physical sciences (Gillette et al., 2015). On the other hand, geologists are often more focused solely on physical Earth processes with a chronological or geologic history perspective. This study encourages teaching geoscience with GIS as a hybrid of geography and geology including elements of both disciplines. In addition, the research for this study was developed for college level introductory physical geography or geology courses with a focus on the connection between Earth science, humans, and living with the environment.

Background:

What is a GIS:

A Geographic Information System or GIS is an interconnected system of five different parts including hardware, software, data, procedures, and people (Law and Collins, 2017). The hardware component is made up of the technical equipment needed to operate a GIS efficiently including computer infrastructure and disk space. The software component stores, analyzes, and displays geographic information while providing a Graphical User Interface (GUI) for easy display, visualizing, processing, editing, analyzing, and querying geographic data. The data, as the most important aspect of a GIS, is designed to allow integration of spatial and non-spatial data that can be organized, accessed, and managed through a Database Management System. The procedure is what makes a GIS work to go from input of data to processing, analyzing, and presenting outputs for numerous applications. The people component represents all persons involved in its operation from the technical specialist to the general users including students, planners, scientists, and engineers.

At its core, GIS is a software that displays digital images of mapped objects and their attributes allowing the user to readily visualize and analyze spatial data from complex datasets (Sinton, 2009). A GIS has many uses including creating thematic maps based on data stored in a

spreadsheet or database. GIS can be used for mapping and cartography as well as various spatial analyses allowing the user to acquire and assess information from several data sources. Some of the most powerful aspects include analytical tools to quantify relationships, use database functions for sorting, perform database searches, provide simple calculations, and run statistical analyses (Hall-Wallace and McAuliffe, 2002).

In a simplified matter GIS is essentially a comprehensive digital mapping program. The GIS framework can assess spatial data over space and time by acquiring, storing, and managing data to reveal previously hidden relationships, patterns, and trends. Furthermore, data can be linked to a map in various ways such as to a specific point or area that can dynamically be updated and represented in charts or graphics. GIS is widely regarded as a foundation for modern spatial decision making (Wiegand, 2001). The use of GIS software to display and analyze geospatial data over a large area such as *Google Earth* may also be referred to as a virtual or digital globe.

Foundation of GIS:

The GIS as we know it today had its origins in Canada dating back to the 1960s (Fu, 2015). Stemming from the need to better guide the development of land, water, and human resources with compact storage and rapid comparison of maps at various scales, the GIS concept was born (Tomlinson, 1968). To address land use problems from indiscriminate settlement, a comprehensive survey of land capability for agriculture, forestry, wildlife, fisheries, recreation, and present land use was developed by the Canada Land Inventory (CLI) (Kemp, 2008). This generated a massive amount of paperwork and a better solution to store and disseminate geospatial data was sought after. In the era before computerized maps, geographic data was often analyzed manually by overlaying printed maps with clear plastic sheets to assess geospatial relationships. This was a very time-consuming process that led Roger Tomlinson, known as the "Father of GIS" to his pioneering work on the Canada Geographic Information System (CGIS). Beginning in 1962 for Canada's most comprehensive and ambitious land resource survey program for the CLI, Roger Tomlinson was instrumental in helping to develop this revolutionary approach to digital mapping (Fisher, 1980). The CGIS that resulted from this project designed to

store maps and support planners with land use analysis is now widely regarded as the first operational GIS (Tomlinson, 1998).

GIS Today:

Today, the main supplier of GIS software, Web GIS, and geodatabase management applications worldwide are provided by the Environmental Systems Research Institute commonly referred to as ESRI based out of Redlands, California. Although ESRI's Graphical User Interface (GUI) based ArcMap and the ArcGIS suite of geospatial processing programs are the most commonly used and taught GIS in higher education in the USA, there are several other GIS software packages in use from GUI to Application Programming Interface (API) based. Several GIS software packages are in use as an alternative to the ESRI GIS suite and are available from commercial and open source providers. To note just a few prominent open source providers of GIS software packages significant to geoscience education include: QGIS formerly known as Quantum GIS that runs on Linux, Unix, Mac OS X and Windows, GRASS (Geographic Resources Analysis Support System) which functions as a complete GIS originally developed by the U.S. Army Corps of Engineers, and SAGA (System for Automated Geoscientific Analyses) useful for geoscientists as it was designed to give scientists and effective but easily learnable platform for implementing geoscientific methods bundled in exchangeable module libraries. Open source GIS software packages may be of high interest to educational intuitions lacking the funding to pay for licensing of GIS software.

Literature Review:

      Definitions:

Table 1. Definitions of main conceptual key spatial terms used in this Practicum with descriptions and references provided.

Key Terms	Definitions	References
Spatial Thinking	A set of abilities to visualize and interpret location, position, distance, direction, relationships, movement and change through space by cognitive processions of spatial data that is stored in memory and can be represented externally by visualizations.	Uttal 2000; Sinton, 2011; Sinton et al. 2013
Critical Spatial Thinking	Critical thinking applied to spatial thinking which can produce spatial reasoning.	Bednarz and Kemp, 2011
Spatial Reasoning	A sub skill of spatial thinking distinguishing it as the specific processes applied while thinking spatially in the context of problem solving and decision-making.	Goodchild and Janelle, 2010
Spatial Literacy	The outcome of critical spatial thinking and spatial reasoning.	Goodchild and Janelle, 2010; Bednarz and Kemp, 2011

      Spatial Thinking:

      To begin to understand how to better teach Geospatial Thinking and provide more geospatial awareness in geosciences, one must first understand the concept of Spatial Thinking. Spatial Thinking is fundamental to problem solving providing a powerful tool to go from description, to analysis, to inference. Spatial Thinking is a broad concept, yet it can be summarized as the ability to study the characteristics and the interconnected processes of nature and human impact in time and at appropriate scales (Kerski, 2008). According to the National

Research Council's (NRC) report: '*Learning to Think Spatially* (NRC, 2006), spatial thinking is vital to everyday life, work, and science with several real-world applications including:

• Visualizing a three-dimensional (3D) object or structure or process by examining observations collected in one or two dimensions

• Describing the position and orientation of objects one may encounter in the real world relative to a conceptual coordinate system anchored to Earth

• Remembering the location and appearance of previously seen items, envisioning the motion of objects or materials through space in three dimensions, and envisioning the processes by which objects change shape

• Using Spatial Thinking to think about time, and considering two-, three-, and four-dimensional systems where the axes are not distance

To further elaborate, Spatial Thinking can be defined as a set of abilities to visualize and interpret location, position, distance, direction, relationships, movement and change through space by cognitive processions of spatial data that is stored in memory and can be represented externally with visualizations (Uttal 2000; Sinton, 2011; Sinton et al. 2013) (Table 1). This concept can be thought of as series of knowledge, tools and skills, and habits of mind. This series can then go on to form a collection of cognitive skills comprised of knowing concepts of space, using tools of representation, and reasoning processes to form knowledge of space (Zwartjes et al., 2017). The links among these three aspects of A) Spatial concepts, B) Spatial representation, and C) Spatial reasoning give Spatial Thinking its power of versatility and applicability (Michel and Hof, 2013) as represented in Figure 1. Given the rise of online maps, mobile GPS apps, and digital navigation, a growing number of the current student population is likely more aware of the possibilities of spatial data. This has great potential to foster an era of increased Spatial Thinking in education with students better able to visualize relationships between and among spatial phenomena (Stoltman and De Chano, 2003).
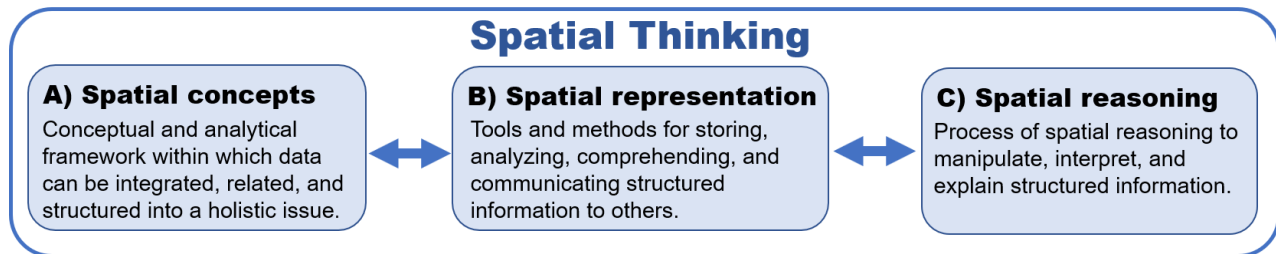
Figure. 1. The development of Spatial Thinking through interconnected dimensions and related concepts. Modified from (NRC, 2006; Michel and Hof, 2013).

Geospatial Thinking:

Defining Geospatial Thinking is more complex than Spatial Thinking. Whereas spatial thinking has a deep-rooted base in the field of psychology, there is a less widely recognized agreement on narrowly defining what Geospatial Thinking is. Geospatial Thinking definitions can range from broad generalizations such as acquiring knowledge, structuring and solving problems, and expressing the solutions effectively using the properties of space (Asami and Longley, 2012) to specific, skill-based ideas such as identifying, analyzing, and understanding the location, scale, patterns, and trends of geographic and temporal relationships among data, phenomena, and issues (Kerski, 2013). Another aspect that can be included in geospatial thinking defined by Bodzin et al., (2014) is to include it as a specialized form of spatial thinking bound by Earth, landscape, and environmental scales. Further adding complexity, Geospatial Thinking can also include reasoning skills that are higher-order cognitive processes providing a way to manipulate, interpret, and explain information, solve problems or make decisions at geographic scales (Baker et al., 2015). Although geospatial thinking can include all aspects discussed here, adding a higher order connection to Earth, landscape, and environmental scales to Spatial Thinking yields a modified meaning of Geospatial Thinking applicable to this study (Figure 2). As this study is more focused on Geospatial Thinking in the context of geoscience, Geospatial Thinking can be defined as a specialized form of Spatial Thinking that is inherently linked to Earth, landscape, and environmental scales (Table 2).
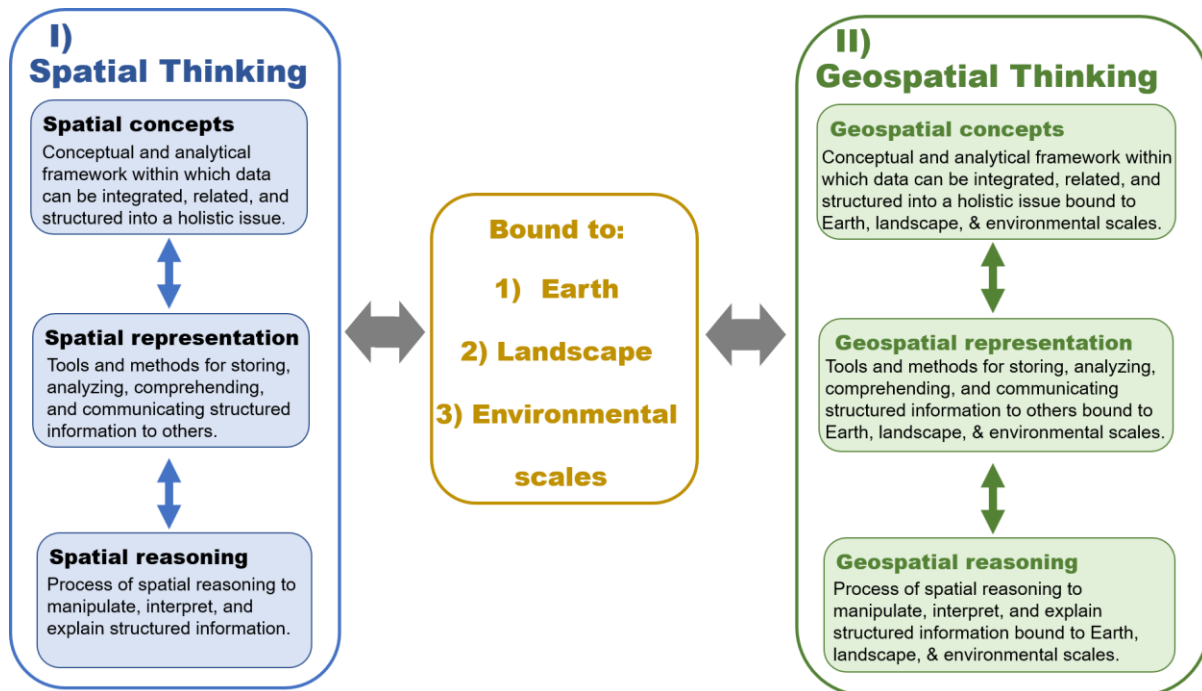
Figure 2. The development of Geospatial Thinking. Geospatial Thinking is defined as a specialized form of I) spatial thinking that is inherently linked to Earth, landscape, and environmental scales to form II) geospatial thinking.

Table 2. Definitions of main conceptual key geospatial terms used in this Practicum with descriptions and references provided.

Key Terms	Definitions	References
Geospatial Thinking	A specialized form of spatial thinking that is inherently linked to Earth, landscape, and environmental scales.	Asami and Longley, 2012; Kerski, 2013; Bozdin et al., 2014; Baker et al., 2015
Critical Geospatial Thinking	Critical thinking applied to geospatial thinking which can produce geospatial reasoning bound to Earth, landscape, and environmental scales.	Defined this study based on various sources
Geospatial Reasoning	A sub skill of geospatial thinking distinguishing it as the specific processes applied while thinking geospatially in the context of problem solving and decision making bound to Earth, landscape, and environmental scales.	Defined this study based on various sources
Geospatial Literacy	A combination of critical geospatial thinking and geospatial reasoning relevant to the Earth, landscape and environmental scales that also includes a GST component.	Defined this study based on various sources

Geospatial Technologies (GST):

Geospatial Technologies (GST), once regarded as only being used by professionals is now being taught in middle school through graduate school. GST often comprise four core components including GIS, Remote Sensing, global positioning systems (GPS), Information Technology (including Web GIS and Programming), and Digital Globes such as *Google Earth* (Baker et al., 2015; Smith, 2019). However, it should be noted that a major component of what makes GIS so powerful to geoscience is the use of Digital Terrain data. Digital Terrain data, also included with GST, encompasses a wide range of data including Earth surface elevation data such as raster-based Digital Elevation Models (DEM) and vector based Triangulated Irregular Networks or TINs.

The increasing availability of Digital Terrain in the few decades has revolutionized GST and has expanded the research capabilities for geoscientists and geospatial scientists alike. In the past, separate topographic maps, aerial imagery, relief maps, and stereoscopic anaglyphs have all been used to aid the understanding of the Earth's surface. However, Digital Terrain data has largely changed that making it important for today's geoscientists to understand its potential applications with GST. For instance, through innovations in remote dissemination and integration with GIS, initial Digital Terrain data can be used to produce even more derivative Digital Terrain data including slope angle, aspect, hydrologic watershed analyses or topographic flow accumulation to name a few (Allen et al., 2008). For this study, GST can be defined as any technology, tool, or resources used in aiding geospatial thinking and analysis that may include GIS, Remote Sensing, GPS, Digital Globes, and Digital Terrain data that may be implemented in computer desktop configurations or with mobile apps and devices. Although GST can include several applications and is becoming increasingly mobile, it has traditionally and mostly commonly been used as Desktop GIS in a classroom setting. However, there is a Web GIS shift growing with increasing use of ArcGIS online and other web based GIS used in classrooms (Smith, 2019).

Table 3. Definitions of main conceptual central theme terms used in this Practicum with descriptions and references provided.

Central Theme	Definitions	References
Geospatial Technologies	Any technology tool or resources used in aiding geospatial thinking and analysis that may include GIS, Remote Sensing, GPS, Digital Globes, and Digital Terrain data that may be implemented in computer desktop configurations or with mobile apps and devices.	Allen et al., 2008; Baker et al., 2015
Geoscience	Earth science with a focus on geology and physical geography relating to the lithosphere, hydrosphere, and interaction with the human environment.	Frodeman, 1995; King, 2008; van der Hoeven Kraft, 2011

Geoscience:

Geoscience is a relatively new term for the Earth sciences that has expanded from just description of Earth processes and materials. Instead, it can include elements of any discipline that pertains to the study of Earth as a system including elements of geology, physical geography, meteorology, oceanography, atmospheric science, geomorphology, and soils (King, 2008; van der Hoeven Kraft, 2011). However, the term geoscience in this study will be focused more in the context of geology as pertaining to the solid surface of the Earth. As geology is unique from other Earth sciences in that it is an interpretive and historical science involving a wide range of methodologies including retrodictive thinking (prediction of the past) for large-scale thinking and often involves integrating large and incomplete data sets (Frodeman, 1995), utilizing GST can be especially important to aid in learning and teaching geoscience.

The geoscience applications discussed in this study are not restricted to only material that would be housed in an introductory geology course. Instead, this study is designed to encompass aspects of geographic thought including geospatial analysis and human interaction that overlaps with physical geography. Whereas geology is more than the identification of rocks, minerals, and landscapes, geography is more complex than merely identification of cities, states, and countries. Geography means "Earth description" and Geology means "study of Earth" from Greek. Both of these fields share in common the aim to better understand phenomena pertaining to the Earth. However, the study of geography has branched out and is commonly divided into three main

components: human geography, physical geography, and technical geography referring to those who study GST (Gillette et al., 2015; Smith, 2019). In the context of this study, geoscience is broadly defined to include Earth science aspects of geology and physical geography relating to the lithosphere, hydrosphere, and interaction with the human environment (Table 3).

The role of maps in geoscience:

A map for a geoscientist can be thought of as the culminated expression of geoscientific and geospatial thought. As geoscience is often a collaborative science, mapping and sharing of observations and interpretations with maps plays a fundamental role in the practice of geoscience. From William Smith's *A Geological Map of England and Wales and Part of Scotland* published in 1815 marking the first detailed nationwide geologic map (Smith, 1815), to mapping today with mobile devices equipped with the latest GST, the ability to make maps is integral to geoscience. Prior to digital mapping, a great emphasis was placed on artistic ability to produce a physiographic map that required the best knowledge of the physiography of the region in question and certain drawing abilities (Raisz, 1931). GIS has since changed that by reducing the need for drawing ability in map making. Thus, greatly advancing the field of geoscience with its ability to regularly produce high precision maps with aesthetically pleasing quality for optimal communication aspects. Maps and GIS go hand in hand in modern geoscience with various applications to display and share geospatial data.

A geoscientist's map may be different from that of a cartographer's as it is representing more than just spatial data. Instead it is often designed to provide new insight and perspective relative to the Earth to make more informed geoscience decisions. Practical applications of GIS that highlight maps in geoscience are provided in Figures 3-7 to demonstrate some of the diverse capabilities GIS can provide to better communicate geoscience. GIS can be used to do more than just display all rock types on a surface. For instance, it can be used to analyze geospatial relationships and only display select rock types, ages, and proximities to certain other rock types to narrow down the most optimal sample locations for a geologist planning fieldwork. An example of this is shown as a case study of developing maps for a sample selection strategy applicable to the enigmatic Ancestral Rocky Mountains by Foley (2017) in Figure 3.

GIS can also enhance existing maps by utilizing Digital Terrain data such as Landsat satellite imagery and ASTER DEM data to display hillshades and textures. As noted in Figure 4, this capability is demonstrated in the context of making a map for field geologists to accurately portray the landscape in a remote location by adding geospatial depth to traditional geologic maps (Foley, 2013). Moreover, GIS can model interpreted 3D geologic structures from 2D terrain by essentially adding an unseen geospatial connection to field observations as depicted in Figure 5 by Foley (2011). In addition to mapping a static surface, GIS has an important role to play for other Earth observation geoscientists who may be interested in correlating dynamic data with locations categorized by attribute data to different global geospatial variables such as in the case of mapping global cropland vegetation as demonstrated in Figure 6 (Foley et al., 2019). Furthermore, GIS can provide the ability elucidate a complex geospatial methodology used to investigate global phenomena relative different variables such as mapping crop water productivity relevant to climate, soil, and latitude as shown in Figure 7 (Foley, 2019). Although there are numerous other applications of using maps to communicate geoscience and geospatial science, this has shown a few examples highlighting that a strong foundation in GST can advance the sharing of Earth science ideas and can even expand maps beyond the two-dimensional.
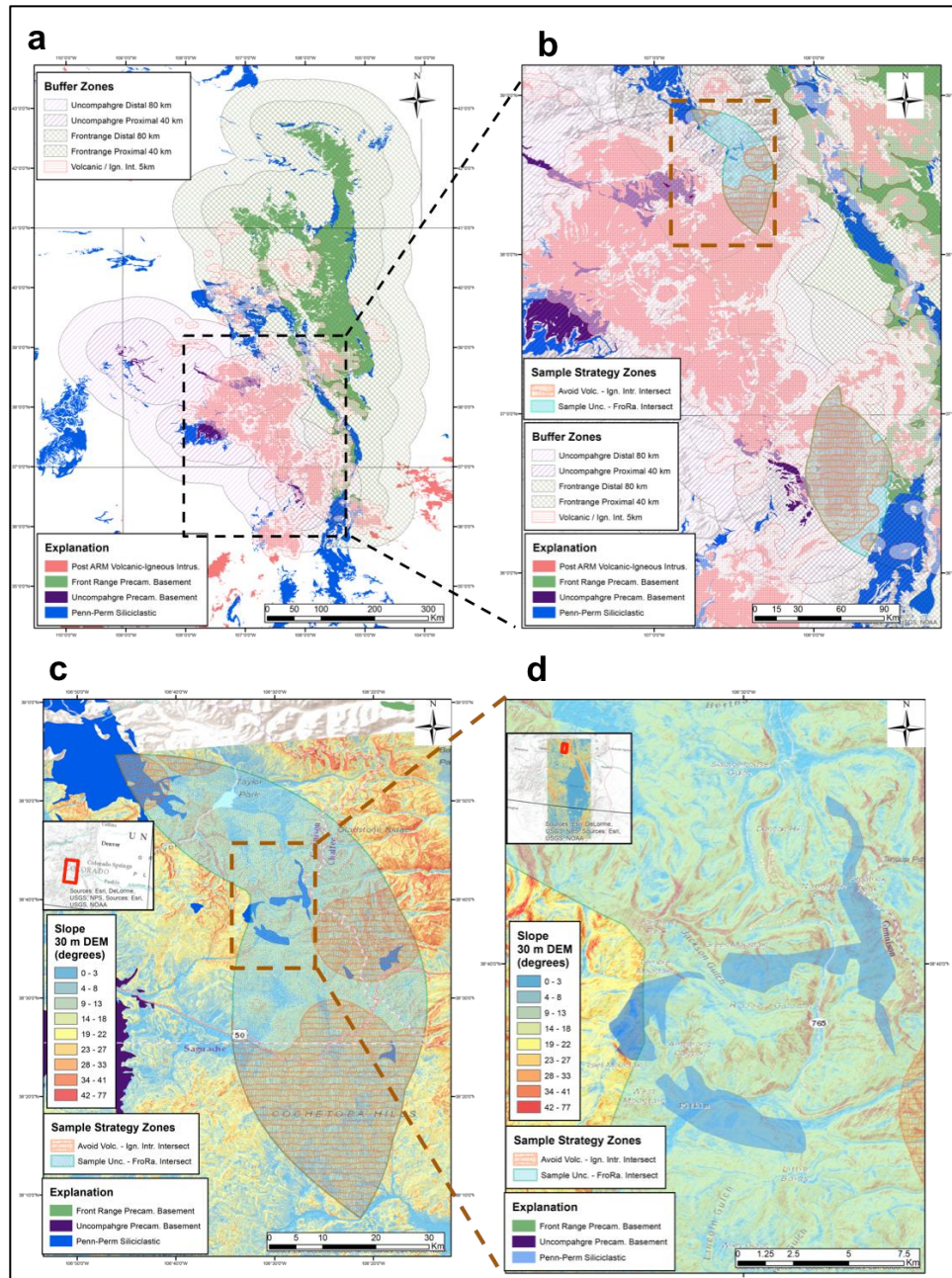
Figure 3 a-d) Ancestral Rocky Mountain (ARM) geology maps. Maps highlight how GIS can help in identifying geology field work sites. This example shows how a variety of geospatial analysis tools combined with geologic maps and a DEM can narrow down a sample area near Pitkin, Colorado (Foley, 2017). Made with ESRI ArcMap GIS.
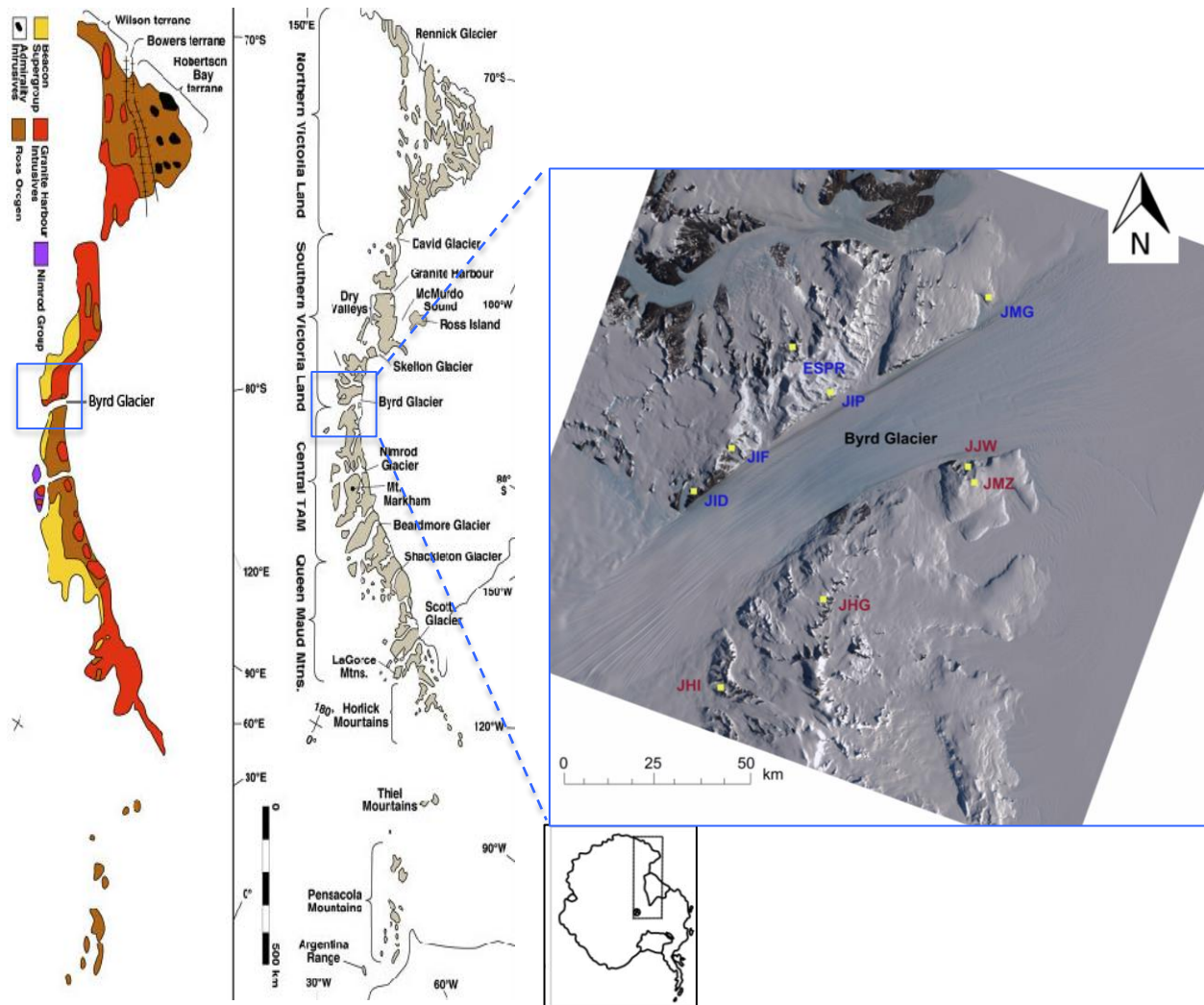
Figure 4. Maps of the Byrd Glacier region of Antarctica within the central Transantarctic Mountains. Locations of Kukri erosion surface with corresponding rock sample locations plotted on a digital elevation model overlain with Landsat image (Foley et al., 2013). Made with ESRI ArcMap, GIS ASTER DEM, and Landsat satellite imagery.
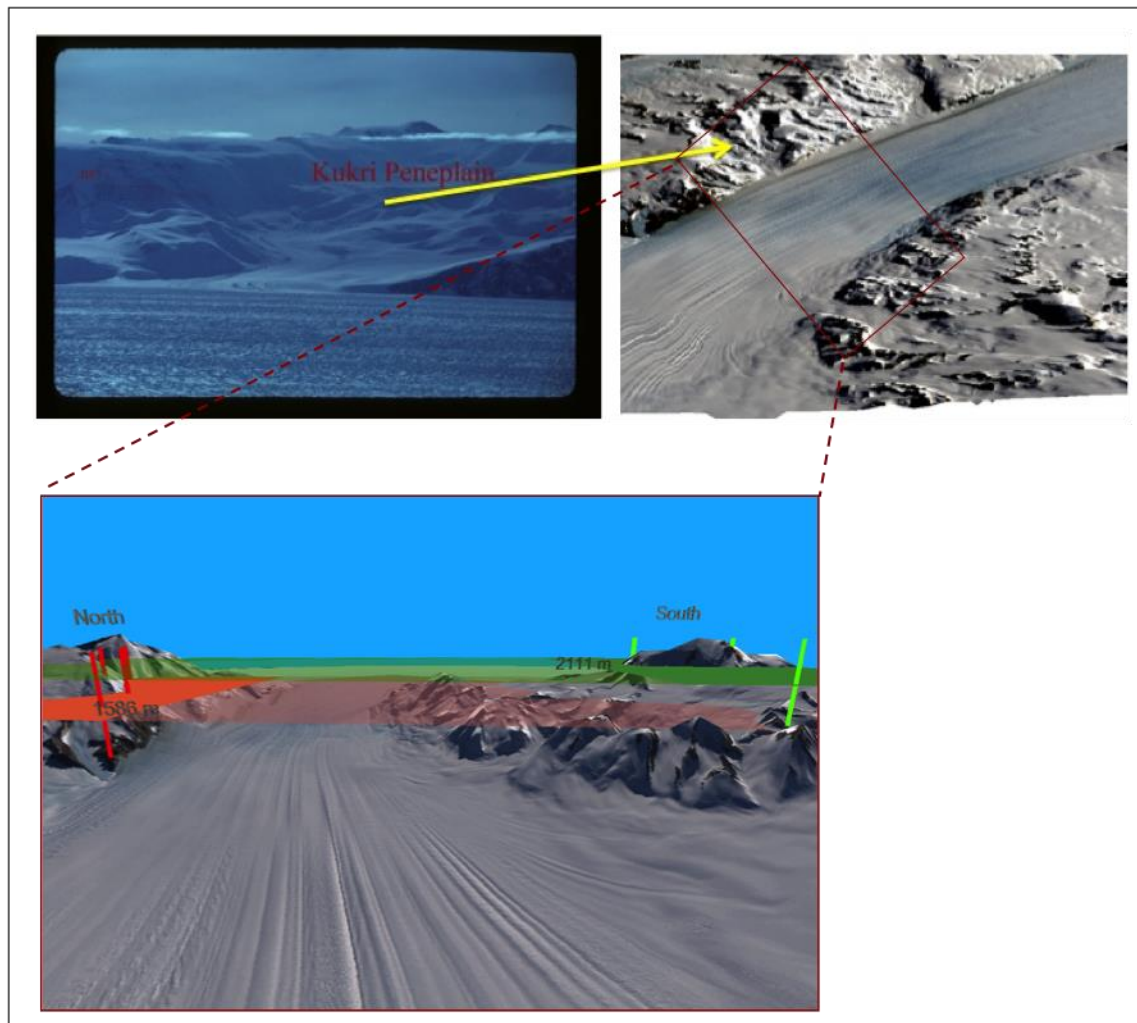
Figure 5. Map of a 3D scene depicting the Byrd Glacier region of Antarctica within the Transantarctic Mountains from the perspective of a viewer on site looking east. The top represents a comparison of on site photos of the Byrd Glacier region to a combined Landsat image-DEM to identify the location and extract elevation of the Kukri Peneplain erosional surface. The lower image displays the Kukri Peneplain projected as planar surfaces north and south of Byrd Glacier to assess tectonic offset (Foley et al., 2011). Made with ESRI ArcMap GIS and ArcScene (which can now seamlessly be done with ArcGIS Pro).

Figure 6. Spatial distribution of global crop water productivity (CWP) agricultural growing sites. Irrigated CWP study sites from 1979-2017 representing three major world food crops. 148 different crop-growing sites were mapped with 60 wheat sites, 43 corn sites, and 45 rice sites (Foley et al., 2019). Map made with ESRI ArcMap GIS.

Figure 7. Geospatial methodology to map global distribution of crop water productivity (CWP). Agricultural growing sites for wheat, corn, and rice were mapped relative to soil, climate, and latitude in attempt to assess and display geospatial relationships to CWP (Foley, 2019). Maps made with ESRI ArcMap GIS.

Connections between geoscience and geospatial education:

To improve geoscience education, first the geoscience thought process must be understood. King (2008) has provided five distinctive attributes of geoscience and geoscience education that require a set of thinking and investigative skills not commonly found in other areas of the general science curriculum including:

• Methodologies of geoscience thinking

• Holistic systems perspective

• Geoscientific spatial abilities

• Understanding of geologic time

• Methodologies and attributes of geoscientific fieldwork

A key component of these geoscience attributes critical for a geoscientist to learn is geoscientific spatial abilities. Next, to better understand Spatial Thinking in geoscience, the NRC (2006) has characterized several linked operations specific to geoscience in sequential order to include the following:

• Observing
• Describing
• Recording
• Classifying
• Recognizing
• Remembering
• Communicating

To provide more insight on Spatial Thinking in geoscience and how these concepts relate to shape, according to the NRC (2006): geoscience spatial thinking involves describing the shape of an object either rigorously and unambiguously, identifying or classifying an object by its shape, and recognizing is significant to recognizing a shape or pattern amid a cluttered or noisy

background. Additionally, communication of geoscience in the context of Spatial Thinking can further involve the two- or three-dimensional shape, internal structure, orientation, and/or position of objects. It is a goal of this study for students to work with GST to learn these linked operations of Spatial Thinking in geoscience, so they may explore new ways of Geospatial Thinking to become better geoscientists.

Connections between Geospatial Technology and Geospatial Thinking:

When teaching geoscience with GIS, a positive effect can be created on the development of Spatial Thinking and reasoning. GIS is inherently an excellent tool to express the five themes of geography, as defined by The *Joint Committee on Geographic Education* (1984): location, place, and relationships with places, movement, and region. When students begin to use GST with geoscience, Geospatial Thinking can be reciprocal in nature by defining a problem, proposing potential solutions, and interpreting results with the aid of GST to solve spatial problems (Baker et al., 2015). Gobert and Clement (1999) found that manipulating visual images to reinforce understanding of reading material is a more effective learning strategy than summarizing the material in writing exercises. They found that students who manipulate visual information build mental models and understand the material more deeply. Furthermore, by using maps and GIS, students can develop new skills of thinking with geospatial data and become more effective communicators with maps. Through the use of GST students can learn to organize their geospatial thoughts for complex issues as layers of a GIS (Sinton and Lund, 2007).

Problem Statement:

What has been done, why it is not enough?

As an undergraduate geoscience student looking at rocks in a lab and going on weekend class field trips, there can be a false impression of attaining a promising career in geoscience simply with the skills learned from only taking the required classes. As upper division courses may culminate with identifying rock types in the field and making small scale geologic maps

with pencils, paper, and a compass in a "field camp", these core concepts regularly needed to graduate do not always translate into employable skills after graduation. Instead, geoscience students are increasingly graduating with Bachelor of Science degrees only to find being unemployed or underemployed with mountains of student debt. This reality may be apparent in the low undergraduate student enrollment in geoscience compared to other much larger physical sciences such as biology (Lewis and Baker, 2010). There is also a stagnation or decrease in geoscience faculty hiring nationwide (Gonzaels et al., 2011). This is demonstrated in the work by Ridky (2002) noting that higher education geology departments are producing 65% fewer undergraduate geoscience majors than they did in the early 1980s, and 50% less than in the mid-1990s.

The current economy is transitioning to a skills-based economy in which most jobs demand advanced skills (Arizona Board of Regents, 2018). In many career paths including the geosciences, future problems and the skill sets needed to solve them are having an increasing geospatial and technological component. This poses the questions of why are higher education geoscience departments graduating students without the necessary technological and analytical skills to be employed in their chosen fields and why would the next generation of students want to choose or stay in the geosciences? To help advance geoscience education and keep graduates competitive in today's modern careers, this study suggests that integrating geoscience education with GST and applied Geospatial Thinking should be implemented.

Challenges to learning Geospatial Technologies in geoscience:

Underemphasis on Geospatial Technology in early geoscience education:

There are many factors at play imposing challenges to the teaching and learning of Geospatial Thinking and GST in traditional geoscience curricula in higher education. Reasons to explain the disparity of geospatial awareness and GST in college geoscience curricula is many fold with several challenges impeding its advancement. First, undergraduates early in their academic pursuit may not have the proper guidance or awareness to seek out GST in their geoscience coursework. If college-level geoscience instruction using GIS is offered within a geoscience department, its focus may be broad, its importance may be underemphasized, and it

may be taught only as an optional general elective next to other classes such as "Evolutionary History of Vertebrates" and "Planetary Science" in which students may not consider as part of a viable career path without advanced PhD level education and hence undervalue its importance. Thus, a course such as a general "Computers in Geology" may be the only technological course offered in a geoscience department that may teach other valuable computational skills but not necessarily GST. Although generalized classes like this can expose some geoscience students to GST, it does not guarantee that they will understand how the technology can be applied within the context of their chosen field.

Further putting up walls to GST education in geoscience is that GIS within geoscience departments is often only taught at the advanced undergraduate or graduate level. This can leave students less likely to take an optional GIS course due to an intimidation factor of only being taught at an advanced level. This can cause apprehension from those less tech savvy students who would most benefit from an introductory level GST course. Therefore, skipping GST in lower division courses and not being considered important enough for required curriculum can deny students the opportunity to learn the basics of GST with the odds of learning it later in their career highly reduced. Given this common scenario, a solid foundation in the capabilities of GST applicable to geoscience beginning in the introductory level should strongly be considered

Separation of Geospatial Technology from geoscience:

A major disconnect in the geospatial and technological education of geoscientists exists in the separation of most geoscience departments from GST classes. Often if a college or university does offer GST classes it is usually not within a geoscience department further limiting exposure to geoscience students. To provide an example of this, a comparison of courses offered within geoscience departments at the major Arizona universities including Arizona State University (ASU), Northern Arizona University (NAU), and the University of Arizona (UA) was conducted. This study searched all undergraduate courses offered within the Geoscience or Geological science departments at ASU, NAU, and UA for both spring and fall 2019 semesters to compare a full academic year. Results indicated that not a single course was listed with the subject focused on GIS or other GST.

For an undergraduate student in a traditional geoscience department to seek GST education, often this student will have to take on additional coursework outside of their department not applicable to their degree requirements. Furthermore, this instruction is provided mainly in geography departments and is meant for those who want to become GIS professionals leaving many in the geosciences on the outside. This results in the relationship between mappings, GIS, and other GST as poorly understood outside the discipline of geography and is its teaching is lacking the perspectives of non-geographers to provide insight on how to improve (NRC, 2006). However, if a geoscience student does enroll in college-level GIS instruction in a geography department, the learning objectives may not be applicable to geoscientists in the practice of geoscience as they can be focused on learning the tool first and problem solving later. Moreover, the geospatial methods and technology courses outside of geoscience departments are usually compartmentalized into specializations such as cartography, remote sensing, or GIS with a focus on a variety of non-geoscience applications such as urban/city planning, database management, or demographic and social sciences. This compartmentalization and departmental separation render the incorporation of technical learning in a primarily non-technical undergraduate program such as geoscience even more difficult (Brown and Olson, 2001).

Culture of traditional geoscience education:

Another major challenge to integrating GST into geoscience is the culture of traditional geoscience education that can be hesitant to change. That is, geoscience stemming from the introductory level has often been taught with an emphasis on factual recall as opposed constructive learning. This lack of an interactive learning approach may discourage students interested in technology and geospatial science from taking geoscience courses and entering the world of geoscience. This assumption can be gauged from an examination of introductory science textbooks across disciplines published in North American and the UK (e.g. Holden, 2008; Smithson et al., 2008). In this comparative science textbook terminology study by *Day et al.* (2012), it was noted that there was an enormous average of 881 terms contained in physical geography texts which is higher than comparable textbooks in environmental science (676 terms), chemistry (634 terms), geology (575 terms), or human geography (368 terms).

With geoscience teaching often based on factual recall, this can leave students only cramming for bubble sheet exams as opposed to thinking critically and applying substantial independent analysis that will carry with them after the semester. Therefore, students may be missing an opportunity to learn how to think with geospatial awareness and GST as they are learning basic geoscience principles. Additionally, sometimes instructors may offer supplemental reading or provide links to resources on GIS and GST without engaging students in the application to geoscience. This material can often go unread without active instructor engagement in the subject matter. It is rare for today's students to read everything that is assigned to them, instead they are often are so busy that they may have little time for additional reading, studying, thought or reflection outside of class (Day et al., 2012).

Underutilization of available technology:

The underutilization of applied technology integrated into introductory geoscience courses poses a challenge to engage students in applied GST learning. Within the last few decades at many higher education institutions, the move away from teaching small selected groups of well qualified students towards larger, more diversely qualified groups of students warrants that new teaching approaches should be considered (Boyle, 2007; Chappell, 2007). In larger universities shifting to larger classrooms with more students and less opportunity for an instructor to individually assist small groups of students, next generation educators will have to develop new strategies designed for large classrooms.

As most large university introductory courses are offered in large lecture halls and many small colleges may lack abundant technological resources, having a desktop computer at every seat in a classroom may be unfeasible. However, with the advent of Web GIS, ESRI Story Maps, and freely available digital globes such as Google Earth that can be readily and freely accessed from handheld devices, large classroom laboratories with desktop computers and paying for costly computer programs that needed be downloaded and licensed may no longer be necessary to teach GST. Instead, there is great potential to incorporate GST into geoscience education with what students may already have available. That is, the access to the web with personal laptops and smart devices that are increasingly available to many of today's college students that they

may already be required to have and are bringing to class. This leaves significant room for improvement in optimizing geospatial awareness for college students who have access to personal computers or mobile devices to learn with free web-based GST.

Along with underutilization of available technology there can be an accompanying lack of incentive to learn GST. Even in large classes that do not provide a computer laboratory with the latest GST hardware and software, a personal digital access and online component is still expected in many college classes and is often overlooked. For example, if technological and web access is required and incorporated into a geoscience class, it is often in the form of an online Learning Management System (LMS) and only used to "digitize" traditional assignments and quizzes. Although useful for instructors, it sometimes is only ever used for efficiency in automated grading assessment and not applied learning.

As long as LMS online access may be a required technological component asked of students to have, why not use that resource as an incentive to teach and learn GST with what is available? If students are not required or encouraged to learn GST while taking an introductory course yet a quarter of their grade is based on the number of posts in an online LMS "Discussion" forum, what would be their incentive to learn GST? Therefore, there is significant room for improvement as far as using online education platforms to provide incentives to explore GST. However, there are ways that instructors who may have access to basic computer labs that do not have licensed GIS software or who can ask students to use their own web access can utilize free interactive mapping and data exploration visualization resources for geoscience education. For example, online programs such as GeoMapApp (www.geomapapp.org) or Jules Verne Voyager, Jr: An Interactive Map Tool for Teaching Plate Tectonics from UNAVCO (http://jules.unavco.org/VoyagerJr/Earth) can be great educational resources to introduce GST in an introductory geoscience class. Furthermore, many undergraduate geoscience students have access to a geoscience department computer lab with Desktop GIS capabilities in which they could explore more if they were provided an incentive to do so.

Pre-Geospatial Technology era geoscience instructor pedagogy:

In addition to the challenges of adding new courses with new techniques in the overall higher education system, there also exists a challenge with incorporating new approaches in the teaching of geoscience. As for many distinguished geology instructors that were trained in a pre-GST era when all that was customary to produce a geologic map was paper and pencils, those instructors may find it challenging to teach new technological methods. That is, some instructors are accustomed to teaching the way it has always been and lack the motivation to learn new skills such as GST in order teach geoscience with GST. This can be due to several factors including that historically, the graduate training of educators in higher education seldom included much serious engagement with the scholarship of teaching and learning leaving instructors highly qualified in their field yet lacking in what has come to be known as the 'science of learning' (DiBiase et al., 2011). Furthermore, many geoscience faculty members have adopted the practices they were taught by their mentors in an era when GST was not as relevant and have since not learned or embraced GST.

Lack of diversity in geoscience:

Lastly, a major issue in the advancement of geoscience that GST may be able to help with is the severe lack of diversity in geosciences. That is, geoscience departments have had difficulty attracting and retaining students from diverse and underrepresented groups, who comprise only 6.3% of undergraduate majors nationally (Huntoon and Lane, 2007). This is well below the percentage of minority students in the general K-16 population and is one of the greatest equity challenges in higher education. The geosciences continue to lag far behind other sciences in recruiting and retaining diverse populations. A consequence of this is that in the U.S. the capacity for preparedness in natural geohazards mitigation, natural resource management and development, national security, and geoscience education is being undermined and is losing its competitive edge in the global market (Czujko and Henley 2003). To further examine the lack of diversity in geosciences, O'Connell and Holmes (2011) has noted in *Obstacles to the recruitment of minorities into the geosciences: A call to action,* that in 2008, >85,000 Hispanic, Black (U.S. National Science Foundation, 2010 [NSF term]), and American Indian/Native Alaskan students, collectively called underrepresented minorities, received Bachelor's degrees in science, technology, engineering, and mathematics (STEM). However, of that number, only 192

Hispanic, 89 Black, and 28 American Indian/Native Alaskan students earned degrees in geoscience. Thus, there is clearly room to grow in making STEM and especially geoscience more accessible to diverse populations and underrepresented groups.

Way forward:

Overcome challenges facing geospatial technologies in geoscience:

It can be inferred that if a student decided to major in geoscience that they are interested in continuing in the field after graduation. However, not all geoscience students can go on to be Professors or have top level research positions as volcanologists traveling the world as many undergraduates dream of. If modern geoscience students are only given traditional instruction from faculty who were educated in the pre-GST era, it may take extra encouragement to change. Plate tectonics was a geospatial idea and its acceptance did not occur in the geoscience community overnight. Therefore, to propose changing the established pedagogy of geoscience education it may also take considerable time. However, an emphasis on the benefits of teaching the skills necessary for students to have a competitive edge in finding meaningful careers in geoscience earlier in their education will be of utmost importance.

To overcome the challenges in updating geoscience education with the needs of modern geoscience careers, a multifaceted and systematic approach will be needed. First, GST education should be offered and considered as part of the required curriculum for geoscience students in addition to being offered at the introductory level. Then, GST classes should be offered within geoscience departments and focus on learning geoscience with GIS instead of learning about GIS separately. Instructors also should actively engage students with a constructivist framework approach to GST education where learning occurs as students are actively involved in the process of constructing knowledge as opposed to passively being provided information. Next, technology available to students should be optimized and utilized with the importance of learning GST emphasized. For example, if students have computer access even with just a web browser they can project any number of layers onto a virtual globe to visualize how different variables might be related which can help to learn complex geoscience topics (Gillette et al., 2015).

To help provide a way forward in improving GST geoscience education, geoscience departments may consider hiring qualified instructors with experience in teaching GST at the college level, teaching underrepresented groups and diverse populations, and being motivated to learn new GST skills to cultivate a better geoscience learning environment in today's educational landscape. Additionally, geoscience departments may want to focus on providing GST training to current faculty. This can have benefits to both instructor and student as noted by the *Learning to think spatially* report by the NRC, that for individual professors who have made the leap from only teaching their specialty to teaching with GIS, many have described that although the experience may be frustrating it can be vastly rewarding (NRC, 2006).

Increasing diversity in geoscience:

The lack of diversity and inclusion of underrepresented groups in geoscience undergraduates has been attributed to many factors, however, it is especially associated with a lack of pre-college exposure (Levine et al., 2011). Most geoscience college students have some pre-college exposure to geoscience, and a lack of pre-college geoscience exposure cuts across ethnic and socioeconomic divisions (O'Connell and Holmes, 2011). To increase diversity in geoscience, GST may be able to help reach potential students who have limited exposure to geoscience either by way of access to nature or formal instruction by bringing geoscience to the classroom with motivated faculty. An initiative to increase exposure and geoscience awareness at the pre-college level for underrepresented groups may be beneficial. For example, GST can be utilized to showcase geoscience and demonstrate the potential of STEM careers with presentations or virtual geoscience field trips even without leaving the classroom to provide pre-college exposure.

To close the diversity gap, two key populations that must be considered as the U.S. looks to build the future geosciences workforce and optimize productivity are the nation's youth and its growing underrepresented minority community. By focusing on both demographics, the U.S. can address the identified shortage of high-quality candidates for knowledge-intensive jobs in STEM and the geosciences. This can then help to develop the innovative enterprises that lead to discovery and new technology (NRC, 2006). To broaden participation in geoscience, it is

suggested by this study that geoscientist professionals and students should work to actively increase exposure to the geosciences and geoscience careers at all educational levels where possible and to provide education and public outreach in geoscience study via GST and geospatial awareness. For example, a demonstration involving high quality 3D maps of sea level rise hazards effecting neighborhoods or showing how active volcanoes in Hawai'i making headlines are mapped may make a stronger impact to motivate K-12 students into studying STEM and geoscience as opposed to a lecture. Also, at the college level where instructors are, it is suggested that geoscience faculty should consider (1) extending themselves to reach underrepresented students, (2) providing information about geoscience careers, and (3) provide students with information to help their communities endorse geoscience using GIS and GST as a way to share geoscience (O'Connell and Holmes, 2011).

Project Design:

Critical Geospatial Thinking as the next step in geoscience education:

To better advance the education of next generation geoscientists it is important to help students develop Critical Spatial Thinking and Critical Geospatial Thinking skills. Critical Geospatial Thinking can be thought of as a series of steps that educators can focus on teaching and that students can focus on learning in stages. First, it begins with Spatial Thinking, and then through Sources Assessment and adding critical thinking, it can lead to Critical Spatial Thinking. This can in turn lead to utilizing GST and applying critical thinking to develop Critical Geospatial Thinking (Figure 8). This progression of thought can help future geoscientists develop the geospatial skills required to connect spatial problems and spatial relations to the Earth and its representation on conventional or digital and interactive maps (Huynh and Sharpe, 2013). To get there, educators can begin with developing lessons for students in categories involving location, identity, magnitude (including all spatial aspects), and time. Then, educators can use geospatial methods and tools to link reality with maps and technologies to help develop Critical Smart Geospatial Thinking (Zwartjes et al., 2017).
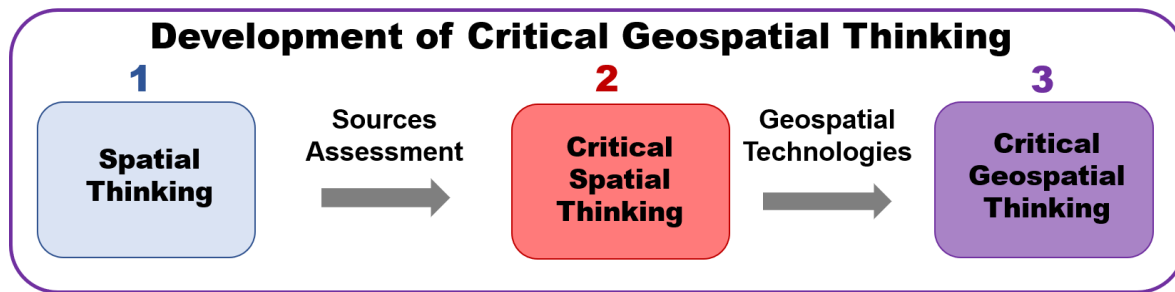
Figure 8. The development of Critical Geospatial Thinking as a process. First, it begins with Spatial Thinking, and then through Sources Assessment and adding Critical Thinking it can lead to Critical Spatial Thinking. This in turn can lead to using GST and applying critical thinking to develop Critical Geospatial Thinking. Modified from Zwartjes et al., (2017).

Spatial Literacy:

Spatial Literacy takes Spatial Thinking to the next level as an important concept significant to a wide range of disciplines including geoscience. Being spatially proficient, or being able to think in, with, and through space is increasingly valuable and generative (Frujita, 2001). However, little is known empirically about its character, nature, and development. Spatial Literacy involves having a broad range of perspectives, knowledge, skills, and habits of mind or dispositions relevant to Spatial Thinking (Goodchild and Janelle, 2010). When critical thinking is applied to Spatial Thinking, it can lead to spatial reasoning, a sub skill of Spatial Thinking distinguishing it as the specific processes applied while thinking spatially in the context of problem solving and decision making (Bednarz and Kemp, 2011). Therefore, for this study, Spatial Literacy can be defined as the outcome of critical Spatial Thinking and Spatial Reasoning or making inferences and informed decisions with reasoning about spatial aspects (Figure 9). If one can think critically and reason in, with, and about spatial concepts, then that person can be considered Spatially Literate.

Geospatial Literacy:

The concept of Spatial Literacy can be expanded on with a geospatial component applied to formulate Geospatial Literacy. Similar to Spatial Literacy, Geospatial Literacy results from the integration of applied Critical Geospatial Thinking with the skill of Geospatial Reasoning or making inferences and informed decisions with reasoning about geospatial aspects. However, to

distinguish Geospatial Literacy from Spatial Literacy, Geospatial Literacy is extrapolated on to include the specific processes applied in problem solving and decision making relevant to Earth, landscape and environmental scales (Figure 9). Therefore, if one can think critically and reason in and within the sphere of geospatial concepts incorporating Earth, landscape, and environmental scales, then that person can be considered Geospatially Literate. As a goal of this study is to produce geoscientists with improved geospatial literacy adapted to 21st century geoscience careers, this study also includes GST skills such as proficiency in GIS as well as part of the definition. For this study, Geospatial Literacy can be defined as a combination of Critical Geospatial Thinking and Geospatial Reasoning relevant to the Earth, landscape and environmental scales that also includes an applied GST component.
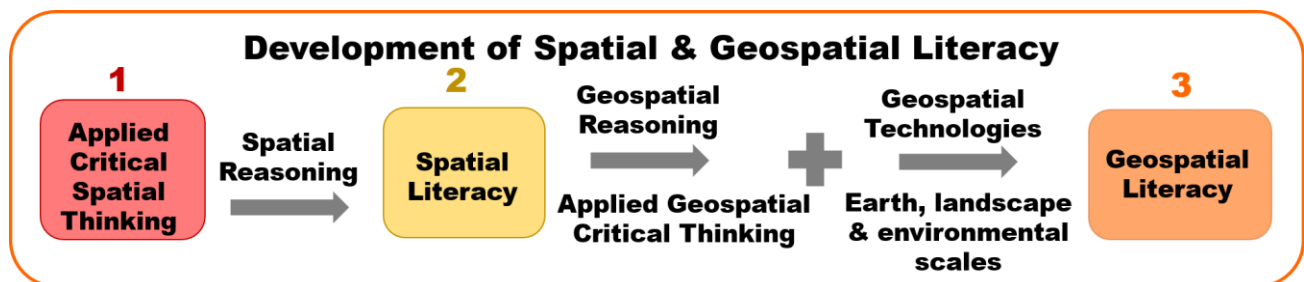
Figure 9. The stages of development in Spatial and Geospatial Literacy. When applied Critical Spatial Thinking is combined with Spatial Reasoning it can result in Spatial Literacy. Geospatial Literacy can be developed when Spatial Literacy is combined with applied Geospatial Critical Thinking, Geospatial Reasoning, and Geospatial Technologies bound by Earth, landscape, and environmental scales.

Integrate geoscience education with Geospatial Technologies:

To promote more Geospatial Literacy amongst geoscience students, GST should be integrated directly within geoscience education. To foster an environment of increasing Geospatial Literacy, GIS, and other GST, the practical applications of GST should be used alongside geoscience education starting at the introductory level. Instead of teaching a lab and lecture separately, this study suggests to integrate a computer lab component and lecture to actively engage students in geoscience discussion and GST practice. Teaching in this style may also provide a great capacity to promote learning through geographic literacy (knowledge about geography) with information literacy (information search strategies, critical evaluation of sources) leading to enhanced Geographic Information Literacy, or the possession of concepts,

abilities, and habits of mind (emotional dispositions). This allows an individual to understand and use geographic information properly and to participate more fully in the public debate about geography-related issues (Miller and Keller, 2005).

Foster geospatial literacy in geoscience:

A geospatial focus involving both components of the geographic and cognitive thought is integral to foster Geospatial Literacy in geoscience education. Thinking critically and geospatially is fundamental to learning geoscience as it involves more than just knowing the location of geologic materials, but rather how they connect through processes at various scales. It also encompasses geographic questions such as why a certain geologic feature is there, how it got there, and pose what if scenarios related to processes over time and space. Moreover, being able to think critically about the Earth and interaction with people on a global scale will be vital to future geoscientists dealing with environmental issues. Having geospatial skills provides a student with the ability observe patterns, associations, and spatial order that are essential because they assist in visualizing spatial arrangements and patterns (Zwartjes et al., 2017). Once skills in Critical Geospatial Thinking can be established through applied instruction of GST, quite possibly in a hybrid lab and lecture integrated classroom suggested by this study, this can help develop Geospatial Literacy. These skills are especially important to learn as they are not pragmatic skills that can be easily taught, but rather skills that a student can learn as part of engagement in an active geospatial learning process integrated with GST (King, 2006; Roche 2014).

Development of Geospatial Thinking modules to increase Geospatial Literacy:

This study suggests to design geoscience-GST lab-lecture hybrids known as modules with enhanced Geospatial Thinking in mind to increase Geospatial Literacy for introductory geoscience courses. These should involve key components of geoscientific and geographic skillsets along with the ability to visualize and think in two and three-dimensions which can be an asset to successfully interpreting many geoscience concepts (Hall-Wallace and McAuliffe, 2002). To formulate these proposed modules, it is suggested to base them on the five critical skillsets proposed by the *NRC* (2006) for critical geoscientific thought integrated with five skillsets of geographic thought proposed by ESRI, (2003) to include 1) asking geographic

questions, 2) acquiring geographic information/resources, 3) exploring /organizing geographic information/ resources, 4) analyzing geographic information, and 5) acting on geographic knowledge or answering geographic questions (Figure 10). As these skillsets are designed to build competence in Geospatial Literacy in geosciences, they should also include an inherent link to Earth, landscape and environmental scales. Examples of these proposed modules to use as guidelines are demonstrated in Appendices 1 and 2.

Institutions of higher learning that struggle to differentiate themselves from other schools could possibly benefit from offering classes using the most up to date GST making an impact in geoscience and geospatial science in their curriculum. With less students entering the geosciences, geoscience schools may have to compete for students in part because their goals, activities and curricula are often quite similar (Sinton, 2009). However, by providing classes with training in ArcGIS Pro for students interested in any field of observing and analyzing the surface of the Earth (e.g. geology, geography, environmental science), compared to other schools only teaching ArcMap GIS or no GST, this could provide a great way for a college to be more competitive. Furthermore, this may help a Geoscience department attract and retain high quality students as well as increase rankings.
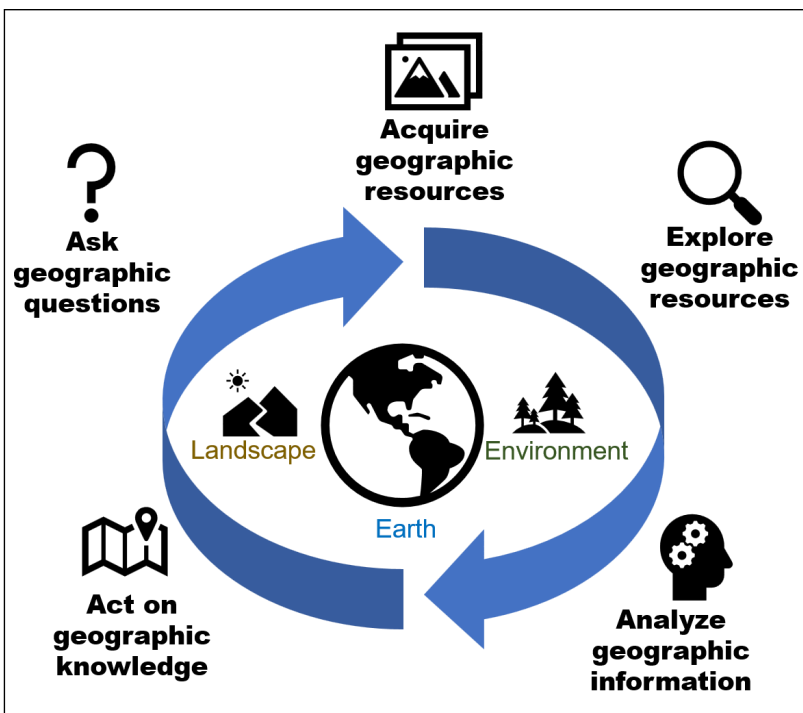
Figure 10. Geospatial Thinking relevant to geoscience to increase Geospatial Literacy. Interconnected geographic inquiry process displayed in a geospatial context relevant to Earth, landscape, and environmental scales are displayed. Modified from ESRI, (2003).

Project Implementation:

    Constructivist learning approach:

        The best way to learn GIS is through making GIS work for you (Manone, 2016). This can describe the constructivist framework in GST education and a better way for teaching GST for geoscience students. With a constructivist approach, instead of only being instructed on what to do from a tutorial, a student can learn how to construct a desired geospatial outcome and learn invaluable technological skills in the process. This constructivist approach to education is the foundation for a broad range of active learning approaches including inquiry-based learning and problem-based learning. These inductive approaches allow students to build theory and generalizations from case studies as opposed to more classical approaches where students focus on learning theory and study only a few applied examples (Day et al., 2012).

        The constructivist framework is especially important to learning GST as students are typically more engaged in the active learning required to learn GST with a constructivist approach. Instead of instructors relying on students that may opt to read supplementary GST material outside of class, this study suggests to fuse it directly into class. Research has shown that in the case of GIS integration, the easiest way to implement GIS in the classroom is to investigate with GIS by tasking students to perform real world geographic inquiry. This has been documented by Liu and Zhu (2008) in the context of teaching GIS from a constructivist framework emphasizing problem solving and inquiry-based learning as opposed to sequential instruction for a specific task. As GIS provides many useful tools for implementing a constructivist learning environment (Zwartjes et al., 2017), educators of geoscience teaching, and GST should actively facilitate a constructivist approach. This can allow their students to develop Geospatial Literacy and become better geoscientists.

    Why use ArcGIS Pro:

        This study suggests to use ArcGIS Pro as the preferred GST tool to train early academic career geoscience students. Today is an exciting time to be engaged in the GIS field with Web GIS, or the combination of the web and GIS extending the reach of GIS far beyond what anyone could have imagined previously (Fu, 2015). ArcGIS Pro, as ESRI's next generation 64-bit desktop software is the forefront of this shift in GIS technology with an intuitive user interface for creating, using, and analyzing professional 2D and 3D maps (Gorr and Kurland, 2016).

Ongoing development by ESRI has extended the software's capabilities and reworked its architecture to keep up with advances in technology with significant changes from the previous ARC/INFO software including modifications to GIS data models, data storage, and user interfaces (Smith et al., 2017). As three-dimensional thinking skills are widely recognized to be of critical importance to geoscientists (Giorgis et al., 2015), the linked 2D-3D analytical and visual aspects will be invaluable to geoscientists. Through its advanced capabilities, ArcGIS Pro can provide a great way to increase Geospatial Literacy through applied GST in the geosciences.

This Practicum study proposes to use ArcGIS Pro as a tool to engage active learning of students from diverse technological backgrounds for several reasons. First, ArcGIS Pro will likely be easier for a student with no previous experience in GIS to use as it was designed to be more user friendly. One aspect of this is having the ability to have all work organized into projects as opposed to collections of separate files. The ArcGIS Pro projects can contain maps, layouts, layers, tables, tasks, tools and connections to servers, databases, folders, and styles. This essentially allows to have all of the resources needed for a project in one place. Next, for users familiar with the Microsoft system, ArcGIS Pro uses a horizontal ribbon across the top of the application window to display and organize functionality with relevant tools readily accessible that is familiar to Microsoft users.

Another key asset for future geoscientists will be having the ability to share geospatial data in visually appealing ways. ArcGIS Pro can provide this with many sharing options including 2D and 3D layouts, web maps, story maps, editable feature layers, and sharing with ArcGIS online through the portal (Keranen and Kolvoord, 2017). Moreover, an especially useful component for communicating geoscience in the 21st century is with Web GIS which is a capability of using ArcGIS Pro. Having GIS integrated with the web removes the constraint of distance and thus allows users the freedom to interact with GIS apps globally and access information almost instantly. Furthermore, by logging into the online portal, a living atlas of base maps, imagery, and geographic information is built into this platform that can greatly benefit geoscientists. Whether it is the first-time using GIS as a student or if a seasoned professional is switching to ArcGIS Pro from ArcMap or another GIS platform, its seamless ability to connect to ArcGIS online enabling collaboration to be easily shared and opened by others will greatly benefit the overall GIS and geoscience community.

Geologic hazards and learning Geospatial Technology:

This study suggests to introduce applied Geospatial Thinking into introductory geoscience classes through the connection of geologic hazards and humans to further optimize student interest. In introductory geology courses it is common to cover geologic processes and related phenomena such as earthquakes, volcanoes, landslides, tsunamis, and floods. In introductory physical geography courses, it is common to study the interaction of the lithosphere, hydrosphere, atmosphere, and biosphere interconnected with humans. By studying geologic hazards, critical components of both geology and physical geography can be utilized. Therefore, by having students engaged in interactive GIS modules mapping of natural hazards they can learn core elements of geology and physical geography combined into geoscience with GST. Potential modules can implement Geospatial Thinking and technological skills such as mapping areas where past geologic hazards have occurred, assessing locations where geologic hazards are likely to occur again, and to assess potential damage of geologic hazards. Any of the mentioned geologic hazards would provide a great teaching topic such as that already outlined for earthquakes in Modules 1 and 2 displayed in Appendices 1 and 2. Exploring geologic hazards is in line with a major goal of this study for students to develop Geospatial Literacy applicable to the environment they live in through the use of GST.

Place-based geoscience and Geospatial Technology learning:

Everyone has a sense of "Where", often this can be where you are from, where you live, or where you consider to be home. To ascribe a sense of place to a location gives more significance and meaning to an individual (Semken and Freeman, 2008; Apple et al., 2014). Geologic hazards that may affect a student's local community and can provide interesting learning exercises to generate incentives in applied Critical Geospatial Thinking. Therefore, it is suggested by this study that teaching modules should be designed with a "sense of place" to better engage students by learning about geoscience concepts designed by instructors to be relevant to their communities. For instance, for students at Northern Arizona University, earthquakes in Coconino County could provide a great educational topic as outlined in Appendix 1 and 2. Furthermore, to actively engage student learning it is suggested to coincide GIS module

topics with the course lecture schedule. For example, when earthquakes are being taught in lecture, a GIS earthquake module can be used to compliment learning about earthquakes with applied Geospatial Thinking and GST.

Proposed earthquakes GIS module:

Flagstaff may not come to mind first on the topic of earthquakes, however it is a seismically active place residing within the Northern Arizona Seismic Belt (NASB) (Brumbaugh et al., 2016). This provides a great learning opportunity for place-based geoscience study for schools in Northern Arizona such as NAU or Coconino Community College. The NASB can provide a great geospatial awareness exercise with several possibilities for geoscience and GST modules such as mapping historical earthquakes relative to active faults and identifying patterns. Also, students can learn to use ArcGIS Pro to display a depth component of 2D spatial data as 3D to visualize the depth of earthquakes below the surface. This can help students better understand earthquakes by analyzing earthquake correlations to the hypocenter, epicenter and magnitude for Coconino County (Module 1 in Appendix 1). However, the location of teaching exercises within Modules 1 and 2 can be changed to anywhere that has data available from ArcGIS online as all datasets in this study were acquired from open source ArcGIS online portal resources so that the locations can be modified for other place-based learning opportunities. To change the location, all that would be needed is to change GIS features added by searching for similar features from the desired location and the same teaching methodology and geoprocessing tools can be applied.

Another suggested learning outcome could be to actively engage student learning in the human connection to damage caused by geologic hazards by building off of Module 1. An example of this is provided in Module 2 (Appendix 2) regarding a study of Flagstaff's three greater than 6.0 magnitude earthquakes that occurred from 1906-1912 (Brumbaugh, 2014). This Module 2 involves Critical Geospatial Thinking by mapping the epicenter location of a historic >6.0 magnitude 1906 earthquake to explore what damage it could potentially cause if it were to happen today. Students can then apply critical geospatial reasoning and use GST to identify where large earthquakes have occurred relative to the current city limits. Also, students can apply the use of spatial analysis tools to determine the zones and rates of seismic P-waves and S-waves

as they emanate from the epicenter. This concept can be explored to determine where a seismic station should be located to detect an initial P-wave to provide an early warning system before an impending and more damaging S-wave would arrive (Young and Conway, 2012). Students could also discover geoprocessing tools to do an interpolation of all past earthquakes to determine where a future earthquake may occur while learning about raster and vector datasets. As of this writing, both Modules 1 and 2 have not been tested by introductory geoscience students and have yet to be implemented in a class. However, this study proposes to use these Modules as a guideline to use in future geoscience classes.

Implementation of Geospatial Literacy to fieldwork with ArcGIS Pro:

In geoscience education, geoscientists are taught to make observations of their natural surroundings and to derive interpretations of the past, present, and future relevant to Earth science. As a student is taught field mapping, they may take several data points and then compile that into a geologic map. Therefore, geoscience in the practice of geologic mapping is inherently linked to geospatial science and thought. With that inherent geospatial thinking, students should not stop learning in the field and leaving the map behind when more 2D and 3D geospatial relationships can be conceptualized. Therefore, this study suggests to expand Geospatial Literacy to field work by having students digitize field-based maps in ArcGIS Pro to allow the wide range of visualization and sharing capabilities to bring the field into the classroom by applying concepts learned in the field with active engagement in GST. One thing that a field geologist can observe is the order and type of rocks, however, a geographer can interpret spatial patterns to connect geologic units and features. By implementing Geospatial Literacy to geologic field work, goals of this study are to combine qualities of geography and geology to complement each other to produce better geoscience and better geoscientists.

Discussion:

Evaluation of geospatial thinking with geospatial technologies:

A strategy to evaluate the effectiveness of increasing Spatial Thinking with the use of ArcGIS Pro is suggested here. Using the work of Hall-Wallace and McAuliffe's (2002) study, *Design, Implementation and Evaluation of GIS-Based Learning Materials in an Introductory*

Geoscience Course as a foundation, students in an introductory geoscience course were provided two standardized tests from *the Kit of Factor References Cognitive Tests* (Ekstrom et al., 1976) after GIS use was implemented to measure spatial thinking. Hall-Wallace and McAuliffe's (2002) investigation could not give a pretest due to logistical problems and were not able to determine whether spatial skills were improved by using GIS exercises. Therefore, this lack of a pretest for comparison leaves room to expand and test the hypothesis that GIS can promote Spatial Thinking and lead to increased Geospatial Literacy. This study suggests updating this assessment strategy to provide both spatial pretests and post tests before and after GIS exercises are completed to determine correlations between spatial skills and GIS performance. The spatial tests proposed to provide to introductory geoscience students before and after working on GST modules are provided below. However, it should be noted that these standardized tests are designed to evaluate Spatial Thinking improvement as the first step in measuring the process of Geospatial Literacy and as of now are not necessarily optimized to test critical thinking.

Cubes comparison test:

The first test suggested by this study to measure improvement in Spatial Thinking of geoscience students using GIS is the Cubes Comparison Test (CCT). This was chosen for a spatial aptitude test as it was designed to assess spatial orientation or the ability to perceive a spatial configuration from an alternate perspective. This can be especially significant to understand surface and subsurface tectonic processes. In the example CCT displayed in Figure 11, the first pair of blue blocks is marked *Different* because they must be drawings of different cubes. If the left cube is turned so that the *A* is upright and facing the user, the *N* would be to the left of the *A* and hidden, not to the right of the *A* as shown on the right-hand member of the pair. Hence the block diagrams must be of different cubes. The second, or lower pair of green blocks is marked the *Same* because the block diagrams could represent the same cube. That is, if the *A* is turned on its side, the *X* becomes hidden, then the *B* is moved to the top, and the *C* which previously was hidden is now visible. Hence these two block diagrams could be of the same cube.
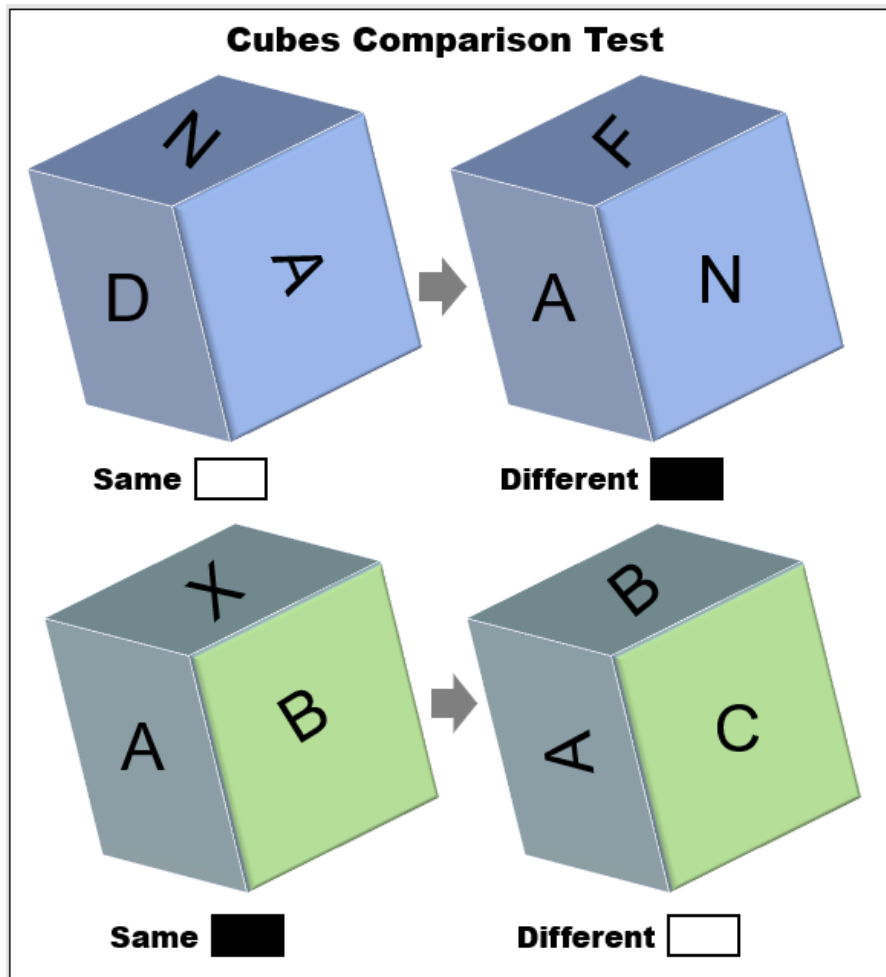
Figure 11. The Cubes Comparison Test proposed to give geoscience students before and after GIS implementation as a measure of improvement in spatial thinking. This cognitive spatial aptitude test was designed to assess spatial orientation or the ability to perceive a spatial configuration from an alternate perspective. Modified from (Ekstrom et al., 1976).

Surface development test:

The second test proposed to measure the improvement in Spatial Thinking of geoscience students using GIS is the Surface Development Test (SDT). This was chosen for a spatial aptitude test as it was designed to assess spatial visualization, or the ability to transform a mental image. This can be especially significant to for geoscientists in the context of understanding landscape evolution over time and space. In the example SDT displayed in Figure 12, the objective is for the test taker to visualize how a two-dimensional piece of paper can be folded to form a three-dimensional object represented on a two-dimensional plane. For the example

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depicted in Figure 12, *Part I.)* is of a piece of paper, which can be folded on the dashed lines to form the object in *Part II.)*. Then the user is tasked to imagine folding *Part I.)* to form *Part II.)* and determine which of the lettered edges on the object are the same as the numbered edges on the piece of paper in *Part I.)*. Then to write the letters of the answers in the numbered spaces in *Part III.)* to measure Spatial Thinking. As most college students may be likely to figure out both CCT and SDT spatial aptitude tests, this study suggests to change the sequence of cubes and shapes as well as timed tests and compare the time taken to accomplish each test following a GIS module as a measure of Spatial Thinking progress.
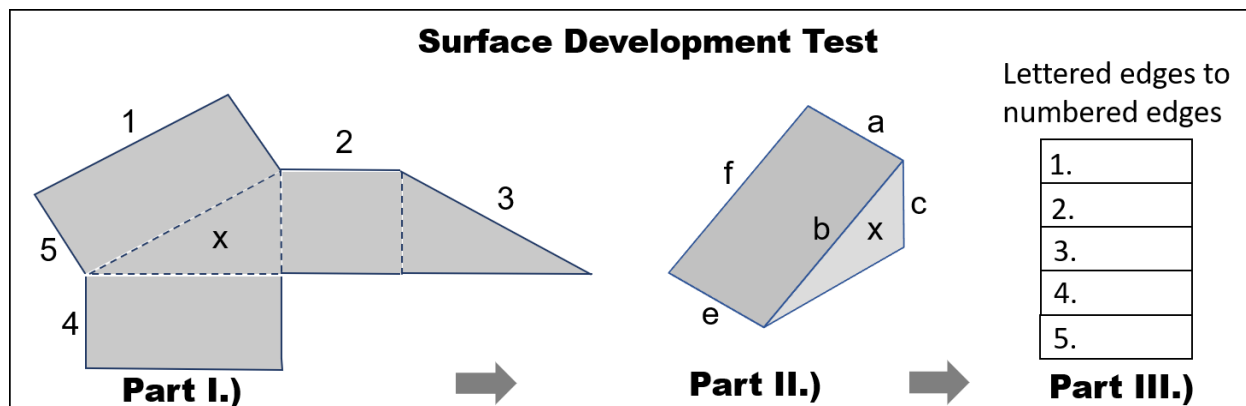
Figure 12. The Surface Development Test. The second test proposed to measure improvement in Spatial Thinking of geoscience students using GIS. This cognitive spatial aptitude test was designed to assess spatial visualization, or the ability to transform a mental image. Modified from (Ekstrom et al., 1976).

Future Work:

> **Evaluation of Geospatial Thinking with Geospatial Technologies:**

Future work on the evaluation of Geospatial Thinking with GST has been proposed by this study to further update this strategy to be more geoscience specific and more up to date with technology. First, for the CCT, modified cubes designed and implemented to have geoscience specific patterns instead of arbitrary letters would be beneficial for geoscience students. Future suggestions include to modify the faces of the cube to display rock sequences and or landscapes linked to specific rock types. An example may include matching types of volcanic rock to their associated style of volcanism, for instance, basalt or lava rock to effusive shield volcanoes and pyroclastic flows or volcanic ash to explosive stratovolcanoes. This can also assess the

connection of geoscience and Geospatial Thinking to GIS as well as provide a learning tool to complement geoscience and geospatial education.

To further advance the evaluation of Spatial Thinking, it is suggested to implement both CCT and SDT tests as online versions with interactive visual displays through a LMS. Having instant online accessible tests can generate a cognitive Spatial Thinking test at various stages in a module to focus on specific aspects of cogitative Spatial Thinking enhancement. For example, a test could be given when a student begins a GIS assignment and immediately following submission of an assignment with the option to provide tests during mid GIS module or after specific tasks. Often in GIS labs, students finish their labs at various times and it would be inefficient to have an assessment at the end of class and expect all students to finish their module at the same time or even be at the same place within their module. Therefore, advantages of using a LMS can automate the grading that can provide students and faculty immediate feedback while allowing students to work at their own pace.

Conclusions:

This study has provided insight to indicate that there is room for improvement in modern geoscience education and that GST can help to improve it. By making students more Geospatially Literate with increasing use of GST in geoscience education, this can advance the overall field by embracing technological innovation, aid in overcoming challenges facing geoscience, and produce better geoscientists well suited for modern careers. To help make these improvements in geoscience, a two-part approach is suggested by this study. First to incorporate GST directly into currently offered classes, especially the use of GIS into introductory level geoscience courses such as those provided in Modules 1 and 2 (Appendix 1 and 2) to be used as guidelines. Next to, offer additional and separate GST and GIS courses designed specifically for geoscientists within geoscience departments that can count for required credit to earn a geoscience degree. It is suggested that GIS modules and GST courses for geoscientists implemented in geoscience education to be based on concepts previously discussed in this study to include 1) asking geographic questions, 2) acquiring geographic information/resources, 3) exploring /organizing geographic information/ resources, 4) analyzing geographic information, and 5) acting on geographic knowledge or answering geographic questions all relevant to geoscience (Figure 10).

To help initiate GST courses for geoscience students at schools without any GST classes, new classes could be modeled off of existing GST classes catered to geoscience within geoscience departments. These can then be re-focused to have a sense of place-based education ideally suited to where they are taught. An example to use as a reference could be the "GIS for Geologists" course offered at the undergraduate level in the Geological Sciences Department at the University of Colorado Boulder (CU) that is designed to provide an introduction to GIS techniques focused on geological applications covering GIS analyzing, mapping, and GPS use (CU, 2017). It is interesting to note how as of 2019, the US News and World Report (USNWR) ranks CU as number one in their international ranking of the top Higher Education Geoscience programs. For comparison of Arizona universities with geoscience programs assessed in this study for GST classes in which all were lacking, on the USNWR list of the top 200 higher education geoscience programs, ASU was ranked 92nd and UA was ranked 29th with NAU not making the top 200. However, on a different ranking by *geology-schools.com*, in 2018 NAU was ranked #216 out of 532 higher education geology programs evaluated. This clearly shows that the NAU geology department has room to grow in improving the quality of geoscience education and to be competitive with other universities in the state.

This study further suggests offering GIS and GST classes for geoscientists at different skill levels including introductory, intermediate, and advanced for larger schools within geoscience departments. These courses should be designed for students at any GST skill level from beginner to expert. Furthermore, geoscience GST courses should allow the option to be taken consecutively from the introductory level that could allow a geoscience student to focus in geospatial science and technology applied to geoscience throughout the completion of a Bachelor of Science degree. Where as many geoscience programs allow a student to specialize in a focus such as sedimentology, volcanology, or structural geology, it is the hope of this study that a focus can be made for a geospatial geoscientist specialty that could offer an undergraduate "GIS and GST for Geoscience Certification". This can help to make recent graduates more competitive in the 21st century career market and graduate school application process. Moreover, for geology programs with a low ranking, especially considering that all major Arizona universities lacked a GST geoscience course offered in 2019, having GIS for Geoscientists classes and or an undergraduate Certificate program may help a geoscience program stand out and improve its ranking.

For smaller colleges with low enrollment geoscience programs and or those lacking funding, there may be additional challenges to implementing GST education into geoscience However, many of these challenges can be overcome with alternatives to traditional GST education. First, if a college does not have the funding to pay for even reduced cost student licenses of the ESRI suite of GIS software packages such as ArcGIS Pro, a school may opt to use free open source GIS software. For example, QGIS can provide a great alternative to fee based commercial GIS as it is able to perform many of the main functions of ESRI GIS software allowing users to analyze and edit spatial information, support vector and raster layers, and compose and export graphical maps. Next, if a college may not be permitted to provide any additional GST courses or be unable to hire GIS instructors and a geoscience student wanted to learn more about GST, there still is potential to learn GST without imposing a burden on the student or academic institution. This can be done with Massive Open Online Courses or MOOCs, which are online courses offered indecently of college programs aimed at unlimited participation and open access via the web (Kaplan and Haenlein, 2016). With a MOOC a student may be able to stay in his/her program and yet learn GST without having to apply to or attend a different school, pay any more tuition costs, or even having to conflict with their current class schedule.

MOOCs are available from several online sources such as the *edX* platform that provides free interactive classes that can grant documentation of course completion. Some of these MOOCs can even rival traditional courses as they can contain user forums to support community interactions among students, instructors, and teaching assistants, in addition to offering immediate feedback to quizzes and assignments. If a geoscience student could enroll in a GIS or GST oriented MOOC, this could provide many benefits for students without access to GST to provide quality education. These benefits may include, improving access to higher education, providing an affordable alternative to traditional higher education, sustainable development goals, online collaboration, and a flexible learning schedule. An example of a GIS MOOC that could be useful to any Earth scientist is one titled *Geographic Information Systems* offered by Mathew Sisk of Notre Dame through *edX* that is designed to provide a basic understanding of how GIS and satellite imagery can be used to visualize and analyze spatial data (Sisk, 2016).

MOOCs can help provide a way forward to help improve geoscience education with GST for schools who may not have the resources or ability to provide GST education. Instead of seeing a MOOC as competition, if a geoscience department could encourage a GST or GIS MOOC to its students to coincide with their curriculum possibility during a break in the academic calendar, they could complement traditional geoscience education and not interfere with it. Furthermore, MOOCs could be of great benefit to underprivileged or low-income students without access to GST education and help underfunded programs that cannot afford GST educational resources. To help close the diversity gap MOOCs may want to be considered as a way to provide GST education to students that do not have any pre-college exposure or access to GST or geoscience education.

It is suggested by this study to develop GIS and other GST MOOCs designed specifically for geoscience that are applicable to a wide range of geoscience educators and students. This is elaborated on further to suggest for GST and geoscience education professionals to collaborate in developing GST MOOCs for geoscience as they could help advance the field of geoscience beyond just their current undergraduate students at a handful of intuitions. Furthermore, they should be designed so geoscientists at any point in their career could take geoscience GST MOOCs from recent graduates to senior level professionals who may not have the time, money, or desire to go back to school and re-enroll in costly higher education. Also, MOOCs could provide an opportunity to train current geoscience instructors in GIS and other GST without schools having to pay for training or send faculty members away to workshops.

With the world of today's technology and careers changing at an ever-increasing rate, geoscientists must adapt to stay competitive. The easy geoscience problems have been solved and readily available resources have been found. Future geoscience jobs will require solving complex problems involving big datasets. Traditional geoscience education from the pre-GST era meant to prepare students for traditional geoscience careers such as field mapping has changed leaving significant room to advance. Current and future geoscientists will need a better understanding of geospatial relationships from the surface to the subsurface in both 2D and 3D to address new geoscience frontiers. Therefore, the merging of geoscience with geospatial science and GST will be of key interest to those geoscientists interested in making an impact in modern geoscience and maybe even developing new fields geoscience study. A major goal of this

Practicum was to demonstrate how learning new GST skills such as GIS can be a powerful tool for geoscientists to develop better problem-solving strategies in Earth science to take on the geoscience problems of the future.

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ArcGIS Pro Modules

Appendices to

INCERASING GEOSPATIAL LITERACY WITH GEOSPATIAL TECHNOLOGIES TO
IMPROVE GEOSCIENCE EDUCATION

by

Daniel J. Foley

Appendix 1: Earthquakes in Coconino County & Flagstaff Geologic Hazard Investigation

&

Appendix 2: Investigation of Flagstaff Geologic Hazards Module 2

Purpose:

The objective of the GST modules provided in these appendices are to enhance geospatial thinking for an introductory college level geoscience class. This Module will use ArcGIS Pro to help develop geospatial literacy.

Goals:

• Import an ArcMap map document.

• Create 2D and 3D features and modify their symbols.

• Perform analysis using geoprocessing tools and raster processing functions.

• Create map layouts, project packages, and web layers to share your work.

Learning Objectives:

After completing this course, you will be able to perform the following tasks:

- Identify the components of the ArcGIS Pro interface.

- Create a project in ArcGIS Pro.

- Use geoprocessing tools in ArcGIS Pro to analyze data.

- Use ArcGIS Pro to share a project.

Software Needed:

To complete exercises, you need the following:

ArcGIS Pro 2.1 (Basic, Standard, or Advanced)

Some optional exercise steps may require the 3D Analyst, the Geostatistical Analyst, or the Spatial Analyst extension.

Data:

A Digital Elevation Model (DEM) Arizona is included as file: az_dem_nad27

However, DEMs can be downloaded for any area in the USA via The National Map - Data Delivery – provided by the United States Geological Survey.
https://viewer.nationalmap.gov/basic/

No data is necessary to download. Instead this was designed to showcase the capabilities of using ArcGIS online and the ArcGIS Pro Portal to download any data that may be needed. This lab uses Flagstaff as example. However, the methodology could potentially be applied to anywhere in the US where there is data available online. This can allow any student or instructor who may not be an expert or a professional in a certain geoscience field in order to have access to the appropriate data. This was designed to be a "data less" module to allow it to be replicated elsewhere catered to other areas of interest for geoscience education.

Methods: Will be explained in the Exercises.

Introduction: ArcGIS Pro interface.

ArcGIS Pro is designed to have an intuitive, easy-to-use interface and a file structure that allows you to access all the data associated with your project. The ArcGIS Pro application is web-connected to take advantage of some of the functionality available on ArcGIS Online (or Portal for ArcGIS). ArcGIS Pro has a user-based license model that allows you to use the software on any computer if you sign in using an ArcGIS Online organizational account that has been provisioned with an ArcGIS Pro license. Single and Concurrent Use licenses are also available.

Exercises:

The exercises in these modules are designed to show the user how to become familiar with ArcGIS Pro to investigate the geoscience topic of earthquakes and geologic hazards. All of the GIS exercises here in these modules were designed using the five critical skillsets proposed by the NRC (2006) for critical geoscientific thought integrated with five skillsets of geographic thought proposed by ESRI, (2003) as foundation to include 1) asking geographic questions, 2) acquiring geographic information/resources, 3) exploring /organizing geographic information/ resources, 4) analyzing geographic information, and 5) acting on geographic knowledge or

answering geographic questions all inherently linked to the Earth, landscape, and environmental scales relevant to geoscience as represented in Figure 10 from the main written body of this Practicum Document. An outline is provided of the Modules are provided below.
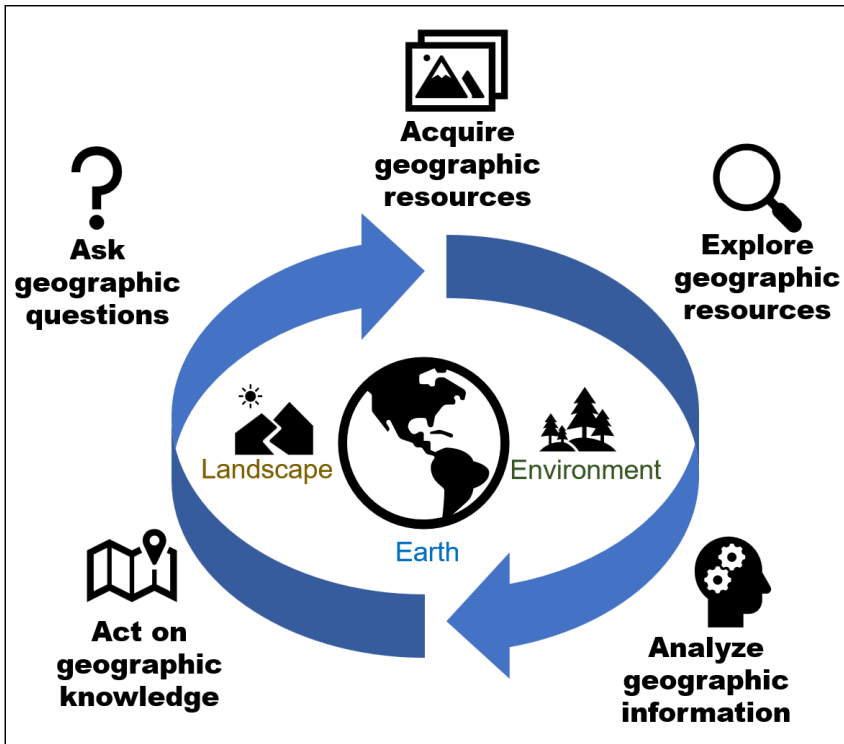
Practicum Figure 10. Geospatial Thinking relevant to geoscience to increase Geospatial Literacy. Interconnected geographic inquiry process displayed in a geospatial context relevant to Earth, landscape, and environmental scales are displayed. Modified from ESRI, (2003).

Project structure: Start a new project

The native structure for ArcGIS Pro is called a project. A project consists of a main file with an APRX file name extension and an entire folder structure designed to contain the project data. These folders contain maps, layouts, tasks, toolboxes, styles, and connections to databases and folders.

When you start ArcGIS Pro, you are prompted to create a project or open an existing project. When you create a project, you are immediately prompted to name the project. The project is created in a folder with the name that you provided.

ArcGIS Pro Module Outline:

☐Apply Critical Geospatial Thinking 3)
- Task 1: Set up time settings display
  - Question 7)
- Task 2: Time Setting Activity
  - Question 8 a,b,c)
- Task 3: Turn off time display

☐ Apply Critical Geospatial Thinking 4 a,b)
- Task 1: Set up fault data
  - Question 9)
- Task 2: Clip Faults to Coconino County
- Task 3: Display both earthquakes and faults in Coconino County.
  ☐ Apply Critical Geospatial Thinking 5 a,b)

  - Question 10 a,b,c)
  - Question 11 a,b,c)
- Task 3: Explore relationship of earthquakes and faults in Coconino County.
  ☐Apply Critical Geospatial Thinking 6a,b)
  ☐ Apply Critical Geospatial Thinking 7)

- Task 1: Create a 3D view of the data
  ☐Apply Critical Geospatial Thinking 8a,b)
- Task 2: Set the elevation surface for the 3D view
- Task 3: Clip DEM to Coconino County
- Task 4: Set up 3D data

☐ Apply Critical Geospatial Thinking 9)
- Task 1: Investigation of earthquake epicenter verse hypocenter
- Task 2: Visualize earthquake hypocenters in 3D
- Task 3: Explore navigating scenes.
- Task 4: Visualize earthquake relation to faults
- Task 5: Visualize 3D fault earthquake relation above and below the surface
  ☐ Apply Critical Geospatial Thinking 10)
- Task 6: Visualize fault earthquake buffer above and below the surface in 3D
  ☐ Apply Critical Geospatial Thinking 11)
- Task 7: Investigate earthquake depth hypocenters

Appendix 2: Investigation of Flagstaff Geologic Hazards Module 2

Appendix 1: Module 1) Explore Earthquakes in Coconino County, AZ with Critical Geospatial Thinking

As often GIS users will be transitioning to ArcGIS Pro from ArcMap, this part is designed to help ArcMap users transition to Pro. ArcGIS Pro allows integration of importing an ArcMap file seamlessly into Pro. Therefore, if a GIS user had a map made in ArcMap that they wanted to add 3D components to in ArcGIS Pro, then this will show you how to bring an ArcMap .mxd file into Pro. This section has been designed to demonstrate the capabilities of building off of ArcMap. However, a way to begin this lab entirely in ArcGISPro is also provided below as a secondary option. We will start with first setting up a project in ArcMap and then learning how to import an ArcMap .mxd file.

Part 1) Set up project and import ArcMap document:

If you would like to set up this project entirely in Arc Pro this beginning in ArcGIS Pro, you can skip to section Part 1C.

Part 1A) Set up project in ArcMap:

Task 1: Set up project in ArcMap
 - Start ArcMap:
  - File
   -New
    -Blank Map
     - Set Default Geodatabase to your home setting:
Here is an example used: D:\ArcGIS_ProData\AZEQ.gdb

Task 2: Add data
 - Add: select "Add" Icon

Figure 1) Add icon selection in ArcMap, select the drop-down arrow for more options.
.

   -Select add basemap option.
    - Basemap
     - Topographic
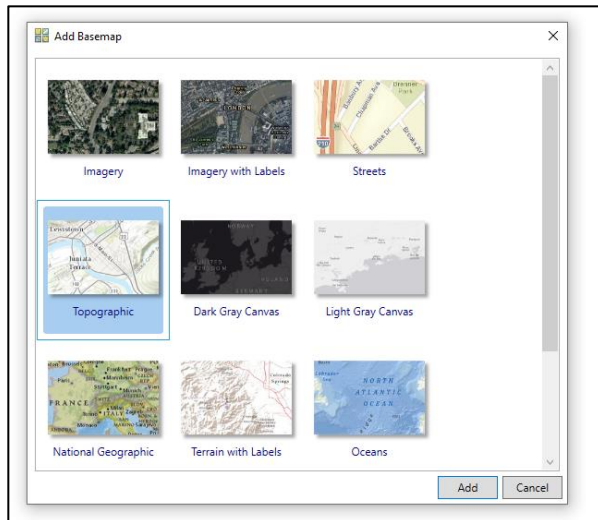
Figure 2) Basemap options to select from. Select topographic option.

Task 3: Select area of interest to study.

- In this case our area of interest is Flagstaff, AZ.
    - Zoom to Flagstaff, AZ USA.
        - Select "Go to XY"
            - Input XY coordinates for Flagstaff, AZ.

☐ The coordinates for Flagstaff, AZ, USA are 35.198284 for latitude and -111.651299 longitude. Input in the following order as displayed in Figure 3.
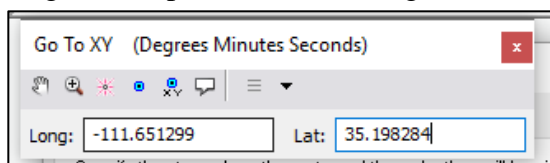
Figure 3). Go To XY operation. Option to select coordinates of desired study area. In this case latitude and longitude is put in for Flagstaff, AZ.

Task 4: Build the project by adding data

-Add Data
    - Select Add from ArcGIS Online
        - Open ArcGIS Online Portal to search

Figure 4) Add icon. Select add from ArcGIS Online option.

- Search for " Arizona Earthquakes".
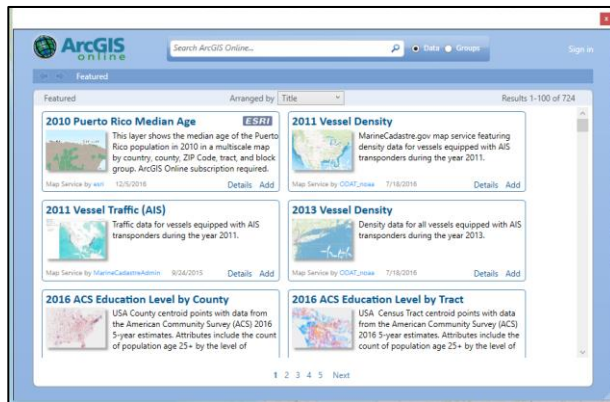
Figure 5) ArcGIS online Add Data Portal.

- Add "AZGS_Earthquake" dataset to Map
    - Select Add
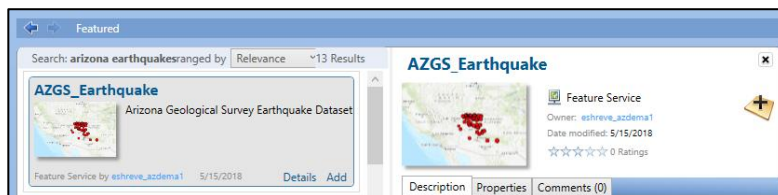
Figure 6) AZGS_Earthquake dataset from ArcGIS Online.

- Search for "Coconino County Boundary".
    - Add "Coconino County Boundary".
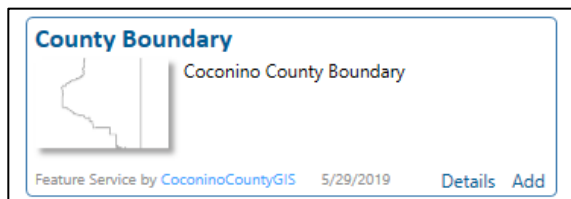
Figure 7) Coconino County Boundary dataset from ArcGIS Online.

☐ If you get a Geographic Coordinate System Warning select OK and proceed
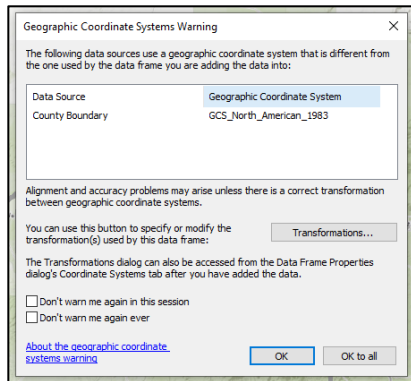
Figure 8) Example of Geographic Coordinate System Warning. Select OK.

☐ Your map should now look like the following in Figure 9.
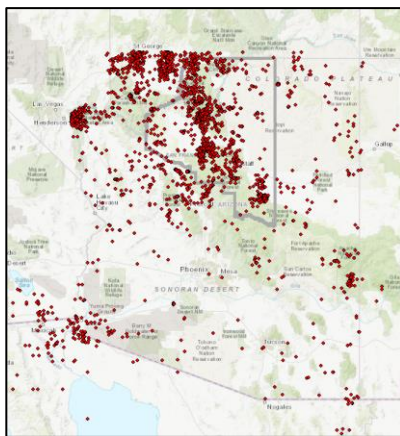
Figure 9) Map of Coconino County Boundary and Arizona Earthquakes.

- Next, add the City of Flagstaff Boundary
- Search for flagstaff city boundary
- Add "City of Flagstaff City Limits"

Figure 10) "City of Flagstaff City Limits" dataset from ArcGIS Online.

☐ Your map should now look like the following in Figure 10.
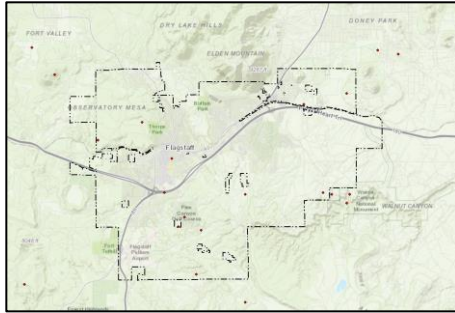
Figure 11) Map of City of Flagstaff City Limits

- Save and Close
    - Save as *FlagstaffQuake.mxd*
        - *Save to local directory that you can browse to later to import*
            - Close

Part 1B) Import ArcMap to ArcGIS Pro

Task 1: Open ArcGIS Pro

- Open ArcGIS Pro
    - Start a new project
        - Select without a template

Insert Tab
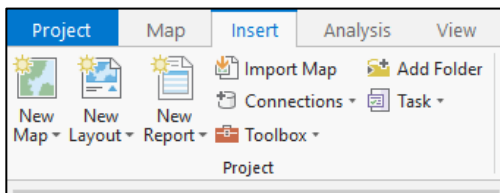
Figure 12) Insert Tab with options displayed.

Task 2: Import ArcMap into ArcGIS Pro

- Select Import Map

Figure 13) Import Map option to select.

    - Browse to FlagstaffQuake.mxd
        - Import
            - Begin module in Pro at Part 2

Part 1C: Set up Project entirely in ArcGIS Pro

- Start New Project in ArcGIS Pro
    - Create New Map
        - Name Flagstaff Earthquake
            - Change Storage to local disk where you can ask

Task 1: Select area of study

☐ In this case, instead of going to XY, we will explore zoom options
            - Zoom to Arizona region with basemap on

Figure 14) Map of Arizona region in ArcGIS Pro.

☐ Instead of adding data from ArcGIS Online as in ArcMap, ArcGIS is seamlessly integrated to online capabilities with the "Portal" Feature. You can add the same datasets added in ArcMap from ArcGIS online into ArcGIS Pro from the Portal.

Task 2: Build project by adding data

    -In the Catalog Pane:
        - Select all Portal
            - Search for Arizona Earthquakes
                - Add to current map = AZGS_Earthquake
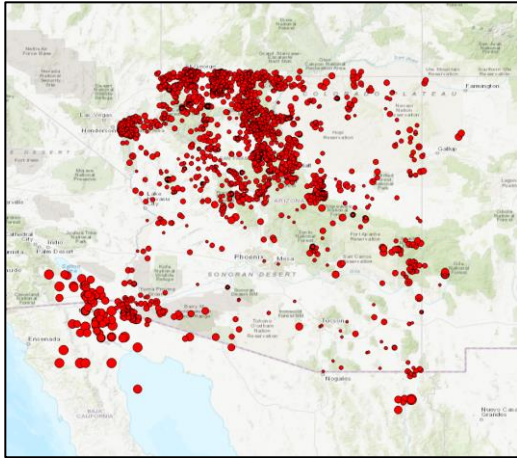
Figure 15) Map of AZGS_Earthquake in ArcGIS Pro.

- All Portal
    - Search for Coconino County Boundary
        - Add

- Search for City of Flagstaff City Limits
    - Add City of Flagstaff City Limits
        - Change outline to solid Black
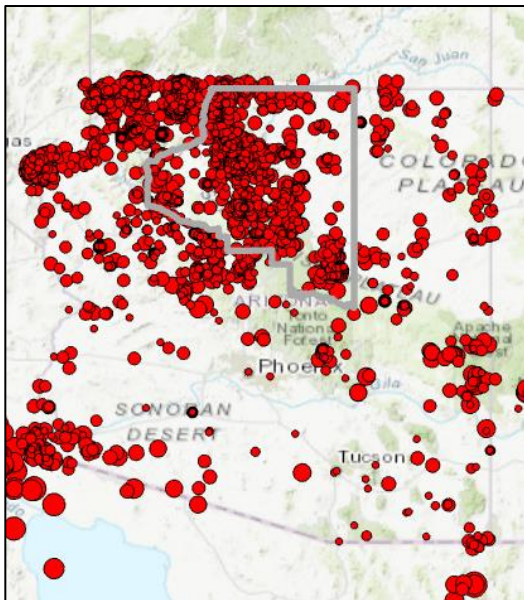
Figure 16) Map of Arizona Earthquakes with Coconino County Boundary displayed in ArcGIS Pro. City of Flagstaff City Limits is displayed yet not visible due to scale.

Part 2) Investigate earthquakes in ArcGIS Pro

☐ Whether you started in ArcMap or in ArcGIS Pro you should be at the same step place now ready to proceed in ArcGIS Pro.

☐ Your contents pane should look like the following in Pro with the following Layers displayed:
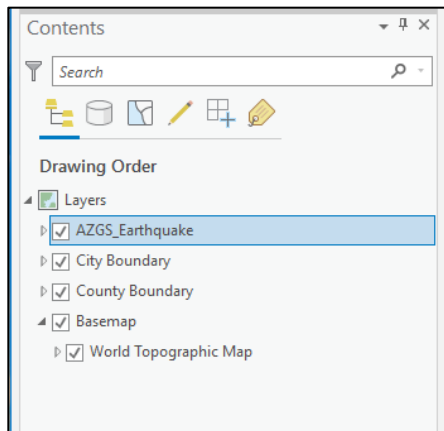
Figure 17) Contents pane in ArcGIS Pro with layers displayed.

Task 1: Change name of map

- Hover mouse cursor over Layers
  - Click once change name
    - Change name to: FlagstaffQuake

Task 2: Explore geospatial scales & attribute table investigate earthquakes

☐This section highlights some capabilities to use GIS to investigate Earthquake frequency at different spatial scales to help explore geospatial thinking and geospatial relationships.

- Open attribute table for AZGS_Earthquake earthquake data.
  - In the bottom corner of the attribute table it displays how many total records are within each dataset.

Question 1) How many total earthquakes are in the AZGS_Earthquake record?   **3348**

☐**Apply Critical Geospatial Thinking 1)**

- *We could just trust that all the earthquakes represented in AZGS_Earthquake layer are Earthquakes within Arizona based on the title*
- *Let's develop critical geospatial thinking and not just trust all data found from ArcGIS Online or the Portal. To think critically let's analyze the outline of the state of Arizona relative to these earthquakes listed on the map.*
- *From exploring the map with more critical thinking at different scales, there are earthquakes that have occurred outside of but adjacent to Arizona.*
- *It looks like these may have been included because in the description the attribute table describes them as occurring within some distance of less than 100km from Arizona.*
- *As some earthquakes are outside of Arizona, to get an idea of how seismically active Coconino County is first let's explore the Portal in Pro and determine how many earthquakes occurred within Arizona*

☐ In this section we will explore critical geospatial thinking, as geospatial thinking is relevant to Earth, regional, and environmental scales.

☐We will look at Regional scales here from state, to county, to city scales.

Task 3: Add Arizona state outline

☐ To determine how many earthquakes from the AZGS_Earthquake dataset have occurred within the Limits of Arizona, first we want to add the state boundary of Arizona.

In Catalog pane:
- Go to Portal
- Select All Portal
- Search for Arizona State Boundary
- Add Arizona State Boundary to current map

Task 4: Clip earthquake dataset to state scale

- In the Analysis Tab, select the Tools "Tool Box":

- Analysis Tab
- Tools

- Search Clip (Figure 18)
- Select Clip (Analysis Tools)
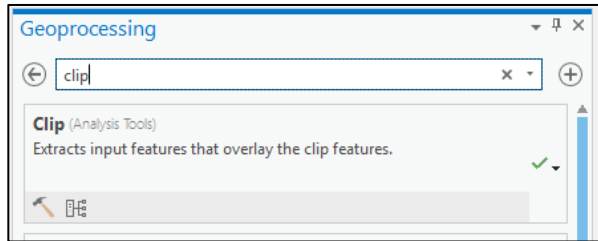
Figure 18) Geoprocessing Clip Tool to select from search.

☐Clip earthquakes to only cover State of Arizona

- Analysis Tab
- Tools
` - Search Clip
- Select Clip Analysis
-Set Clip parameters as in Figure 19a
- Rename EQ_Clip_AZ
-Run   (Figure 19b)

a)   b)
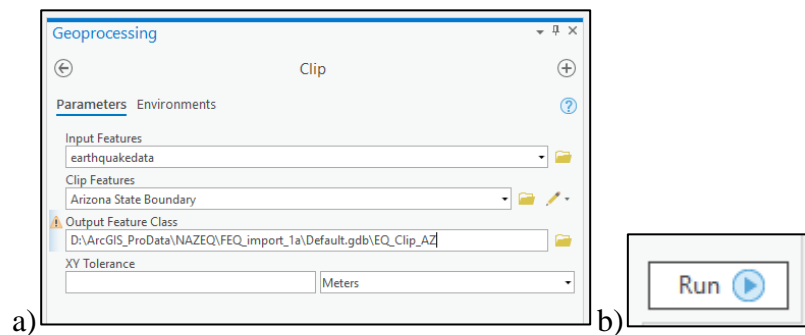
Figure 19a,b) Geoprocesssing Clip Tool parameter setting window and Run icon.

☐ Your map should look like Figure 20 showing earthquakes only within Arizona.
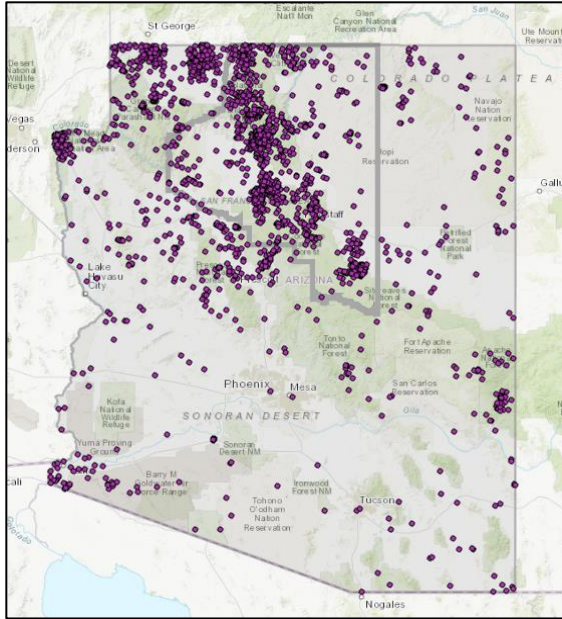
Figure 20) Map displaying earthquakes clipped to within Arizona.

☐ Open attribute table for EQ_Clip_AZ. Compare how many earthquakes were removed.

Question 2) How many Earthquakes have occurred within Arizona on record according to this dataset? **2842**

Task 5: Clip earthquake dataset to county scale

- Clip earthquakes to only cover Coconino County

☐**Apply Critical Geospatial Thinking 2)**

☐*As earthquakes are spread throughout Arizona, we would like to focus on Coconino County. Therefore, we do not need all Earthquakes represented within the state.*

- Analysis Tab
    - Tools
`   - Clip
                    - Set Clip parameters as in Figure 21
                        - Rename EQ_Clip_CC
                            - Run   (Figure 21b)

a) b)
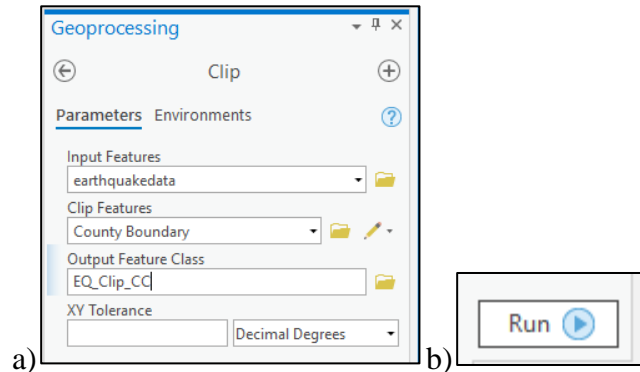
Figure 21a,b) Geoprocesssing Clip Tool parameter setting window and Run icon.

☐ Now only Coconino County earthquakes are represented as in Figure 22.
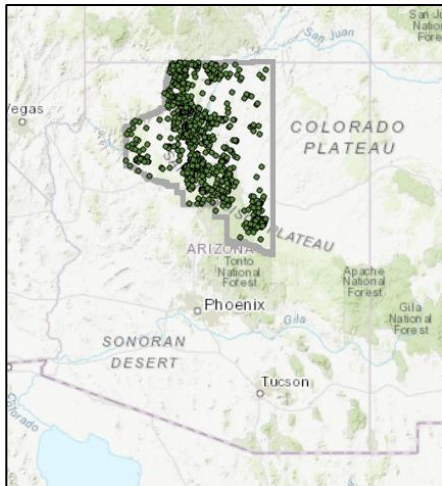
Figure 22) Map of earthquakes clipped to Coconino County.

Task 6: Modify earthquake symbology

☐**Apply Critical Geospatial Thinking 3)**

☐ *Since ArcGIS Pro has great 3D capabilities and we will be exploring earthquakes in 3D let's begin by exploring some 3D options.*

- In Contents - hover cursor over the symbol under EQ_Clip_CC
    - Click to modify symbol
        - Collapse ArcGIS 2D
           - Open ArcGIS 3D
               - Select standing Sphere (Figure 23)
                   - Change Symbol
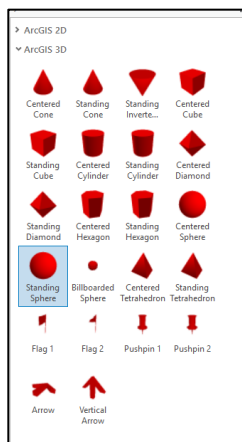
Figure 23) ArcGIS 3D Symbology options. Select standing Sphere

☐ Your map should now display 3D spheres (Figure 24) for earthquake symbols instead of 2D dots, which will be better for working with 3D views in upcoming sections.
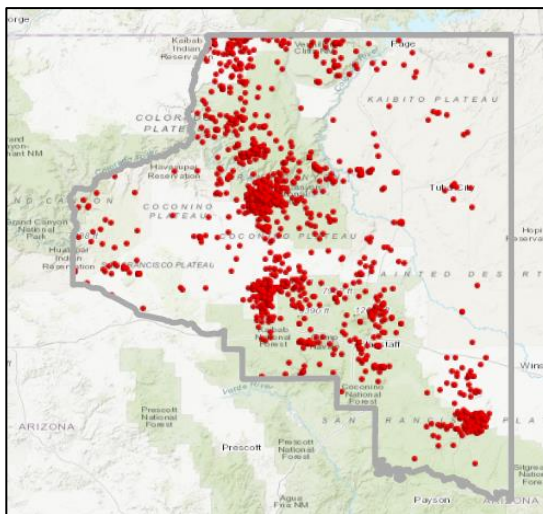
Figure 24) Map of earthquakes in Coconino County displayed as 3D spheres.

☐ Now let's explore how many earthquakes there are in Coconino County relative to the state of Arizona.

☐ Open Attribute table for EQ_Clip_CC

Question 3) How many earthquakes are included in Coconino County? **1471**

Question 4) What percentage of earthquakes within Arizona has occurred within Coconino County?

 2842/1471 = .51759 x 100 = 51.76 %

Question 5) Comparing spatial scales, would you say Coconino County is a seismically active county compared to other Arizona Counties?

Yes, because over half of all earthquakes recorded in this dataset have occurred in Coconino County.

Task 7: Explore earthquakes at city scale

- Analysis Tab
          - Tools
`   - Clip
                              - Set Clip parameters as in Figure 25a
                                   - Rename EQ_Clip_Flag
                                        - Run   (Figure 25b)

b)
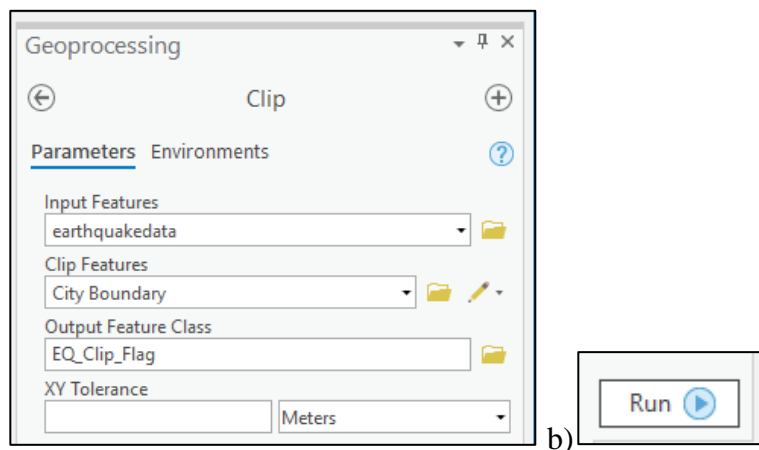
Figure 25 a,b) EQ_Clip_Flag geoprocessing Clip Tool parameter setting window & Run icon.

□Your map should now look like Figure 26
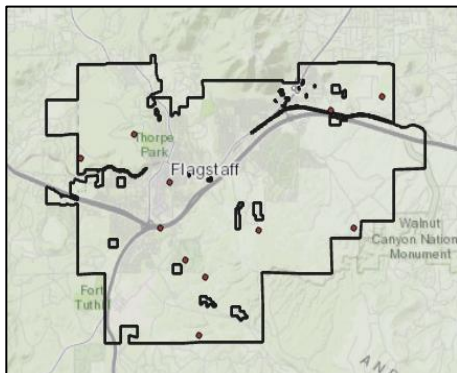
Figure 26) Map of earthquakes within Flagstaff city limits.

Question 6) How many earthquakes have occurred within the city of Flagstaff? 14

Part 3: Visualize temporal and spatial data

☐**Apply Critical Geospatial Thinking 3)**

Currently we can only see our earthquake data in a static format and some areas look rather clustered where it is difficult to distinguish individual earthquakes (Figure 27). Therefore, it can be difficult to determine how many earthquakes have occurred in a certain area and when. This can provide a good lesson to help us learn about the how earthquakes can occur in "clusters" and we can view this temporally. This provides other great learning lessons to better test the hypothesis if earthquakes are related to faults and how, then if we can identify fault zones and patterns of clusters we can help identify a seismic zone, or in this case help identify the Northern Arizona Seismic Belt (NASB). In this section we will learn how to display temporal and spatial data to help increase geospatial thinking by be able to see earthquakes as they have occurred overtime in an animation that can be displayed in Pro. This section provides a great opportunity highlight features in ArcGIS Pro.
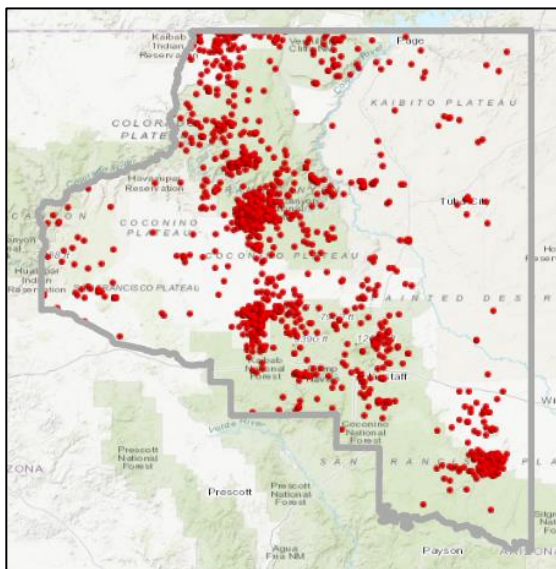
Figure 27) Static display of earthquake data.

Task 1: Set up time settings display

In Contents pane
- Select to Coconino County earthquake data EQ_Clip_CC,
  - Properties (Figure 28a)
    - Time (Figure 28b)
      - Enable every location has a single time

- Set Time properties as displayed in Figure 28
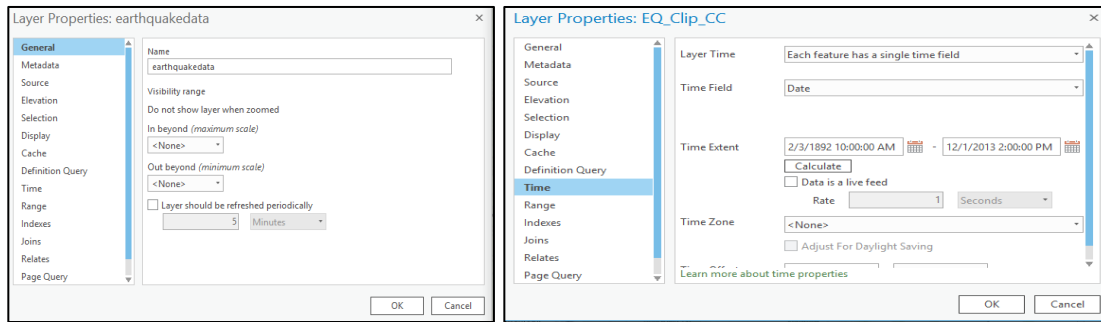
Figure 28a,b) a) Properties **b)** Time Properties settings display.

☐ Open attribute table for EQ_Clip_CC

☐ Look at earthquake data for all of the AZGS_Earthquake - earthquake data dataset for Coconino County - EQ_Clip_CC

Question 7) What is the first and last earthquake for Coconino County?

First: 2/3/1892 Last: 12/1/2013

      - Select Map Tab
          - Select time
               - Display time slider bar as in Figure 29
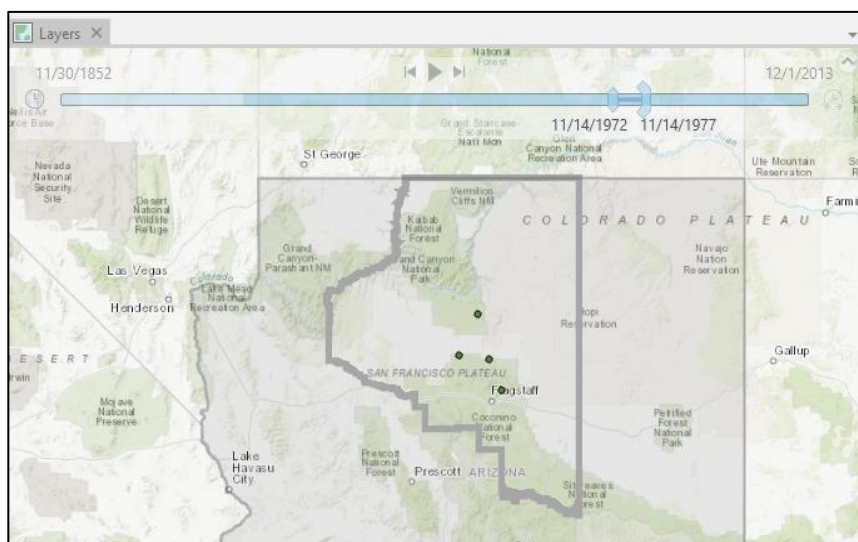
Figure 29) Map of Coconino County earthquakes with time slider bar enabled

Task 2: Time Setting Activity

-Map Tab

- Set time span to every 5 years
- Click play
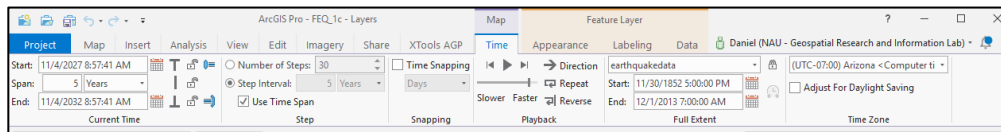
Figure 30) Time display setting to set to every 5 years.
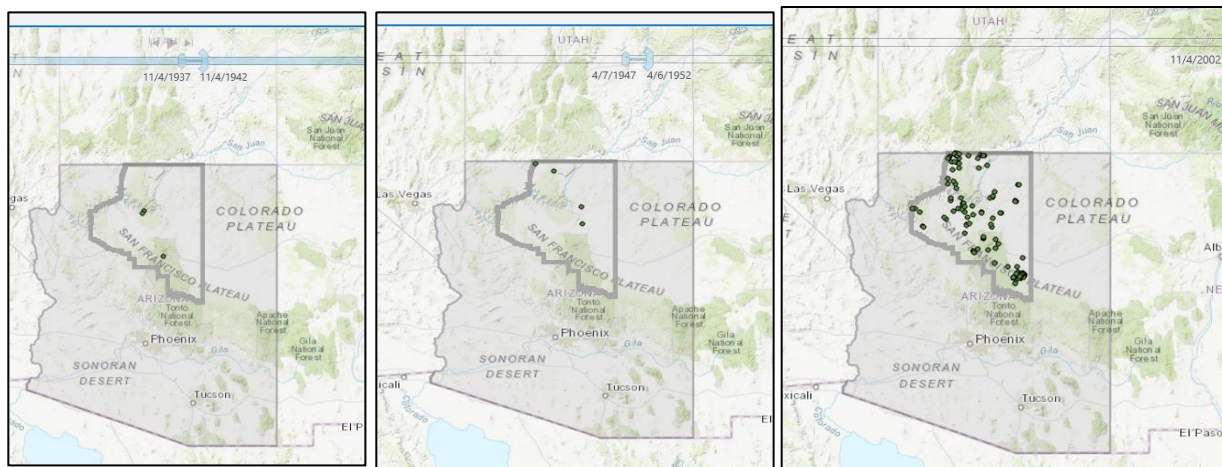
Figure 31 a, b, c) Sequential time series display of earthquakes at different 5-year intervals showing where earthquakes have occurred in different 5-year intervals. This allows increased geospatial thinking by visualizing earthquakes have a time component as well as a spatial component relevant to a location on the Earth.

☐ Watch the Earthquakes in time show up. Here are some questions provided to discuss more critical thinking in relation to space and time as well as geoscience topics.

Question 8a) Does it appear that there have been more earthquakes in more recent times?

Yes, it does appear that more earthquakes have occurred in recent times judging just from the amount displayed over the timeline available in this dataset.

Question 8b) Are earthquakes only recent geoscience phenomena?

No, earthquakes have been occurring in the geologic record long before seismic stations and historical accounts were there to record them.

Question 8c) Why do you think that may be more earthquakes are displayed in more recent times in Coconino County?

It is likely due that more sensors have been put in place and not that more earthquakes have occurred in the last few decades than compared to over a hundred years ago. With modern technology becoming more prevalent and also the area becoming more inhabited, monitoring and reporting of earthquakes has increased.

Question 8d) How could you use GIS to explore the observations you made in part 8a, what you know from part 8b, and what you hypothesize in part 8c?

You can look at the attribute table data and look at the magnitude and depth from more historic earthquakes prior to 1959 up through the most recent. It looks like the more recent earthquakes have lower magnitudes and records depth. The older earthquakes tend to have higher magnitudes and do not have depth recorded. Therefore, this indicates only the larger earthquakes from the when the region was less in inhabited and less seismically monitored were recorded. Furthermore, due to the more advanced technology in seismic monitoring that is a more recent development, the depth of the more recent earthquakes is recorded even if they are low magnitude suggesting that the seismic monitoring is more advanced to record depth of the earthquake and therefore detect low magnitude earthquakes.

Task 3: Turn off time display

☐We do not need to have the interactive time window displayed anymore.

- Go back to time settings to turn off
- Layer Time - select No Time
- Select OK
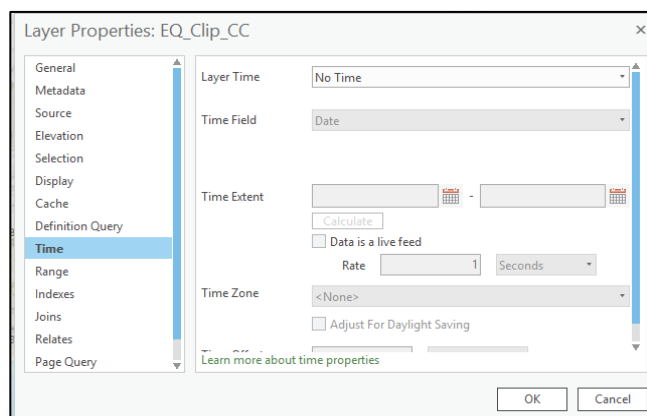
Figure 32) Layer properties window to turn off Time display. Select "No Time" option from layer time settings.

Part 4: Investigate earthquake geospatial relationship to faults

☐ **Apply Critical Geospatial Thinking 4a)**

☐ One of the great features of GIS is to be able to layer different datasets at the same scale. An advantage of ArcGIS Pro is to be able to view in 2D and 3D, as we will explore in future sections.

Task 1: Set up fault data

- Go to Catalog Pane
- Portal
- All Portal
- Search Arizona Faults
- Select Faults of Arizona, USA (Data Basin Dataset) to map
- Add to current map (Figure 33)
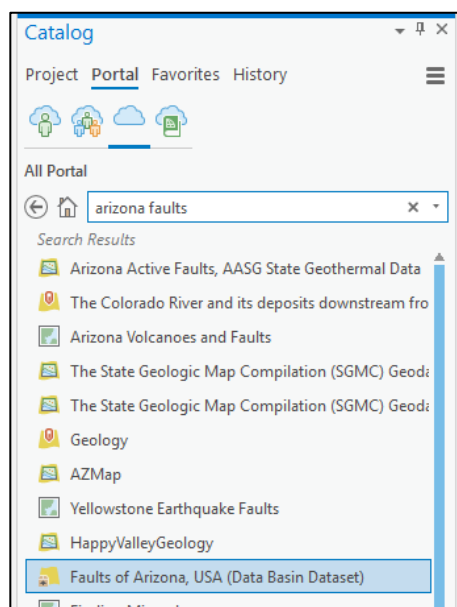
Figure 33) Adding fault data to the current map. Select the Faults of Arizona, USA (Data Basin Dataset).

☐ **Apply Critical Geospatial Thinking 4b)**

☐Let's think geospatially to explore faults and start with opening the Attribute Table,

Question 9) How many faults are mapped in Arizona according to this dataset? **5008**

Task 2: Clip Faults to Coconino County

☐ To clip faults to Coconino County we will use the clip settings from before.

- Analysis Tab
    - Tools
        - Search for Clip
            - Select Clip (Analysis Tools)
                - Clip to Coconino County as in Figure 34
                    - Rename Faults_CC_Clip
                        - Run
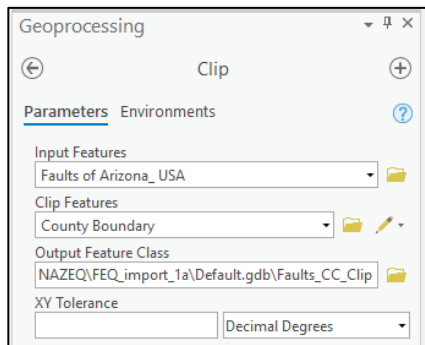
Figure 34) Geoprocessing Clip Tool parameters to set to clip Faults of Arizona_USA to Coconino County.

☐ Now let's only display faults in Coconino County

    - Turn off Faults of Arizona_USA
        - Only display Faults_CC_Clip (Figure 35)
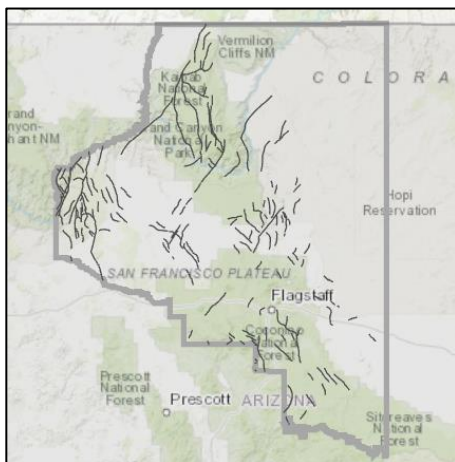
Figure 35) Map of faults in Coconino County displayed.

Task 3: Display both earthquakes and faults in Coconino County.

- In Contents pane

- Turn on Faults_CC_Clip
- EQ_Clip_CC

☐Your map should now look like Figure 36.
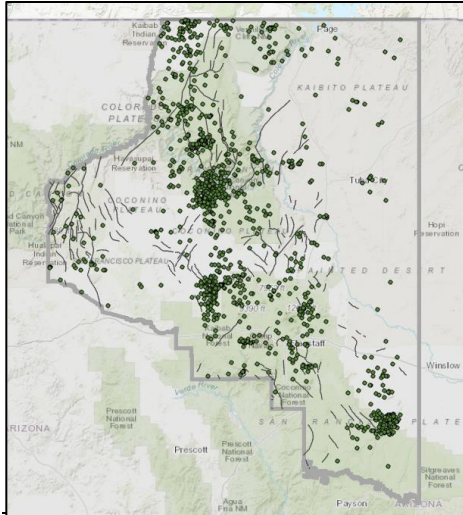
Figure 36) Map displaying both earthquakes and faults in Coconino County.

☐**Apply Critical Geospatial Thinking 5a)**

☐ Here is a great opportunity to explore geoscience and geospatial concepts by exploring the geospatial relationship of faults to earthquakes.

Question 10a) Does there appear to be a relationship to the geospatial location of faults relative to earthquakes?

Yes, it does appear that earthquakes and faults occur in clusters and are associated with each other.

Question 10b) Can you identify a trend?

Yes, there appears to be a major trend of faults and earthquakes moving to the northwest.

Question 10c) What geologic feature does this geospatial pattern represent?

It is the Northern Arizona Seismic Belt (NASB).

☐**Apply Critical Geospatial Thinking 5b)**

Question 11a) How many faults are mapped in Coconino County according to this dataset? **471**

Question 11b) What percentages of faults in Arizona occur within Coconino County?

471/5008 = 0.0940 x100 = 9.4%

Question 11c) Why do you think it is that over 50% of earthquakes have occurred in Coconino County yet contains less than 10% of faults?

It is likely that not all the faults are active. They can be ancient faults mapped due to geologic interpretations yet do not have any currently active earthquakes associated with them.

Task 3: Explore relationship of earthquakes and faults in Coconino County.

☐ we can formulate the hypothesis that earthquakes are related to faults based on geospatial location appearance. However, we have not quantified that. To really test that hypothesis, let's use GIS to quantify the relationship of earthquakes and faults.

☐ Set Buffer to investigate proximity of earthquakes to faults by setting up the parameters as displayed in Figure 37.

    - Analysis Tab
        - Tools
            - Summarize Nearby
                - Set distance to 5 km
                    - Rename EQ_Fault_5km (Figure 37)
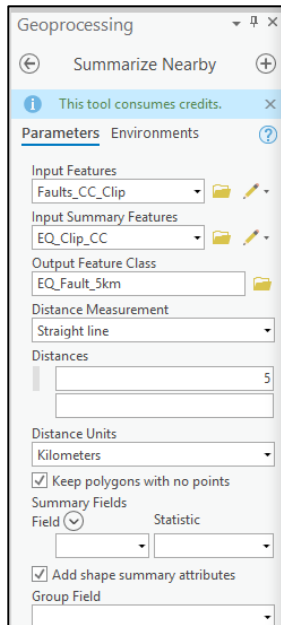
Figure 37) Summarize Nearby tool settings to provide 5km buffer around each fault.

☐ Your map should now look like Figure 38. It is now more visible to see the relationship of faults to earthquakes by expanding the proximity to faults by 5km and making that boundary visible.
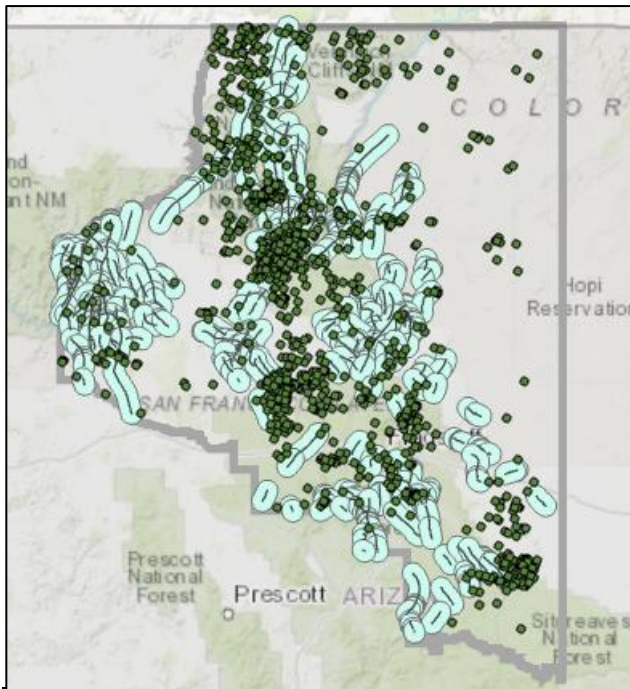
Figure 38) Map of EQ_Fault_5km displayed showing 5km buffer around faults.

☐ Apply Critical Geospatial Thinking 6a)

☐ Now we want to quantify the relationship of how many faults are within the 5km buffer surrounding the faults mapped in Coconino County. We can begin to visualize this geospatial relationship by only displaying the earthquakes that are within 5 km of faults for visual comparison to assess the geospatial relationships of faults to earthquakes.

 - Analysis Tab
  - Search for Clip
   - Select Clip Analysis Tools
    - Rename EQ_Clip_CC_Fault_5km_Clip
     - Set parameters as in Figure 39
      - Run
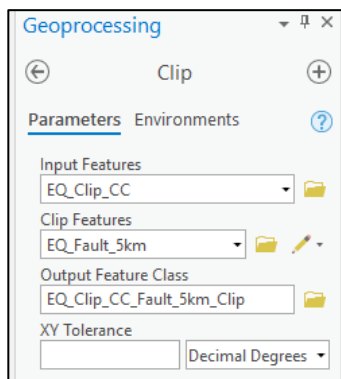
Figure 39) Parameters to clip earthquakes to only display within 5 km of faults.
Your map should now display only earthquakes that occur within 5km of a fault as in Figure 40.

☐Apply Critical Geospatial Thinking 6b)

☐ To quantify the geospatial relationship of earthquakes to distance from faults. Open the attribute table for EQ_Clip_CC_Fault_5km_Clip

Question 12a) How many earthquakes occur with 5 km of a fault line in Coconino County? **798**

Question 12b) What percentages of earthquakes in Coconino County occur within 5km of a fault?

798/1471 = .54248 x 100 = 54.25 %

Question 12c) Are earthquakes and faults related?

Yes, over half of all earthquakes in Coconino County occur within 5km of a fault.
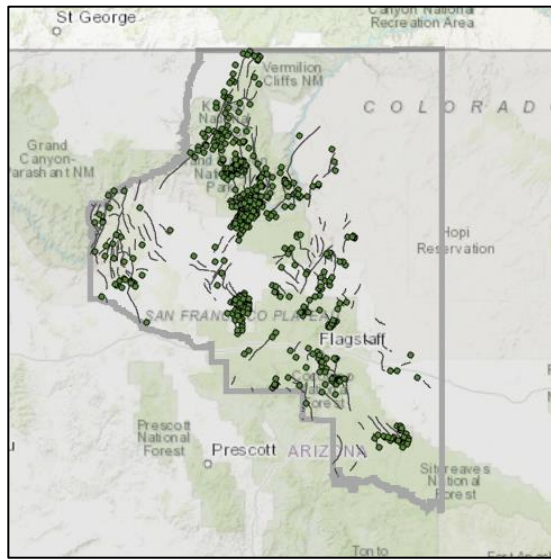
Figure 40) Map of earthquakes that occur within 5km of a fault.

◻**Apply Critical Geospatial Thinking 7)**

◻ To help visualize the capabilities of using GIS to identify earthquakes and faults, let's turn back on the 5km buffer zones to faults to display only earthquakes that occur within 5km of a fault and the faults as in Figure. Compare with figures 36 and 38 to enhance geospatial thinking by comparing where earthquakes have occurred in relation to earthquakes.
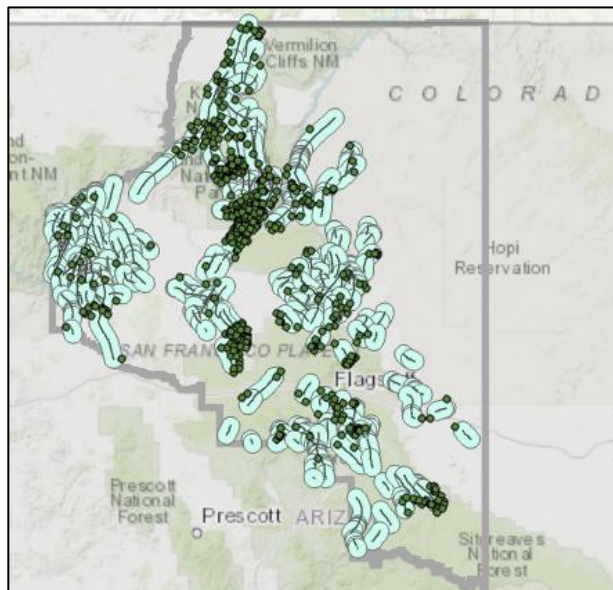
Figure 41) Map of faults, 5 km buffer zones around faults, and earthquakes that occur within 5 km of faults.

Part 5: Explore earthquake geospatial relationships in 3D

        ☐ **Apply Critical Geospatial Thinking 8a)**

☐ To highlight some of the features we can do in ArcGIS Pro to help increase geospatial thinking, let's view in 3D.

Task 1: Create a 3D view of the data
        - On the View tab,

                - in the View group,

                        - click Convert.

                                - Convert to local 3D

                                      - Convert to local 3D scene

                                          - Rename layer FlagstaffQuake"_3D

    -     Now two tabs are displayed: FlagstaffQuake and FlagstaffQuake 3D (Figure 42).

Figure 42) 3D and 2D map tabs. Now a second map has been created in 3D that you can go back and forth between 2D and 3D views.

☐ Now a new map (called a scene) opens in 3D. Despite being displayed in 3D, the map still appears flat. In the next step, you will change how the elevation of the scene is displayed.

 Task 2: Set the elevation surface for the 3D view

☐ The elevation is not at a high enough resolution, and the data is still displayed on the surface. To have a more accurate elevation surface you will have to re set a new elevation surface.

    ●   Add Elevation Data to enhance 3D view
              - Map Tab

- Add Data
  - Add az_dem_nad27

The map is now draped over a 3D framework as displayed in Figure 43.
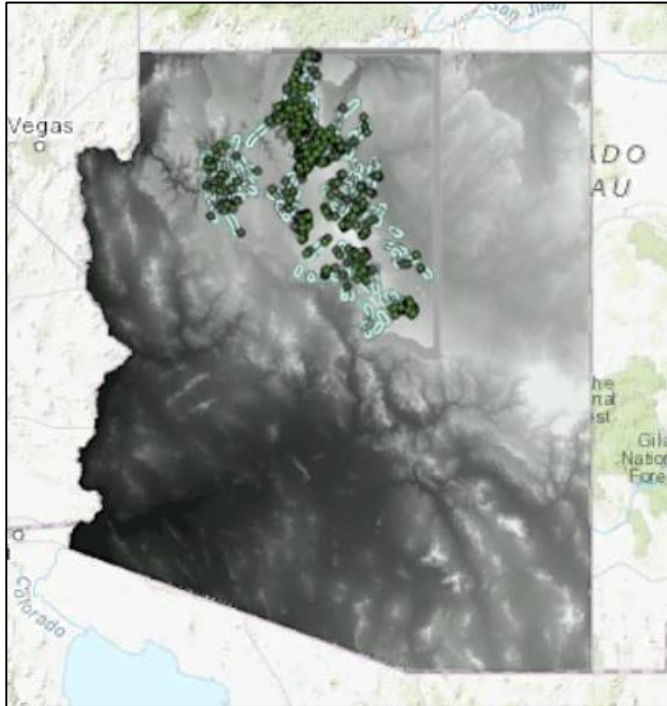
Figure 43) An Arizona Statewide Digital Elevation Model (DEM) is added to the map.

 Apply Critical Geospatial Thinking 8b)

Task 3: Clip DEM to Coconino County

 Now we want to see the scale relative to regional scale on compared to Coconino County.

- Analysis Tab
  - Clip (Raster)
    - Clip to County Boundary
      - Check use input features for clipping geometry
        - Parameters displayed in Figure 44
          - Rename az_dem_nad27_Clip
            - Run
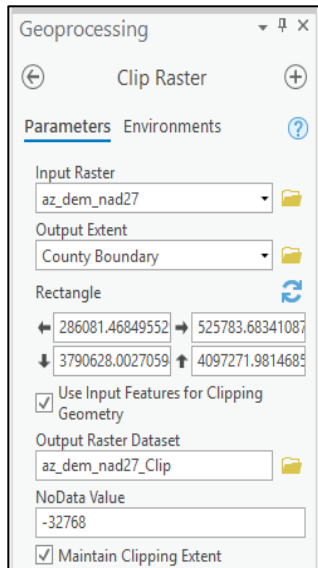
Figure 44) Raster clip parameters for clipping DEM to Coconino County

☐ Your map of the az_dem_nad27_Clip DEM should only be within Coconino County as displayed in Figure 45.

Figure 45) Map of DEM within Coconino County Boundary.

Task 4: Set up 3D data

- Contents Pane
    - Select Elevation Surfaces (Figure 46)
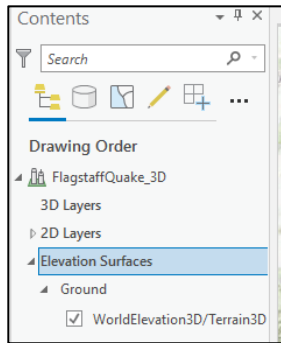
Figure 46) Elevation Surfaces selection display settings.

 - Click on Ground
  - Add Elevation Source
   - Browse to and add az_dem_nad27_Clip elevation source to ground to set to Elevation Surface

Part 6: Explore depth of earthquakes in 3D

☐ **Apply Critical Geospatial Thinking 9)**

☐Now at this stage of our ArcGIS Pro investigation we have a great opportunity to enhance geospatial literacy by combining, critical thinking, spatial and geospatial thinking, as well as apply geospatial technologies to geoscience concepts.

Task 1: Investigation of earthquake epicenter verse hypocenter

☐ Earthquakes do not always occur at the epicenter as often thought. The epicenter is the first place on the surface earthquakes are detected directly above the location of where the earthquake occurs at depth referred to as the hypocenter or focus. Although earthquakes can occur at or very close to the surface, the most often occur in the subsurface and have some depth component. Instead of just learning that earthquakes have a hypocenter and epicenter we can instead explore that concept with 3D interactions.

☐ To visualize the hypocenter of earthquakes first let's explore the depth within the attribute table.

☐ Open attribute table of EQ_Clip_CC, we can see that all of the depth data is listed in an absolute value or positive value. To visualize this in 3D we need to extrude this depth

component. However, to display in the subsurface we need to have a negative value expressed to map the hypocenters at a depth below the surface.

☐ To map the hypocenter of each earthquake in the subsurface relative to the surface we can begin with converting depth values to negative numbers.

- Open attribute table of EQ_Clip_CC data
- Select Depth Field
- Select Calculate Depth Field
- Double click depth
- Set the equation
- Enter: !depth! * -1

☐ This will give all earthquakes a negative depth value so it can be displayed in the subsurface.

☐ Next, so we can visualize the data below the surface , we need to enable underground navigation as in Figure 47.

- Appearance Tab
- Select Ground within Elevation Surface
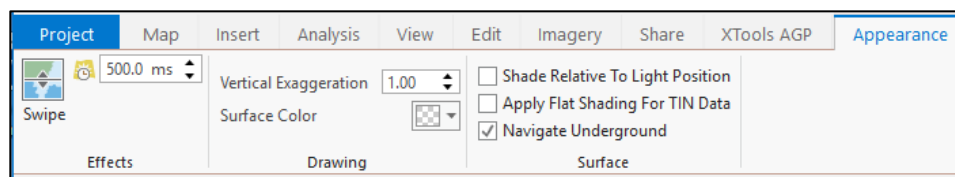
Figure 47) Appearance Tab to set enable Navigate Underground.

☐ Now we want to display Elevation features in 3D:

- Select EQ Clip CC
- Change Symbol
- ArcGIS 3D
- Select Standing Sphere (Figure 48)
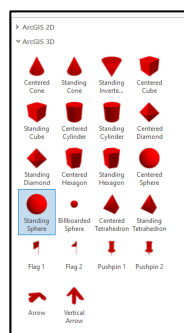
Figure 48) Symbology settings to display earthquake hypocenter in 3D.

Task 2: Explore navigating scenes.

The following is supplemental info from Esri on Navigation controls in 3D. Scenes are slightly different from navigation controls in 2D maps. Some of the actions are the same, but others have been changed to make navigation in 3D easier.

    On the Map tab, ensure that the Explore tool is active.

    Click and drag the scene in any direction.

Left clicking will pan the scene, much like in a 2D map.

    Click the Previous Extent button.

    Right-click the scene and drag the mouse forward and back.

    Roll the center mouse wheel back and forth. Right-clicking the scene and dragging—or rolling the mouse wheel—will zoom the scene in and out.

    Press the center mouse wheel, and then move the mouse forward and back. Pressing the mouse wheel and dragging the mouse forward and back rotates the scene up and down.

    Press the center mouse wheel again and move the mouse to the left and right. Pressing the mouse wheel and dragging the mouse from side to side will rotate the scene around the point that you originally clicked.

Task 3: Visualize earthquake hypocenters in 3D

☐ Explore rotating views to look above (Figure 49a,b) and below the surface (Figure 49b) in 3D.

a)

b)
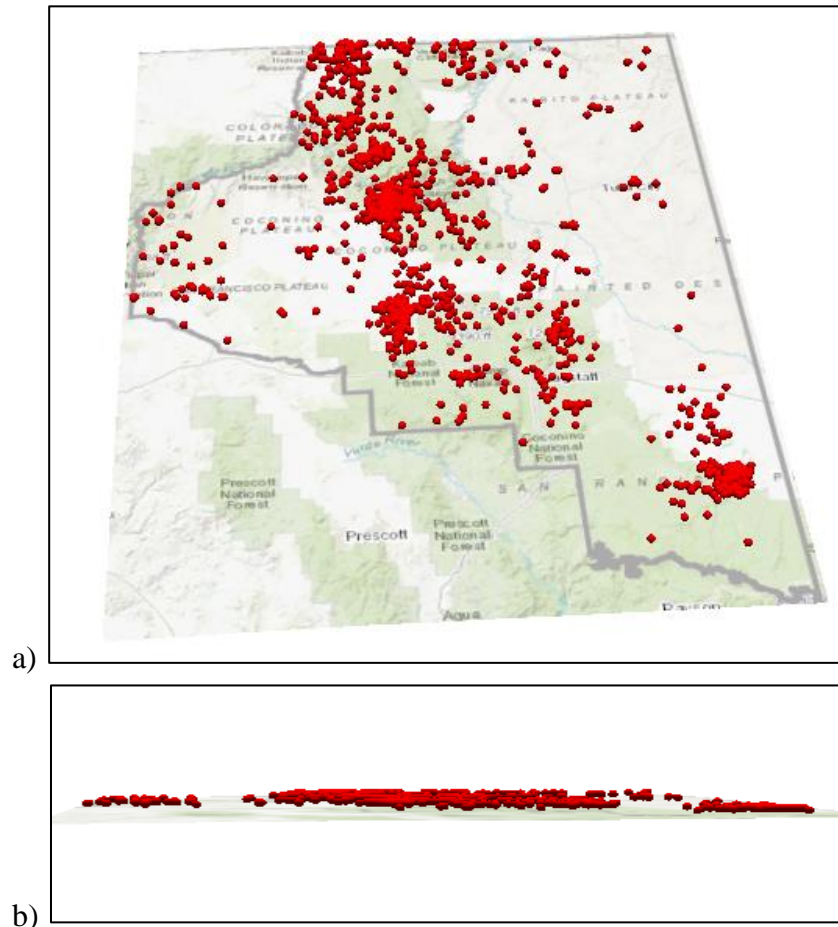
Figure 49 a, b) Rotating views above (Figure 49a,b) and below the surface (Figure 49b) in 3D. The settings are not enabled to view below the subsurface yet.

☐ We still cannot visualize earthquake hypocenters in the subsurface until we adjust the appropriate settings.

- Within FlagstaffQuake_3D
    - 3D Layers
        - Select EQ_Clip_CC
            - go to the Layer Properties
                - Elevation
                    - set the Features are: Relative to the Ground."
                    - Set A field to depth
                    - Set Elevation units to Kilometers

a)

b)
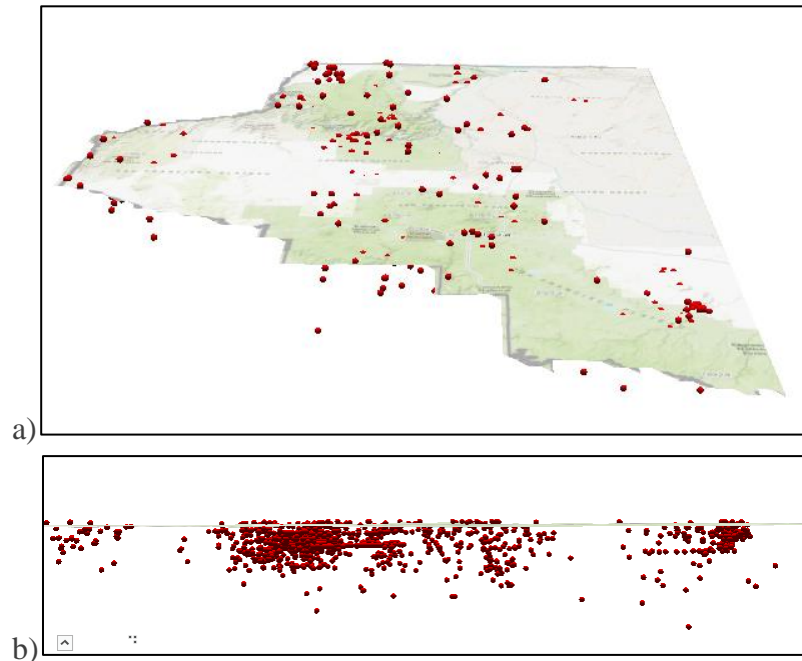
Figure 50 a, b) Map of 3D surface and subsurface views. rotating views to look above (Figure 50a) and below the surface (Figure 50b) in 3D.

☐ Now that we have enabled subsurface data visualization, explore rotating views to look above (Figure 50a) and below the surface (Figure 50b) in 3D.

Task 4: Visualize earthquake relation to faults by extruding 3D depth to faults

☐ **Apply Critical Geospatial Thinking 10a)**

To help increase geospatial literacy by using geospatial technology to learn how to visualize the relationship of faults to earthquakes, we can use ArcGIS Pro to investigate this getting a better view of the elusive subsurface.

To help explore geospatial technologies further, here is a helpful link from Esri that provides additional data on extruding features from 2D to 3D in ArcGIS Pro:

https://pro.arcgis.com/en/pro-app/help/mapping/layer-properties/extrude-features-to-3d-symbology.htm

☐ Extrude features to 3D:
- Select Layer Properties for Faults_CC_Clip
- Select - Faults_CC_Clip
- Properties
- Select Features are
- Select relative to the ground (Figure 52).
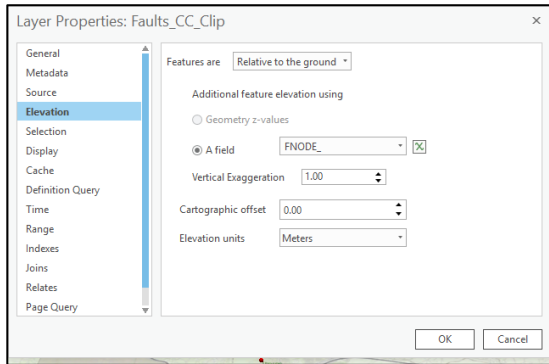
Figure 52) Layer properties for setting features are relative to the ground for 3D display.

☐ Extrude features to 3D:

- Appearance Tab.
- Look for the Elevation settings in Figure 53 display

a) b)
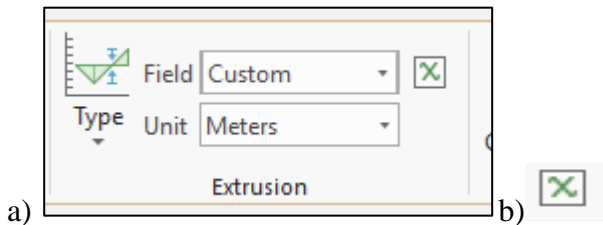
Figure 53 a,b) a) Appearance Tab elevation settings to extrude 3D data, b) Custom field icon.
- Select Type
- Drop down menu
- Select Absolute Height
- Field

-Select Custom
- Select expression builder (figure 54)
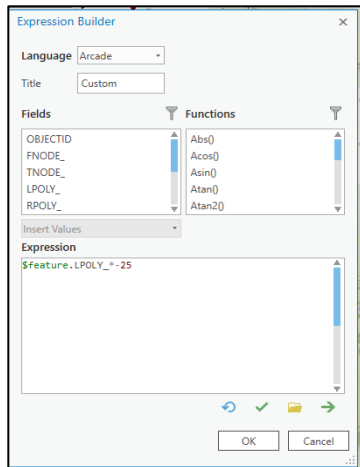
Figure 54) Custom field settings display showing expression builder.

 Expression Builder to set up 3D data:
 - In expression builder type: $feature.LPOLY_*-25

                        -

 Change symbology of Faults_CC_Clip
         - Select Appearance Tab
                 - Set faults to a transparent gray

Task 5: Visualize 3D fault earthquake relation above and below the surface

 Apply Critical Geospatial Thinking 10)

 Now with faults extruded to be visible above and below the surface we can rotate the view in separate screens to see how faults are related to earthquakes at the surface and below the surface in 3D as in Figure 55a and b.
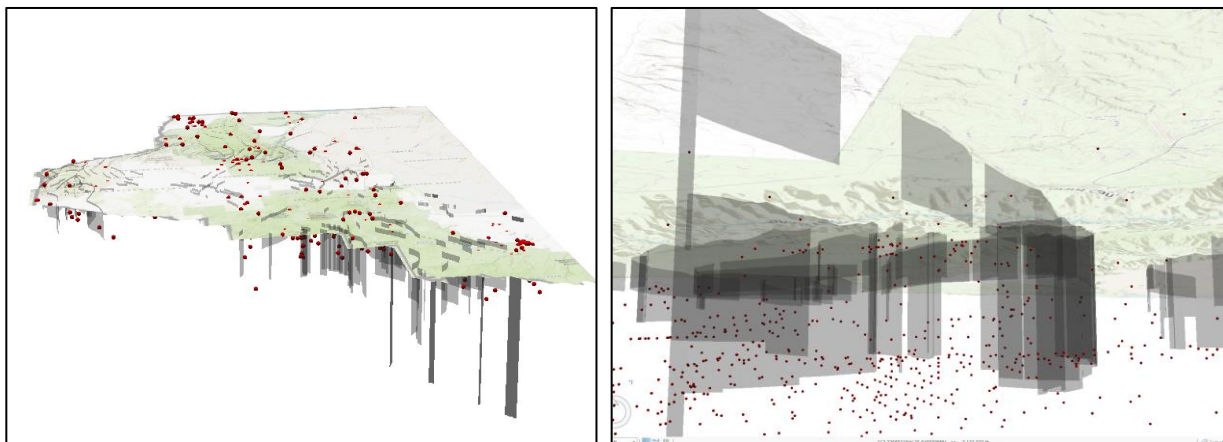
Figure 55 a, b) a) 3D surface at tilted view angle and b) subsurface views of faults.

Task 5: Visualize fault earthquake buffer above and below the surface in 3D

☐ Visualize 5km Buffer in 3D

      - Properties
          - Elevation
             - Set Features Are
               -Relative to ground (Figure 56)
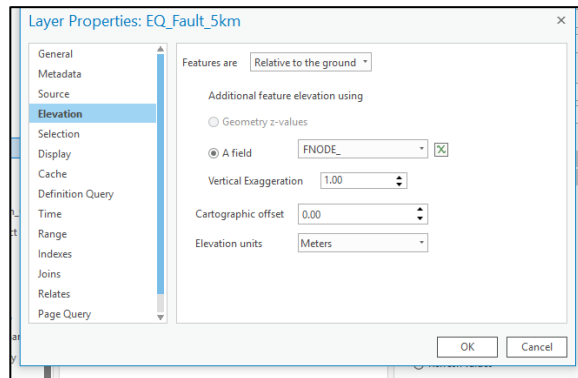
Figure 56) Layer properties settings to display 5km fault buffer in 3D.

☐ Set custom extrusion for 5km Buffer in 3D as displayed in Figure 57

      - Appearance Tab
          - Type
             - Absolute Height
               - Custom
                  - $feature.LPOLY_*-25
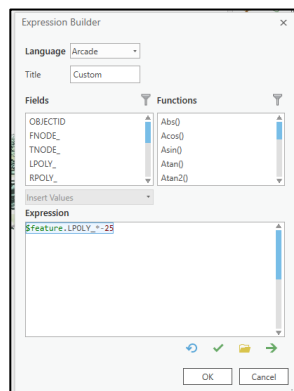
Figure 57) Expression builder settings to display custom extrusion for 5km Buffer in 3D.
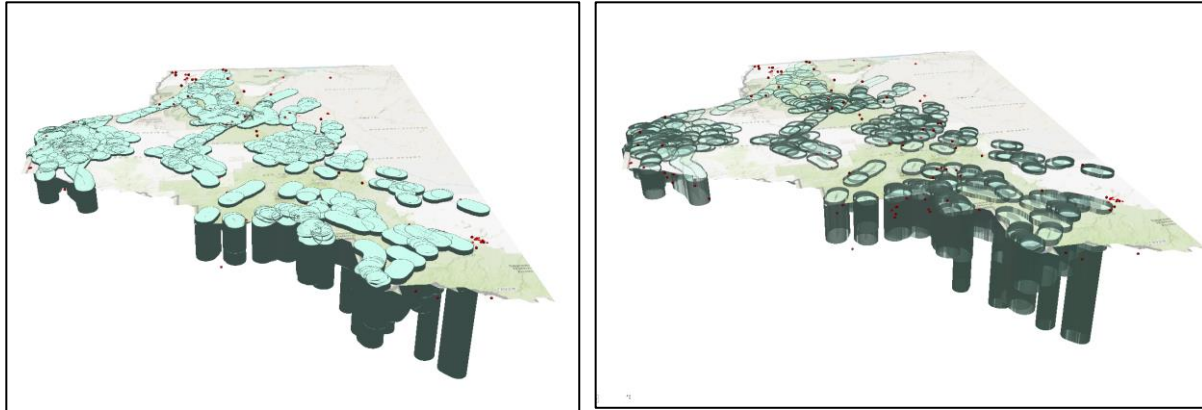
Figure 58a,b) 3D surface and subsurface views**.** Part a) before transparency settings and Part b) after transparency set to better visualize the geospatial relationship between faults and earthquakes.

 Now we can see the 5km fault buffer zones in Figure 58a, however it is difficult to see the relationship to faults if they are opaque, so we will want to change the symbology to be more transparent.

       - Appearance Tab
           - Symbology
                - Transparency settings
                      - display as in Figure 59)
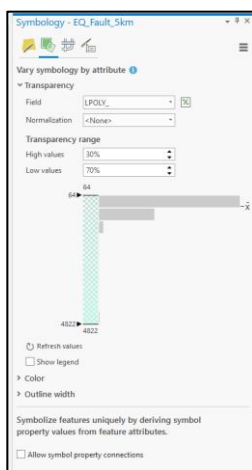
Figure 59) Transparency settings for fault 5km buffers.

 Fault buffer zones are now easier to see as more transparent in Figure 58b.

Task 7: Investigate earthquake depth hypocenters

☐ **Apply Critical Geospatial Thinking 11)**

☐ Let's Explore Depth of earthquakes to visualize difference of epicenter verse hypocenter. Prior to 1959 depth records were not recorded for Earthquakes. For the sake of comparing depths, let's explore editing in the attribute table and remove earthquakes before 1959.

- Open Attribute table
- Sort by Date
- Select All records prior to 1959
- Delete

Question 12) How many earthquakes are now displayed in Coconino County? **1438**

☐ **Apply Critical Geospatial Thinking 11)**

☐ Let's explore magnitude of earthquake to depth
- Appearance Tab
- Symbology
- Change symbology of EQ_Clip_CC to graduate symbols

☐ Now your map should display magnitude relative to size of the sphere. Display so the larger spheres represent higher magnitudes and smaller spheres representing lower magnitudes as in Figures 60a and b.
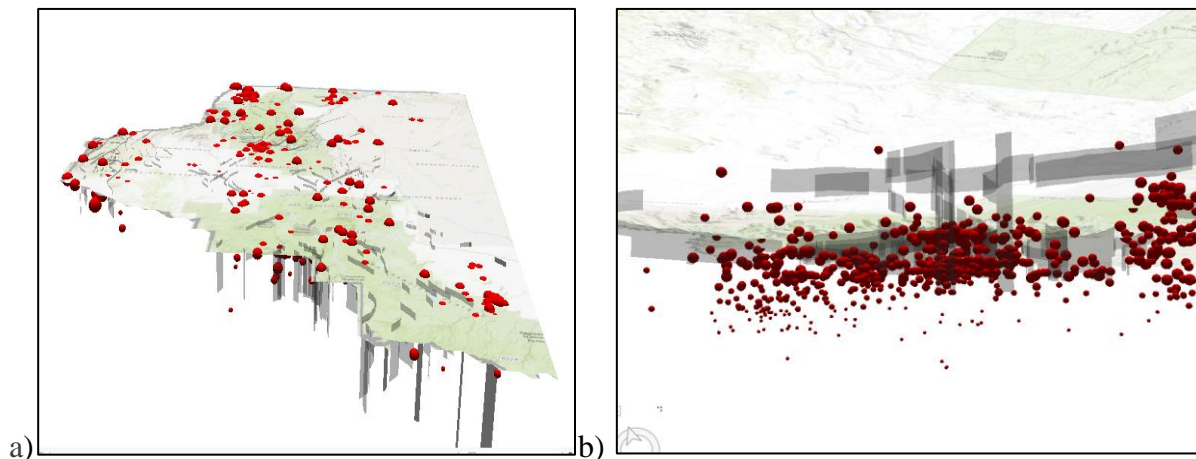
Figure 60a,b) 3D surface and subsurface views of earthquakes at visualizing hypocenters related to magnitude.

Part 7: Explore earthquake-fault geospatial relationships

Task 1: Link 2D and 3D views

☐ Now that we have explored how to set up 3D data we can start to visualize geospatial relationships of earthquakes and faults in 3D. To enhance geospatial thinking and apply critical thinking to better understand geoscience concepts we can compare 2D to 3D data with linked view maps.

☐ To do this you can *explore the 2D map and the 3D scene at the same time by linking your 2D and 3D views.*

> - Click the FlagstaffQuake_3D tab
>> - Drag it to the center of the scene.
>>> - A docking icon appears.
>>>> - Dock the window on one side or the other by dragging the window and then releasing it.

☐ Link and Center Views

> - Project Tab,
>> - View tab
>>> - Link group
>>>> - Link Views down arrow (Figure 61)
>>>>> - Choose Center and Scale.
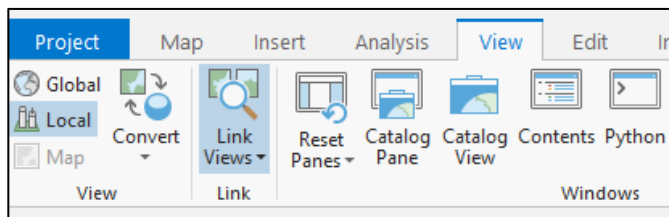
Figure 61) Link views settings display window.

☐ Your views now open in new windows. You can see the chain icons on the title tabs, which indicate that the two views are linked. When you change the extent on one linked view, the other linked view will automatically update to match it.

> - Using the skills that you learned earlier, pan around either the map or the scene.
> - Explore 2D and 3D views by navigating in both modes.

Task 2: Apply critical geospatial thinking to linked 2D and 3D views

☐ We will now explore visualizing depth of earthquakes to enhance geospatial thinking. Therefore, we will use the EQ_Clip_CC dataset where we have removed all prior to 1959 earthquakes that did not have reliable depth settings for the following tasks.

☐ **Apply Critical Geospatial Thinking 12)**

☐ We will now explore visualizing depth of earthquakes to enhance geospatial thinking. The next series of tasks of comparing 2D and 3D views have been designed to foster critical geospatial thinking with geospatial technologies. Now that views can be linked in 2D and 3D simultaneously, this provides great potential for integrating applied geospatial analysis and applied geospatial thinking to see both the surface and subsurface nature of faults and earthquakes in 2D and 3D.

Task 3a: View Coconino County earthquakes in linked 2D and 3D views

Only display earthquakes in Coconino County in both 2D and 3D linked views
    - display only EQ_Clip_CC (Figure 62a)
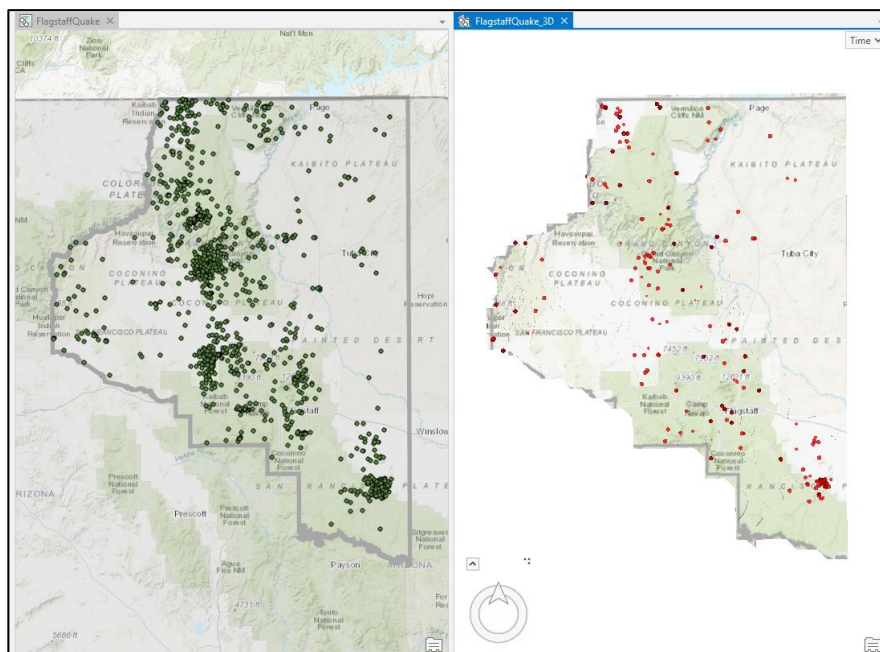
Figure 62a) Map of earthquakes in Coconino County in both 2D and 3D linked views

Task 3b: Rotate linked 2D and 3D views

☐ Here we get a great opportunity to see how the 2D view represents the epicenter and the 3D view represents the hypocenter of the same earthquake in geospatial reference.
    - view below surface in 3D to visualize depth of hypocenter (Figure 62b)
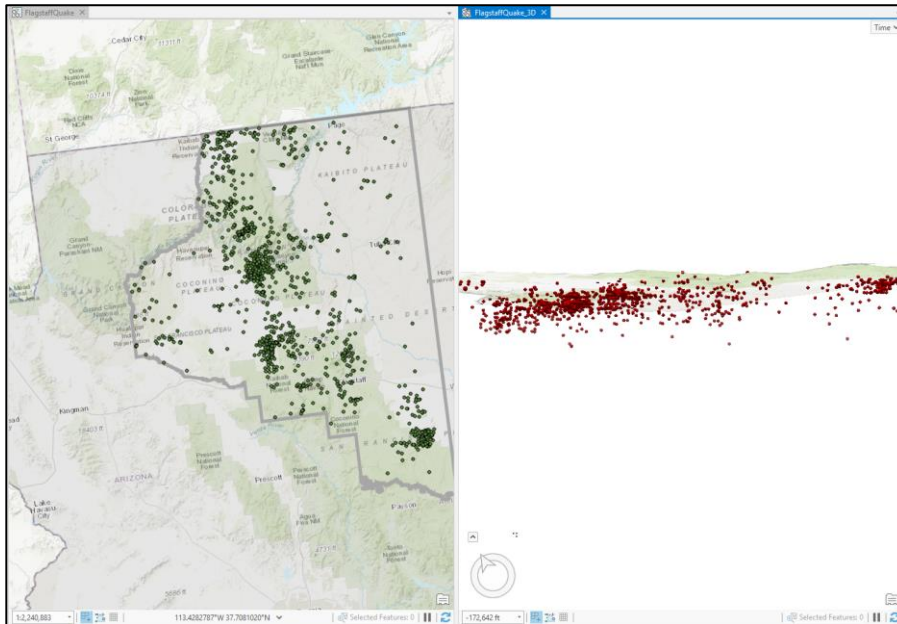
Figure 62b) Map of earthquakes rotated in linked 2D and 3D views to show above and below surface.

Task 4: View earthquakes in the City of Flagstaff in linked 2D and 3D views

☐ Now let's change the geospatial scale to the city level
        - Turn on City of Flagstaff Boundary
                - Zoom in to City of Flagstaff Boundary to explore
                        - Rotate views above and below Flagstaff (Figure 62c)
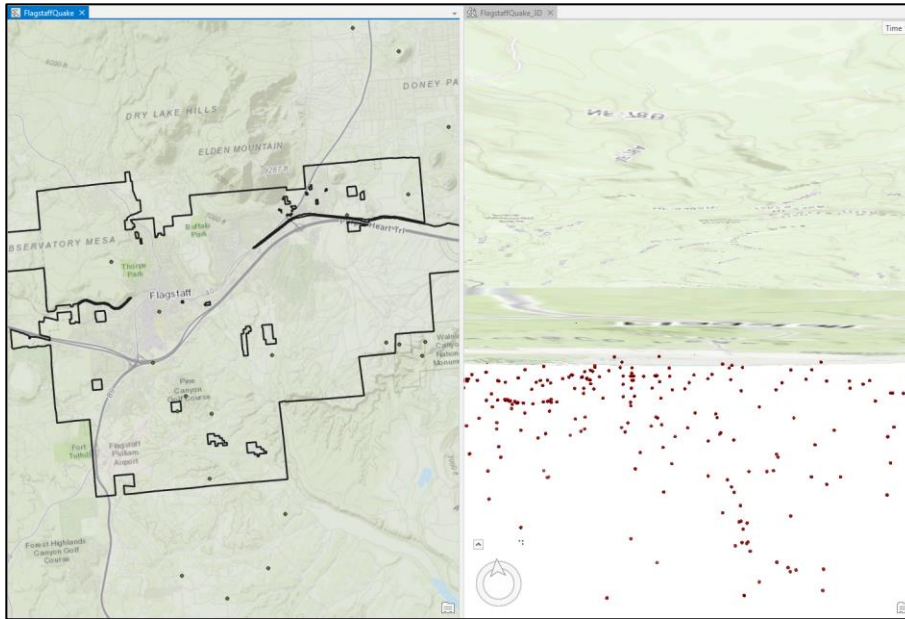
Figure 62c) Map of earthquakes in the City of Flagstaff in linked 2D and 3D views.

Task 5a: View earthquakes and faults in linked 2D and 3D views

  - Turn on Faults in Coconino County
        - Faults_Clip_CC to map (Figure 63a)
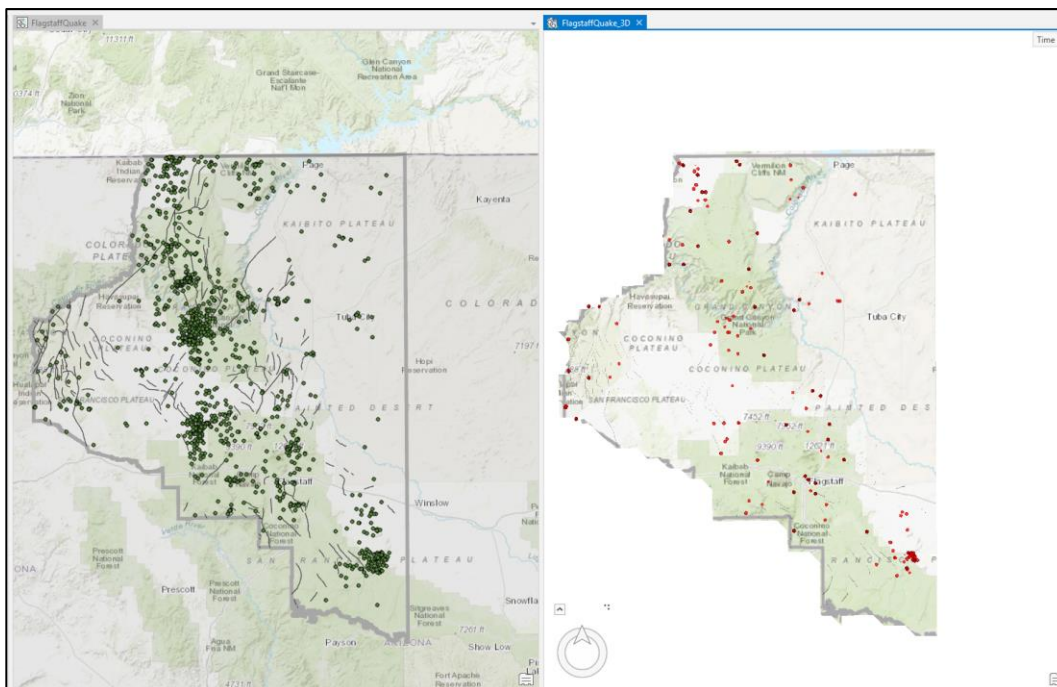
Figure 63a) Map view of earthquakes and faults in linked 2D and 3D views.

Task 5b: Rotate views of earthquakes and faults in linked 2D and 3D views

- Rotate views of faults and earthquakes to view above and below surface at different angles (Figure 63b)
    - Explore subsurface geospatial relationships of hypocenters 3D in views.
        -Compare subsurface to 2D map views of epicenters.
            - Notice where faults are in relation to earthquakes
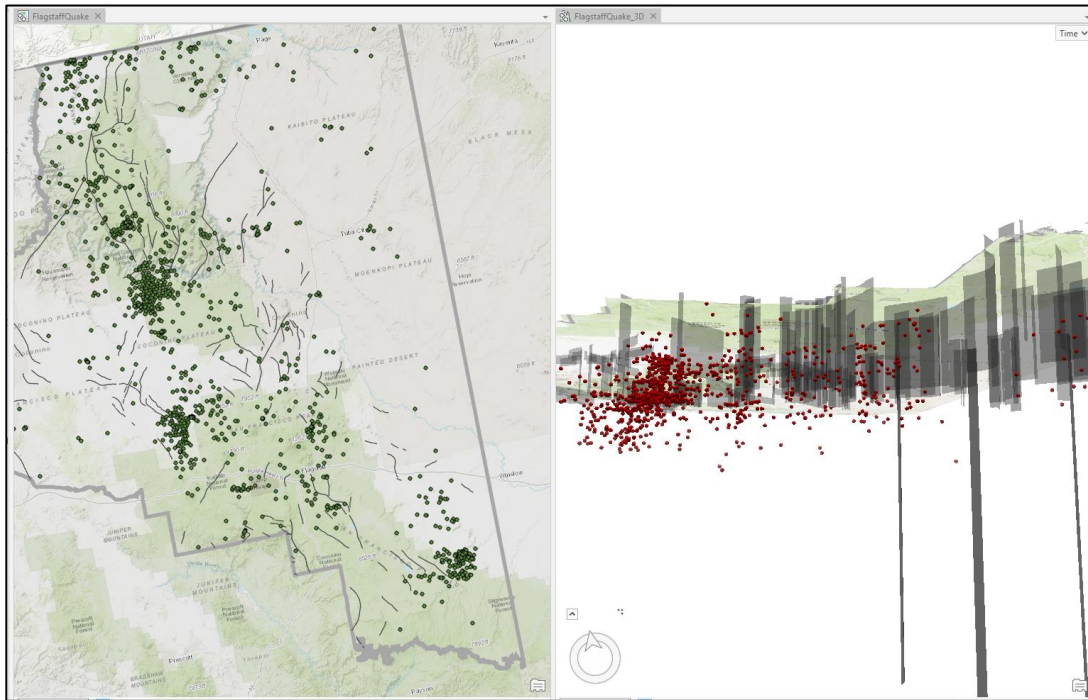
Figure 63b) Rotated views of earthquakes and faults in linked 2D and 3D views of Coconino County showing comparing the surface and the subsurface.

- Rotate views of faults and earthquakes to view above and below surface at different angles (Figure 63c)
    - Explore geospatial relationships of earthquakes and faults at titled 3D views.
        -Compare to 2D map views of epicenters.
            - Notice where faults are in relation to earthquakes on or close to the surface
            - Compare figures 66a and 66b to enhance our geospatial understanding of earthquakes and faults
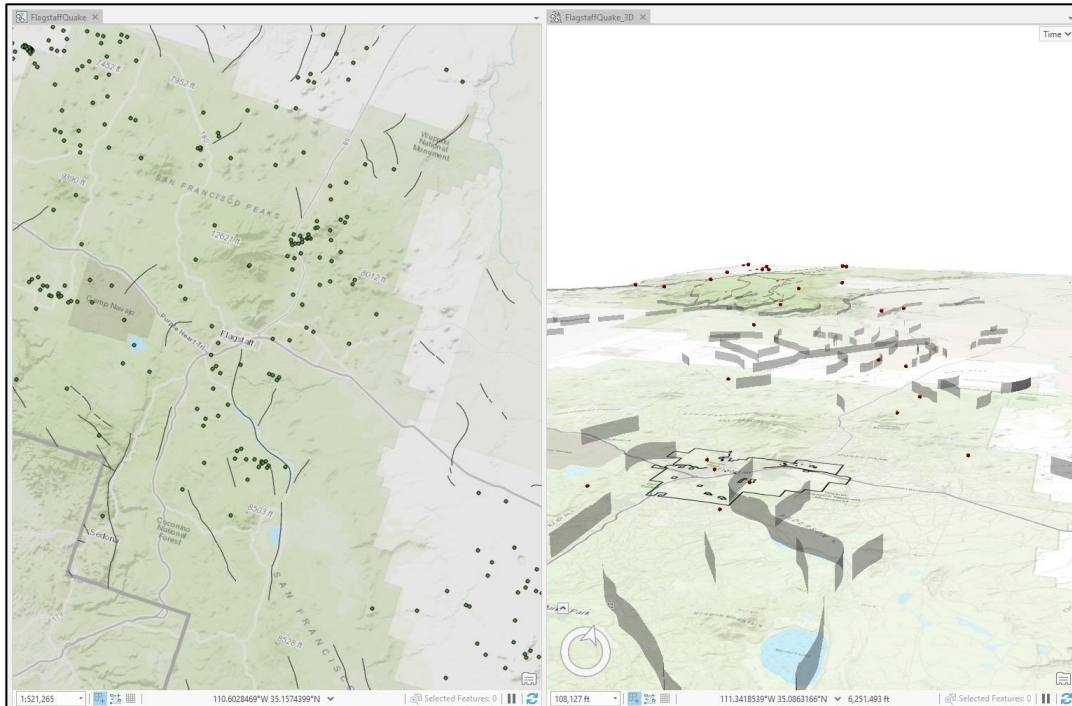
Figure 63c) Rotated views of earthquakes and faults in linked 2D and 3D views of Coconino County showing comparison of map view and tilted view of the same surface view point.

☐ Now let's zoom into Flagstaff to better understand the geospatial relationship of faults to the City of Flagstaff to investigate earthquake hazards in Flagstaff by seeing if we can enhance visualization of a Fault in Flagstaff.

- Zoom into Flagstaff to show where there is a major fault in Flagstaff (Figure 63d)

Question 12) What is this fault that goes through south Flagstaff? **The Lake Mary Fault**
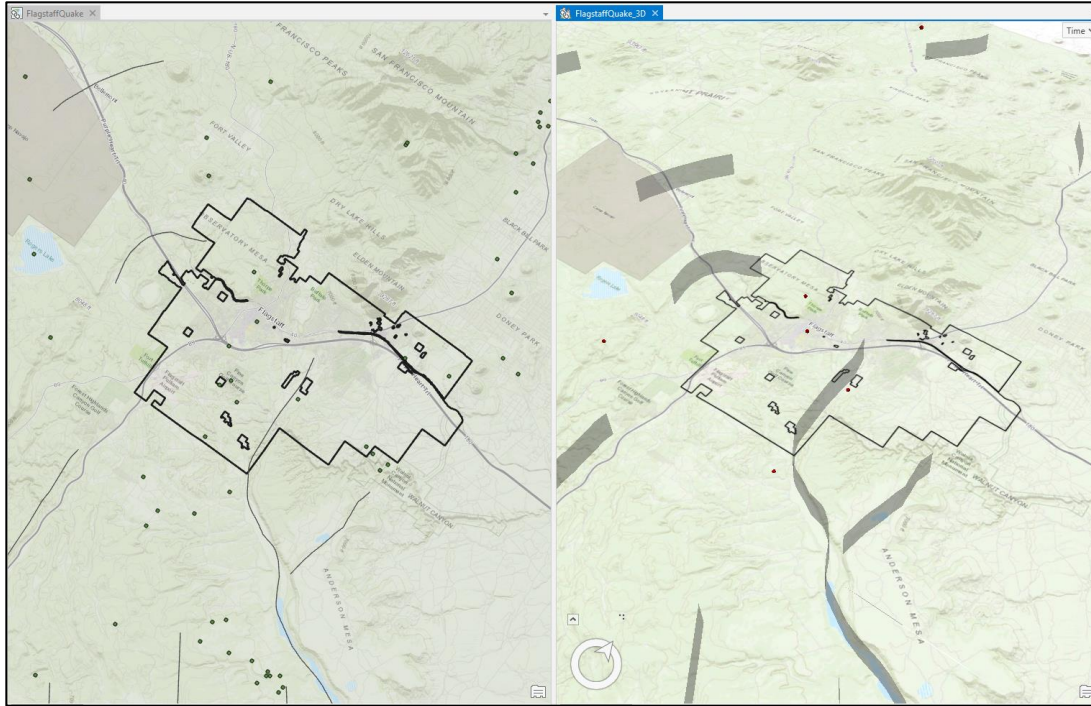
Figure 63d) Map of City of Flagstaff zoomed into to show the Lake Mary Fault cutting through south Flagstaff in linked 2D and 3D views.

☐ Now let's create a more impactful visualization of the Lake Mary Fault under flagstaff by rotating our view from the south underground. To show where the fault is in 2D at a broader scale yet show where the fault is in a more zoomed in view to only highlight one fault we can "unscale" the views by not selecting center and scale.

Task 5c: Unscale 3D and 2D views

- Project Tab
     - View tab
          - Link group
               - Link Views down arrow
                    - Choose Center (Figure 63e)

Figure 63e) Unscaled views of 2d and 3D views. Both views are centered, but the 2D and 3D views are displayed at different scales to focus on where the Lake Mary Fault is in relation to Flagstaff in 2D but a more zoomed in view in 3D to distinguish from other faults.

☐ Now we can re-center and rescale the linked views
- Project Tab
- View tab
- Link group
-Link Views down arrow
- Choose Center and Scale.

Task 6: Investigate an individual in Flagstaff earthquake 3D and 2D views

☐ Let's explore the geospatial relationship of an individual earthquake in both 3D and 2D views
- In map view find an earthquake in the Flagstaff City limits near Pine Canyon Golf Course and select it
- Open Attribute table of EQ_Clip_CC to see what was selected
- You should select FID 50
- If not find FID 50 and select it

☐ **Apply Critical Geospatial Thinking 13)**

☐ Let's view this earthquake in both 2D above the surface and 3D below the surface to learn more about the geospatial relationship of epicenter and hypocenter. In the same linked view, the 2D view represents the epicenter and the 3D view represents the hypocenter of the same earthquake (Figure 64). This provides an opportunity to view at the environmental scale as how it would relate to the environment of people living in Flagstaff.

☐ After this earthquake with FID 50 is selected, it is now highlighted in blue to stand out. In the 2D view it is in the Flagstaff City limits near Pine Canyon Golf Course

Question 13) According to the attribute table, what is the depth and magnitude of earthquake with the FID 50?
FID 50 has a 20 km depth and magnitude of 2.27.
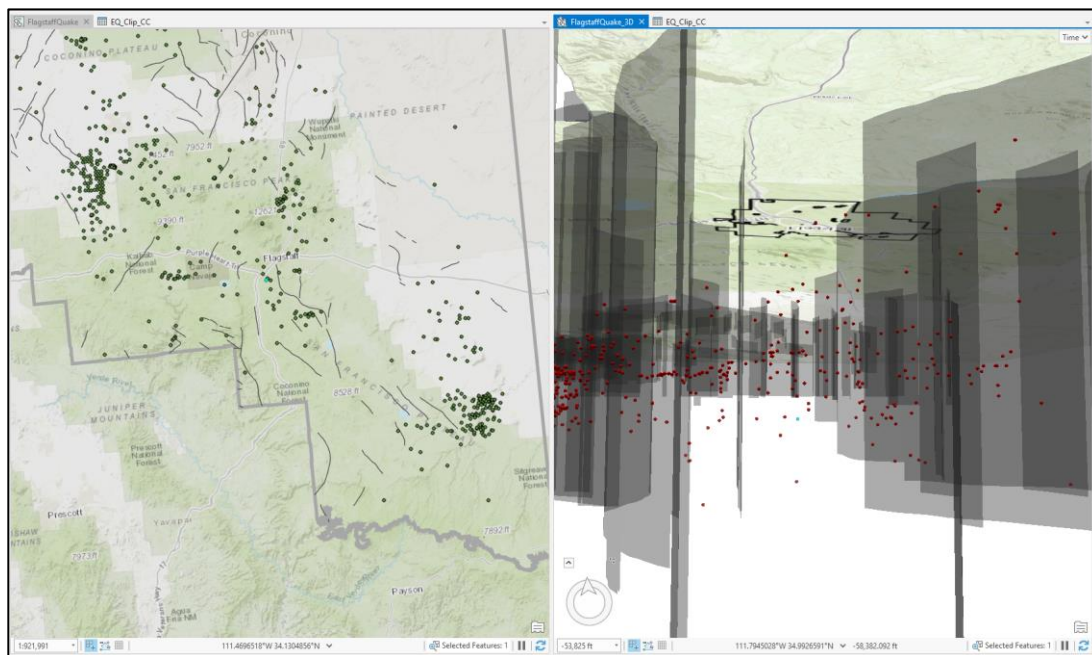
Figure 64) Map of selected earthquake FID 50 highlighted in blue in the same linked view. The 2D view represents the epicenter and the 3D view represents the hypocenter of the same earthquake selected in blue in both views

Task 7: Investigate potentially active faults 3D and 2D views

☐ Let's explore the geospatial relationship of faults to earthquakes in 3D at the regional scale by looking at earthquakes around the Grand Canyon. To help us identify where active faults may be let's look for where there is a high concentration of faults in a linear pattern. To help us determine and view if there is a fault line that has been mapped amongst the earthquakes, let's turn on the EQ_Fault_5KM Buffer to view in linked 2D and 3D views to help identify active faults as in Figure 65a.

- Turn on the EQ_Fault_5KM Buffer (Figure 65a)
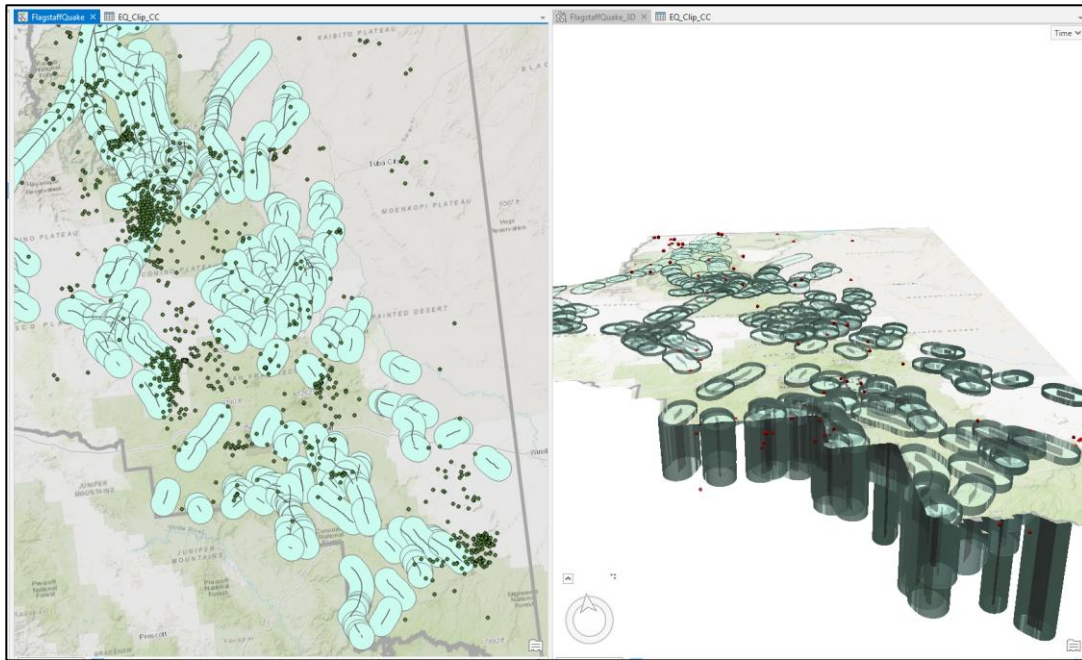
Figure 65a) Map displaying EQ_Fault_5KM Buffer as well as earthquakes and faults in linked 2D and 3D views.

□ On the 2D map all the data appears rather jumbled around the Grand Canyon making it difficult to see identify a major fault line; if we rotate the view in 3D and zoom in we can see a major linear feature extending from the southwest to the northeast in the southern central part of the Grand Canyon in Figure 65b.

- Rotate view to be from the viewpoint of southwest of the Grand Canyon looking to the northeast.
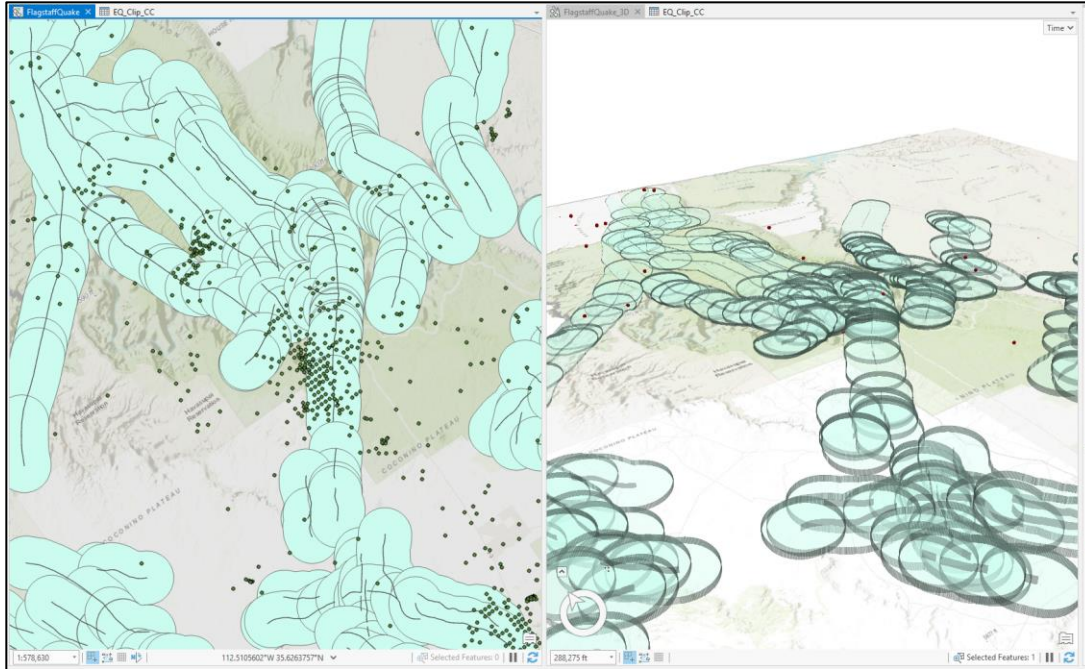
Figure 65b) Zoomed in view of major linear feature with high concentration of earthquakes and faults near the Grand Canyon in linked 2D and 3D views.

☐ On the 2D map all the data it is difficult to see how many earthquakes have occurred around this major linear feature ; if we rotate the view in 3D to view the subsurface and keep the 5km buffers on , we can test the hypothesis that there is a major active fault extending from the southwest to the northeast in the southern central part of the Grand Canyon based on the high concentration of earthquakes we can see in the subsurface (Figure 65c).

- Rotate view to be of the subsurface from the viewpoint of southwest of the Grand Canyon looking to the northeast.

Figure 65c) Subsurface view of major a linear feature with high concentration of earthquakes and faults near the Grand Canyon in linked 2D and 3D views.

 ☐ **Apply Critical Geospatial Thinking 14)**

☐ On the 2D map that shows all earthquakes and within the subsurface, there have been so many earthquakes in this area of interest near the Grand Canyon that it can be difficult to identify a fault. However, we know that we are on to something. So, let's try a new view of displaying the surface at an oblique angle in 3D that will only show earthquakes at or close to the surface to reduce the "noise" and zoom in. With the faults extruding above the surface in 3D and the high concentration of faults visible in 2D, having these views linked can help us identify a major active fault in Figure 65d.

☐ To reduce noise from this highly seismically active area lets only turn on the earthquakes that we previously used the intersect tool to only look at earthquakes within 5 km of a fault and display in linked 3D and 2D views.

- Contents Pane
  - Turn on EQ_Fault_5km_Intersect
    - Rotate views to that of Figure 65d
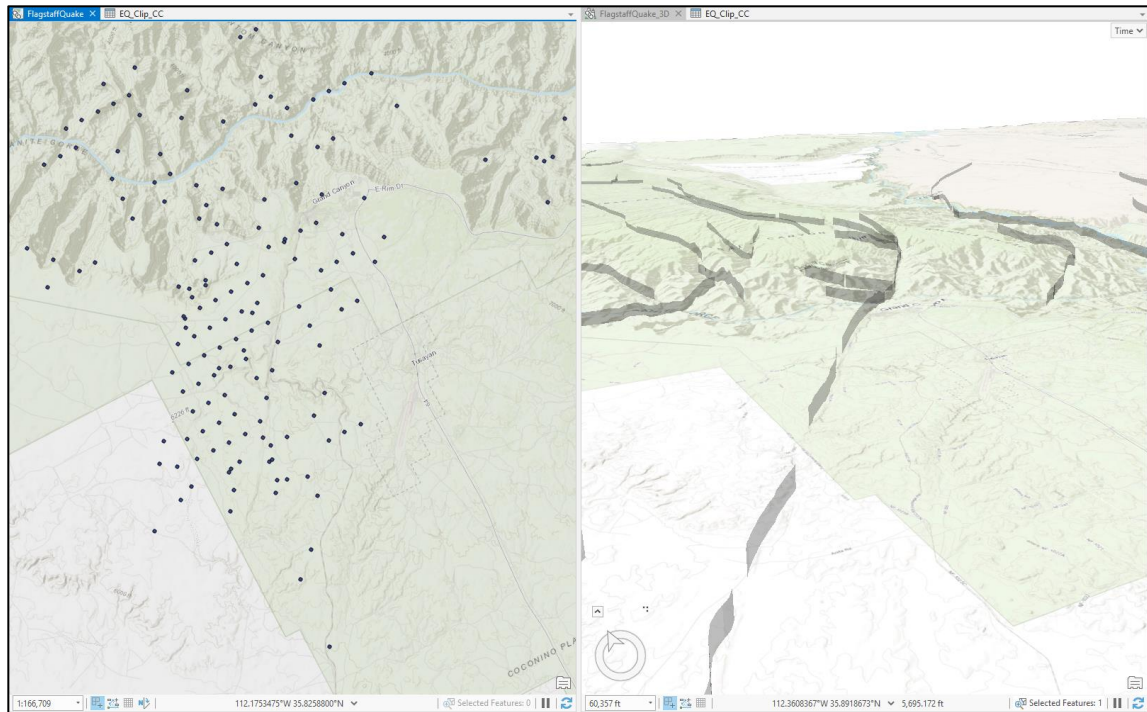
Figure 65d) Linked views of a major fault in the Grand Canyon region at a tilted surface view in 3D and linked 2D map view.

Question 14) What is this fault represented by this major SW-NE linear feature bisecting the Grand Canyon? **The Bright Angel Fault**

Task 8: Explore Bright Angel Fault geospatial relationships in 3D and 2D

☐ Apply Critical Geospatial Thinking 15)

☐ Now that we have identified the Bright Angel fault, let's explore this dataset further to better display the geospatial aspect of faults and earthquakes. We can start by displaying a major fault and learn more about geoscience topics. When we hear of a major fault such as the Lake Mary Fault or the Bright Angel fault and look for it on a map, it may not always be one single continuous line. Instead it can be a collection of related individual faults following a general trend or fault line forming a fault system.

- Open the attribute table for EQ_Clip_CC and also display the 3D map.
- Identify individual faults that form the Bright Angel Fault system
- Select
- Click along Bright Angel Fault to find Object ID number

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☐ Tao make better displays of the Bright Angel Fault for enhanced geospatial thinking we want to be able to clearly distinguish the Bright Angel Fault. This can now be done with features highlighted in blue as displayed in Figure 66a.

Question 15) After you have selected along the Bright Angel Fault system and what are the some of the object numbers you could use to highlight the fault southwest of and within the Grand Canyon?

8 individual faults selected, object ID numbers include 166,164,157,156,154,150, 131, 208
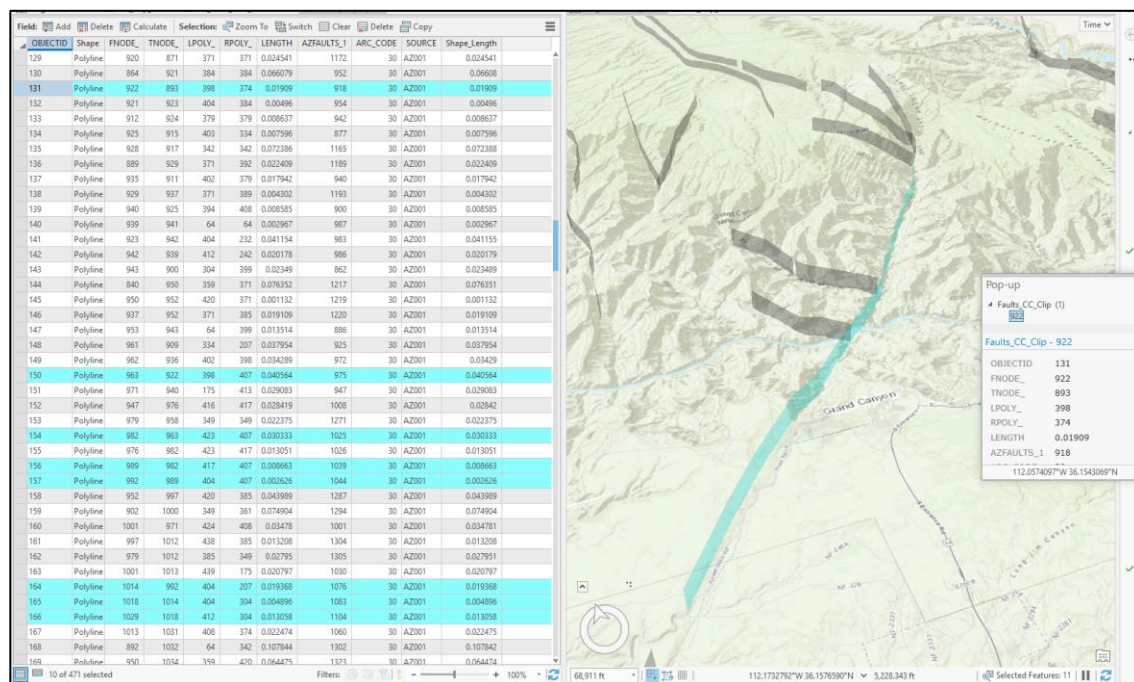
Figure 66a) 3D Map of Bright Angel Fault system and attribute table data. Selected faults are highlighted in blue in both the attribute table and map.

☐ Now to better enhance our geospatial awareness of this major fault let's explore at different linked 2D and 3D views as

- 2D view display earthquakes within 5km buffer of faults
    - 3D view display faults
        - link views and rotate to see subsurface and surface (Figure 66b)
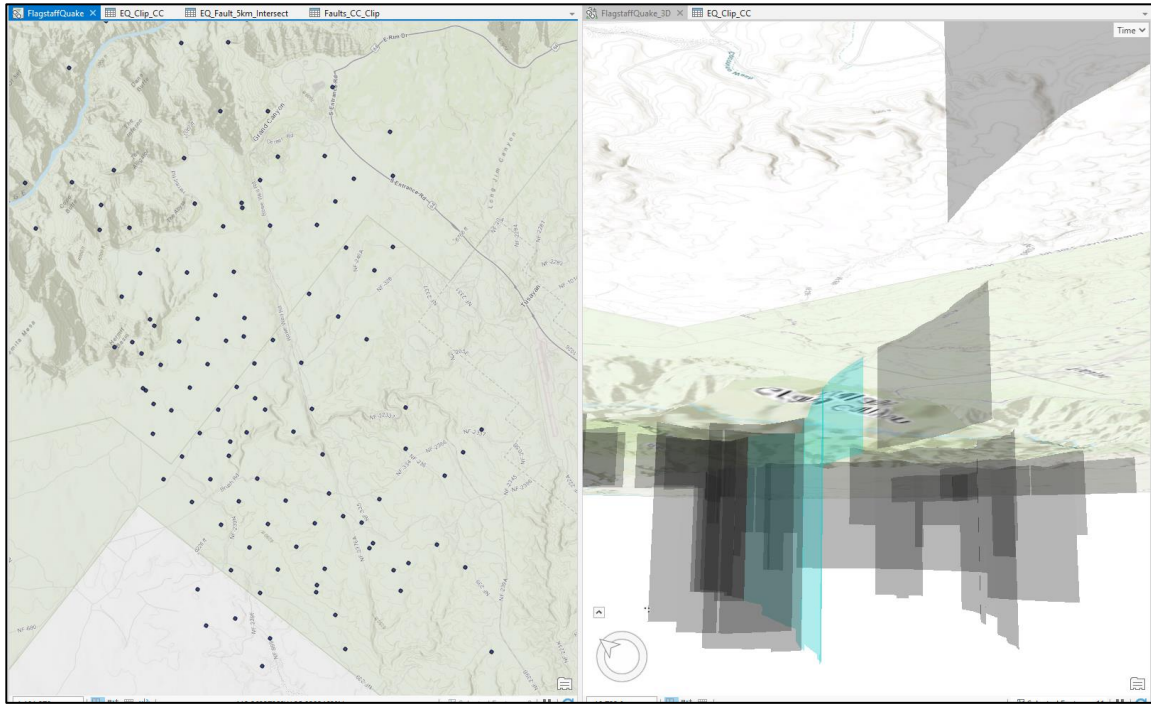
Figure 66b) Map of linked 2D and 3D views of Bright Angel Fault above and below surface.

- 2D view display earthquakes within 5km buffer of faults and faults
  - 3D view display faults and earthquakes
    - link views and rotate to see subsurface and surface (Figure 66c)
      - rotate to further below subsurface to be looking up (Figure 66d)
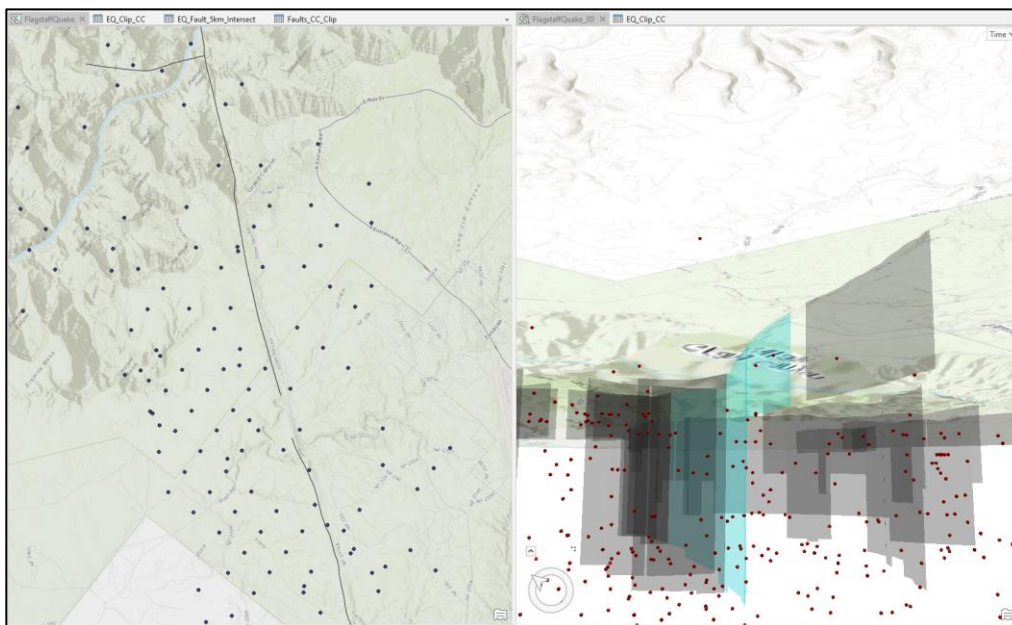
Figure 66c) Map of linked 2D and 3D views of Bright Angel Fault above and below surface showing both earthquakes and faults.

We can further enhance geospatial thinking of viewing faults and earthquakes from different 2D and 3D perspectives as below in Figure 66d.
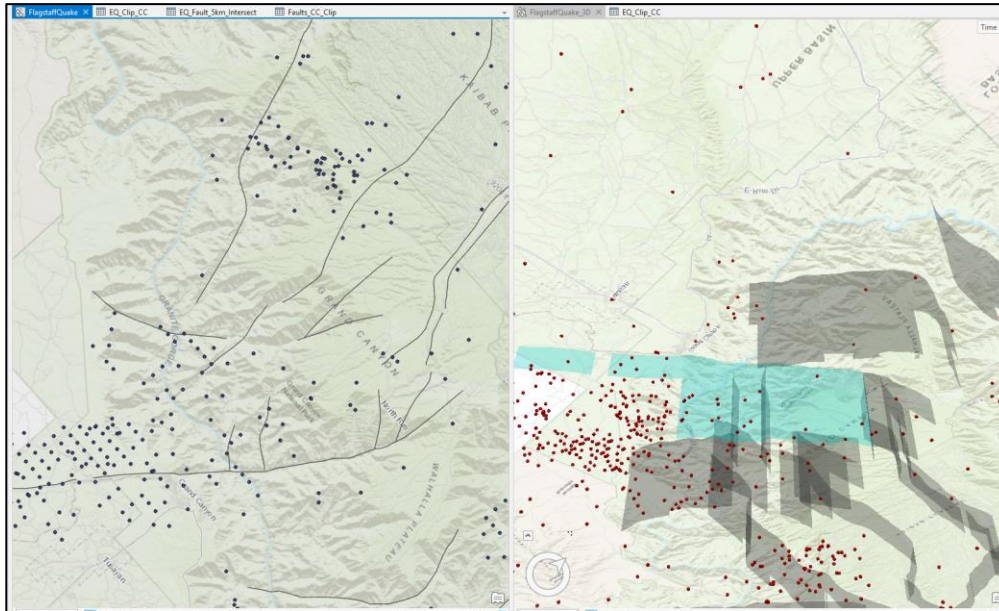
Figure 66d) Rotated view of Bright Angel fault as viewed from deep below the surface looking up to show enhance geospatial thinking of viewing faults and earthquakes from different perspectives.

Task 9: Identify faults using geospatial relationships in 3D and 2D views

 Apply Critical Geospatial Thinking 16)
 Let's explore this dataset we have built in ArcGIS pro to identify other faults that could be active. We can do this by looking for high concentrations of earthquakes forming linear patterns in close proximity to a mapped fault line.

- Explore the Howard Mesa area near Flagstaff (Figure 67)
        - In 2D turn on earthquakes within 5km of faults
                - in 3D turn on faults
                        - rotate view to see extruded faults on surface
                                - look for linear geospatial features to compare
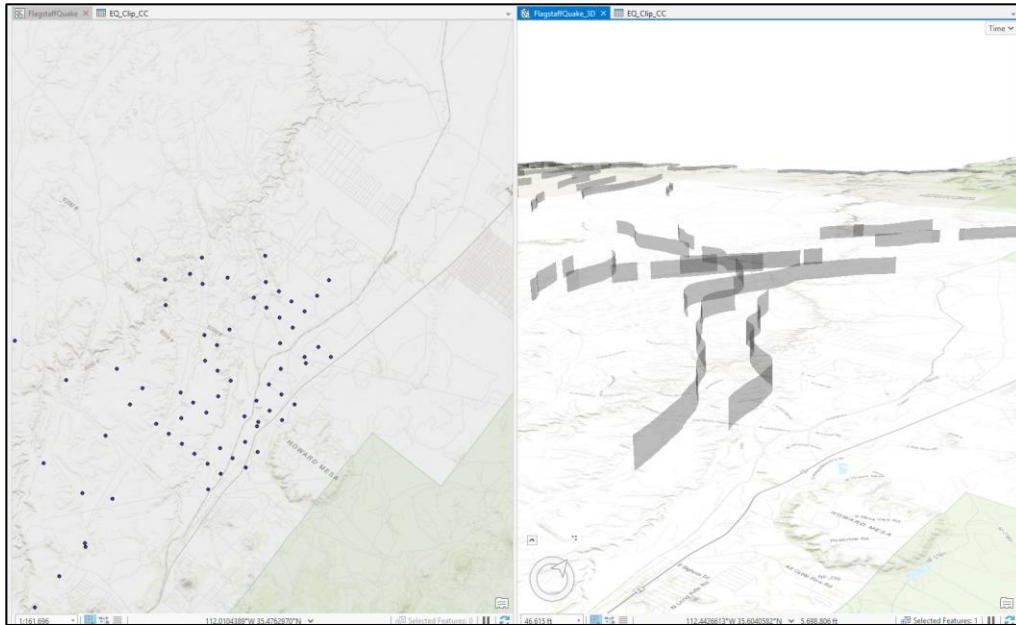
Figure 67) Linked 2D and 3D views of the Howard Mesa area near Flagstaff.

Question 16a) Do you notice any linear feature trends of both earthquakes and faults?

Yes, there appears to be some faults matching up with earthquakes trending southwest northeast.

Question 16b) Could these faults be considered active?

Yes, due to the relatively high concentration of earthquakes along these faults, they could be considered active.

- Explore the Additional Hill and Gray Mountain area NE of Flagstaff (Figure 68)
      - In 2D turn on earthquakes within 5km of faults
            - in 3D turn on faults
                  - rotate view to see extruded faults on surface
                        - look for linear geospatial features to compare
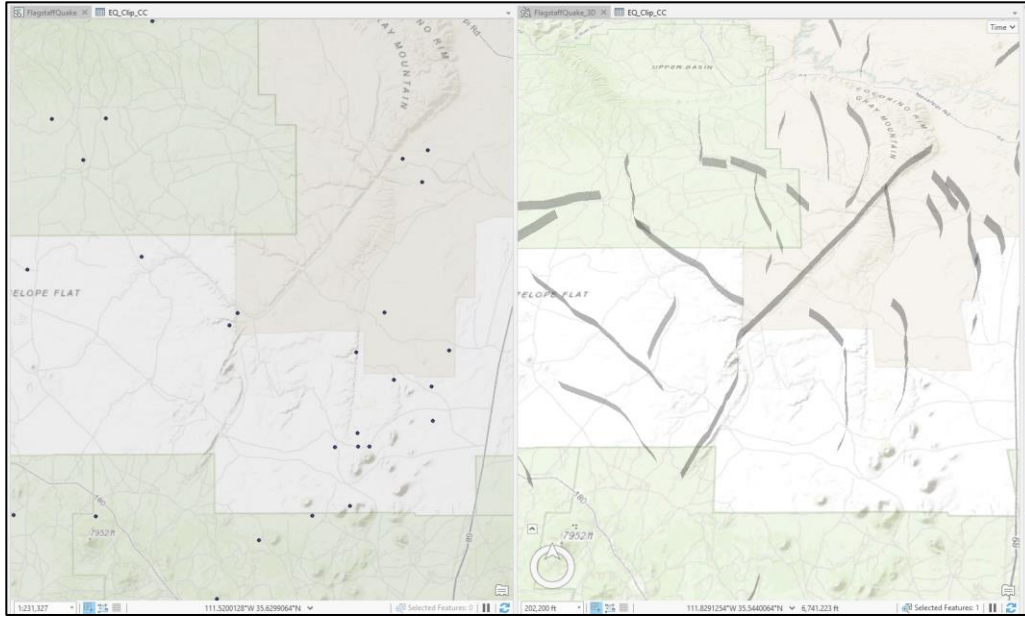
Figure 68) Map of linked 2D and 3D views of the Additional Hill and Gray Mountain area NE of Flagstaff.

Question 16c) Do you notice any linear feature trends of both earthquakes and faults?

Yes, there appears to be a major fault line trending SW-NE with several minor faults trending perpendicular at SE-NW.

Question 16d) Could these faults be considered active?

No or at least less active, due to the relatively low concentration of earthquakes along these faults, they could be considered inactive.

Question 16e) How might the major SW-NE fault line affect the landscape?

From viewing in 3D, it looks like this elevated plateau known as Gray mountain could be related to the major SW-NE fault line and there could have been uplift on the west side and subsidence on the east of this fault to explain the current topography.

Part 8: Explore geospatial relationships of earthquakes to other variables

Part 8A) Earthquake-depth geospatial relationships

Task 1: Explore earthquake-depth geospatial relationships further in 2D & 3D

☐ To visualize the relationship of earthquake depth and magnitude let's explore this concept deeper. This can expand geospatial awareness by not just looking at the spatial location of features, instead we can display aspects of features on where they exist in space as well. We can start by creating 3D views that better quantify the geospatial relationship of depth using ArcGIS Pro.

- For 2D FlagstaffQuake Map
  - In contents pane
    - FlagstaffQuake_2D
      - Select EQ_Clip_CC
        - Appearance Tab
          - Symbology
          - Change to graduated colors by depth as displayed in Figure 69a for 2D
          -
- For 3D FlagstaffQuake Map
  - In contents pane
    - FlagstaffQuake_3D
      - Select EQ_Clip_CC
        - Appearance Tab
          - Symbology
   - Change symbology to graduated colors by depth as displayed in Figure 69b for 3D

a) 2D   b) 3D
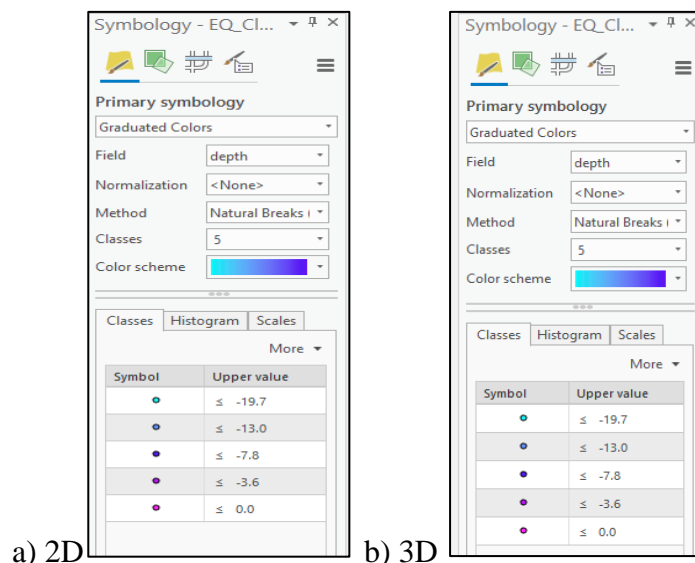
Figure 69a, b) 2D and 3D graduate colors symbology settings.

☐ Your map should now look like Figure 70 showing the colors of earthquakes distinguished by depth.

       - Rotate linked 3D view to visualize below the surface
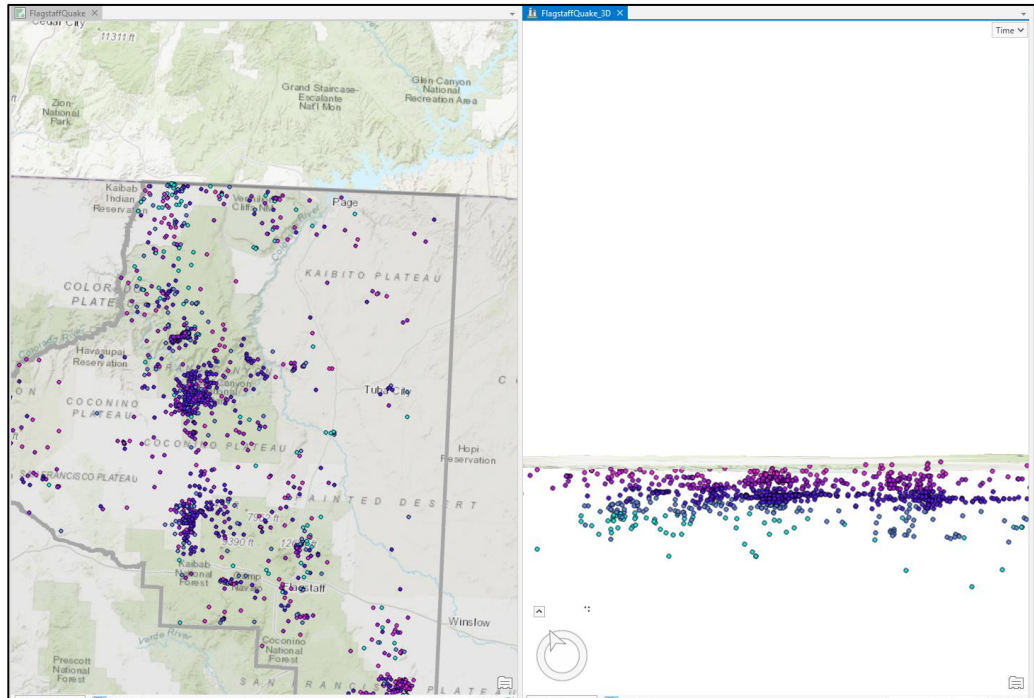
Figure 70a) 2D map view and rotated 3D subsurface view of earthquakes categorized by depth to display different color patterns based on depth at the county scale. Pink is closer to the surface and light blue is deeper.

☐ Now we can change the scale to view at the city level to visualize where earthquakes have occurred in relative to Flagstaff as in Figure 70b.

       - Turn on City of Flagstaff boundary

          - Zoom into Flagstaff area

             - Rotate linked 3D view to visualize below the surface of Flagstaff

                - Explore earthquake depth
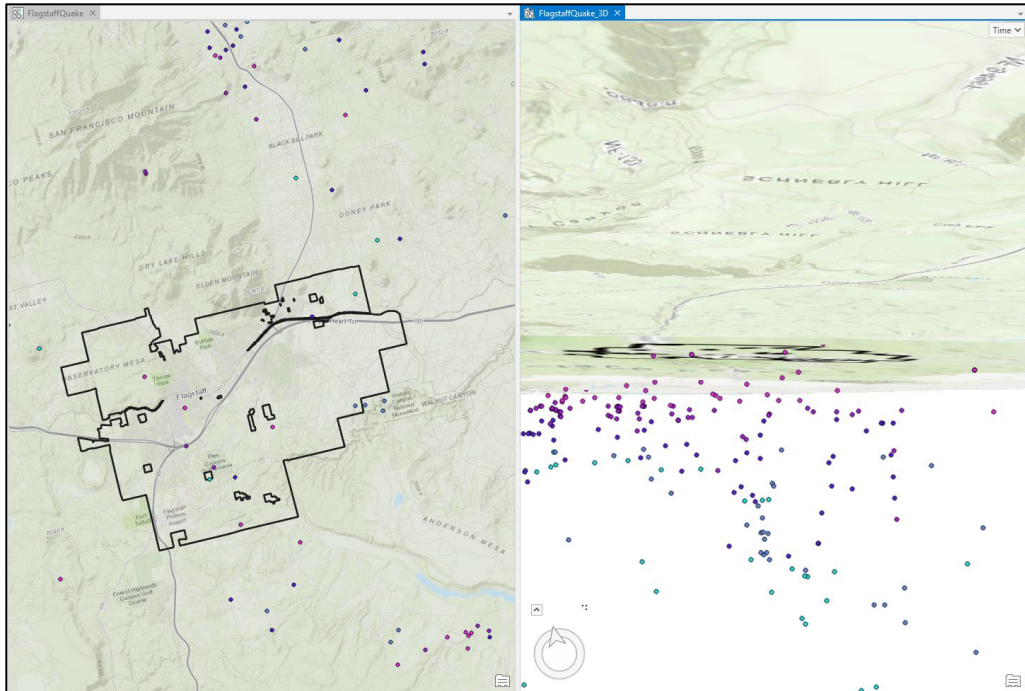
Figure 70b) 2D map view and rotated 3D subsurface view of earthquakes categorized by depth to display different color patterns based on depth at the city scale. Pink is closer to the surface and light blue is deeper.

Part 8B) Magnitude and depth geospatial relationship of earthquakes

Task 1: Explore magnitude-depth geospatial relationships of earthquakes in 2D & 3D

□ Apply Critical Geospatial Thinking 17)

□ Now we can change the symbology further to better visualize the geospatial relationship of magnitude and depth. We can apply critical geospatial thinking by formulating hypotheses of how magnitude is related to depth of earthquakes in Coconino County and test those hypotheses using Arc GIS Pro.

    - For 3D FlagstaffQuake Map
        - In contents pane
            - FlagstaffQuake_3D
                - Select EQ_Clip_CC
                    - Appearance Tab
                        - Symbology
                        - Change symbology to graduated symbols by magnitude as displayed in Figure 71 for 3D
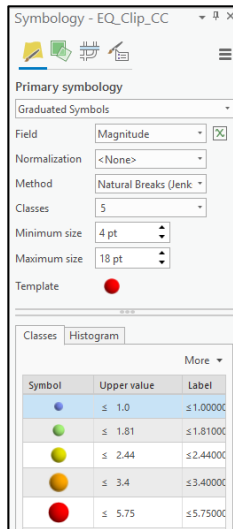
Figure 71) Symbology settings for graduated symbols categorizing earthquake data by magnitude displayed as different color and size 3D spheres.

- Look at geospatial relationship of magnitude and depth in 3D as displayed in Figure 72
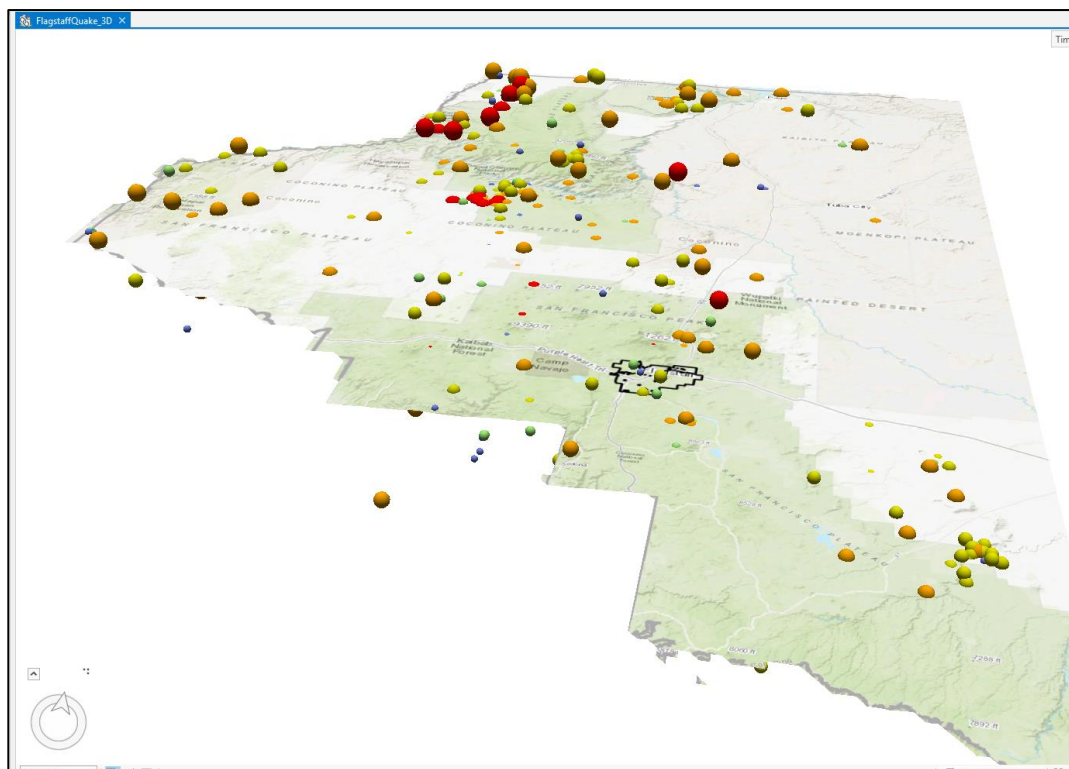
Figure 72a) Map displaying the geospatial relationship of magnitude and depth in 3D for earthquakes in Coconino County with recorded depth and magnitude.

☐ It is difficult to ascertain geospatial relationships of depth and magnitude at this view angle so let's change views to better see depth by looking at the subsurface.

- Rotate 3D views underground to visualize the geospatial relationship of magnitude and depth in the subsurface from different viewpoints as displayed in Figures 72 b, c, and d.

b)

c)

d)
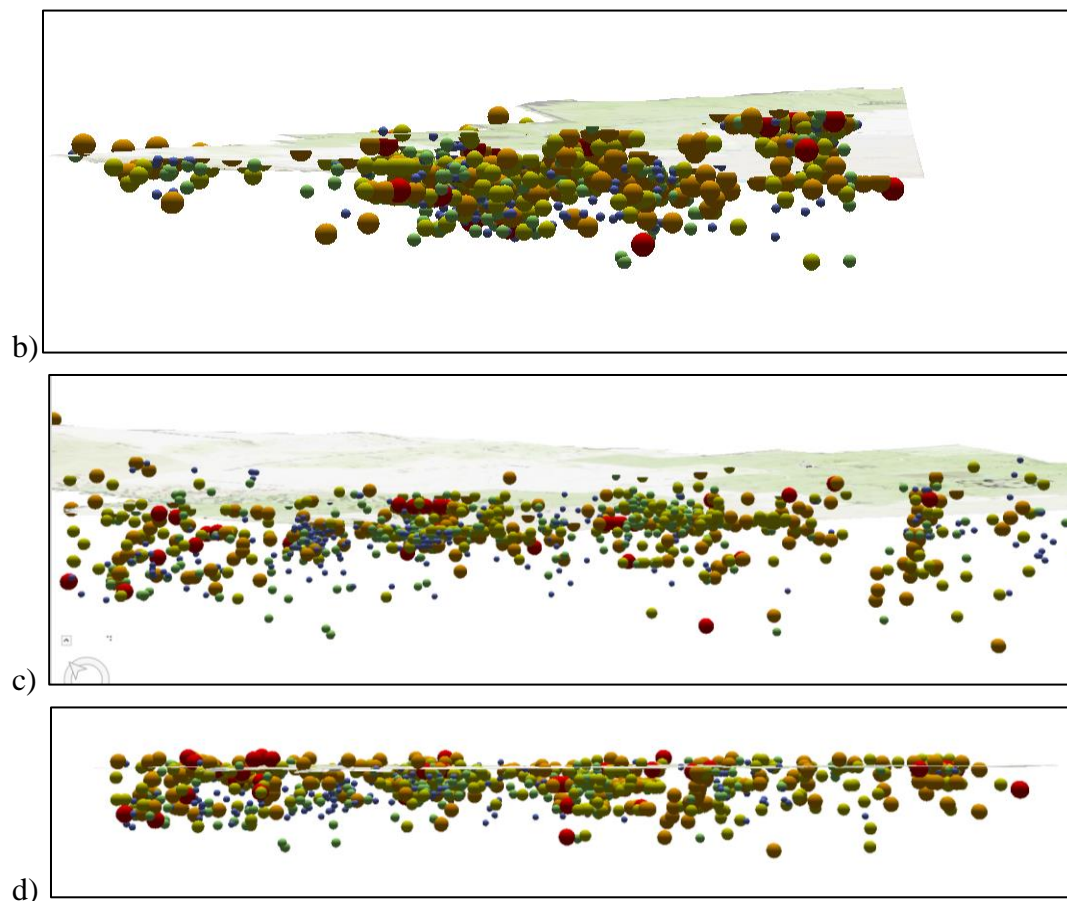
Figure 72 b, c, d) Different rotated 3D views of geospatial relationship of magnitude and depth in the subsurface from different viewpoints. The highest magnitude earthquakes are displayed in large red spheres and the smallest are in small blue spheres.

Question 17) According to earthquake data in Coconino County that has both magnitude and depth recorded, from viewing the mapped data, is there a correlation with depth and magnitude that you can quantify from viewing geospatial relationships in 3D?

It is difficult to say at this scale purely from viewing, however, we can use other features in Pro to help us quantify this.

Task 3: Investigate geospatial relationships of earthquakes with charts

☐ Apply Critical Geospatial Thinking 18)

☐ A feature available in Arc GIS Pro to help quantify geospatial relationships of features related to earthquakes is the use of Charts. Charts is an enabled feature available in ArcGIS Pro

- Hover mouse over EQ_Clip_CC
  - Left click
    - Select Create chart
      - Select Scatter plot
        - Set X to depth and Y to magnitude (Figure 73a)
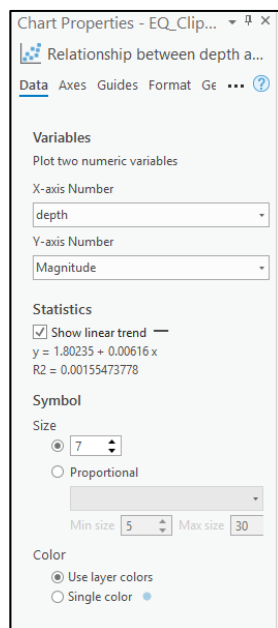
Figure 73a) Chart Properties settings**.**

- Display chart (Figure 73b)
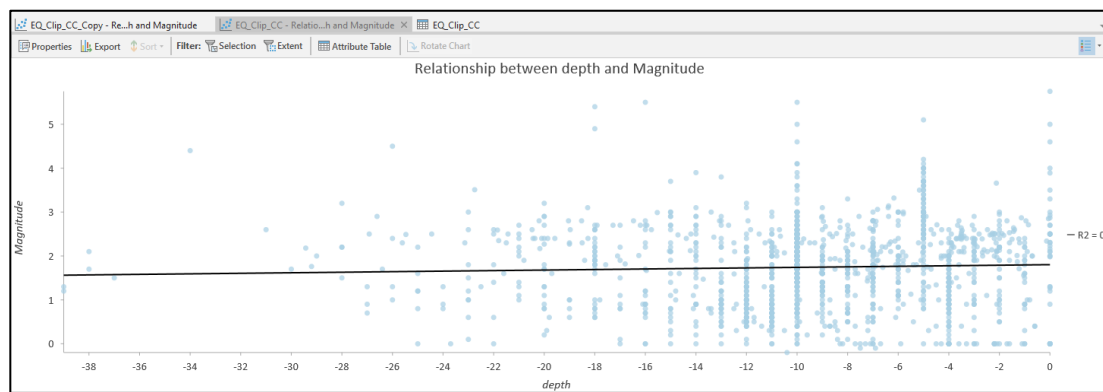
Figure 73b) Chart display of relationship between depth and magnitude.

Question 18a) According to earthquake data in Coconino County that has both magnitude and depth recorded, from viewing the chart displaying the data, is there a correlation with depth and magnitude that you can quantify from the chart?

Yes, as the line of regression has a positive slope and the equation of the line in Figure 73a displays a positive value, this suggests that earthquake magnitude decreases with depth and increases closer to the surface.

Question 18b) How does this relate to earthquake hazards in Flagstaff?

Larger magnitude quakes are more damaging the closer to the surface they occurred, therefore there is significant earthquake hazards in the Flagstaff area.

- Export as a graphic as .svg (Figure 73c)
  - Label Depth vs. Magnitude to share
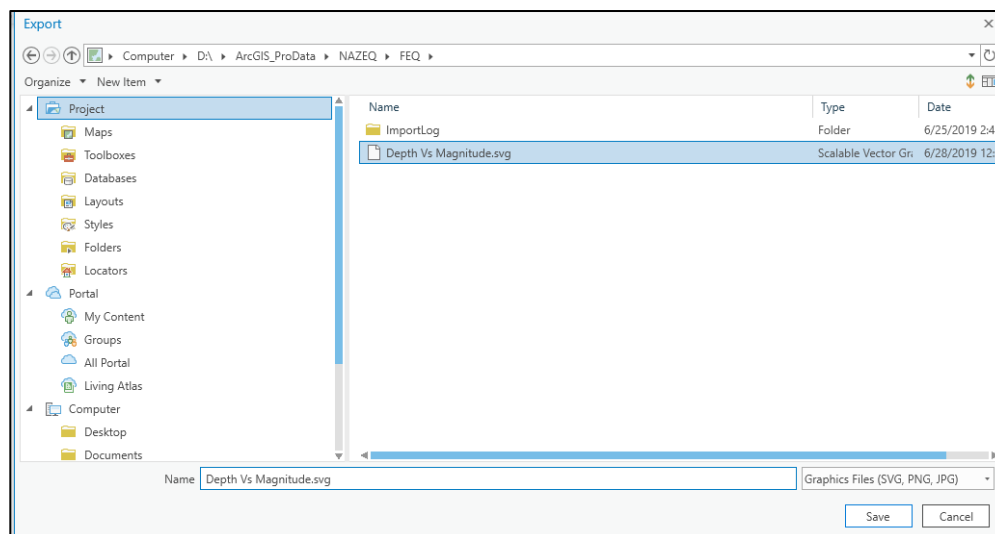
Figure 73c) Export depth verse Magnitude chart to share.

Task 4: Investigate geospatial relationship of earthquake depth and time

☐ Now let's explore the relationship of the year and earthquake occurred verse depth. We can now investigate when earthquakes have occurred relative to their depth and view when geospatial data has occurred to enhance geospatial thinking.

☐ Apply Critical Geospatial Thinking 19)

- Change the symbology to categorize the earthquake data by time
- Select to display graduated colors (Figure 74)
- Change the field to Year
- Set symbology parameters to that displayed in Figure 74

Symbology - EQ_Clip_CC

Primary symbology

Graduated Colors	
Field	Year
Normalization	<None>
Method	Natural Breaks (Jenk
Classes	5
Color scheme	

Classes Histogram Scales

More ▼

Symbol	▲	Upper value	▲	Label
●		≤ 1972.0		≤1972
●		≤ 1985.0		≤1985
●		≤ 1994.0		≤1994
●		≤ 2002.0		≤2002
●		≤ 2013.0		≤2013
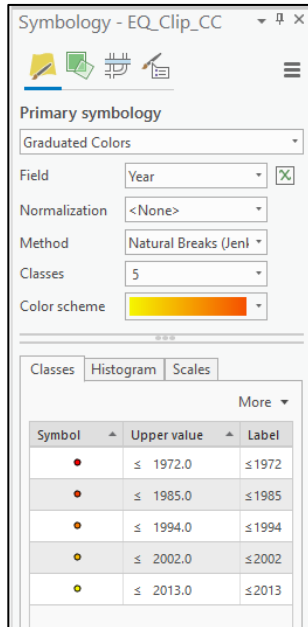
Figure 74a) Symbology settings to display earthquakes categorized by time. Yellow represents younger earthquakes and red represents older earthquakes.

- Visualize data in 3D above and below the surface as displayed in Figure 74b and c

b)

c)
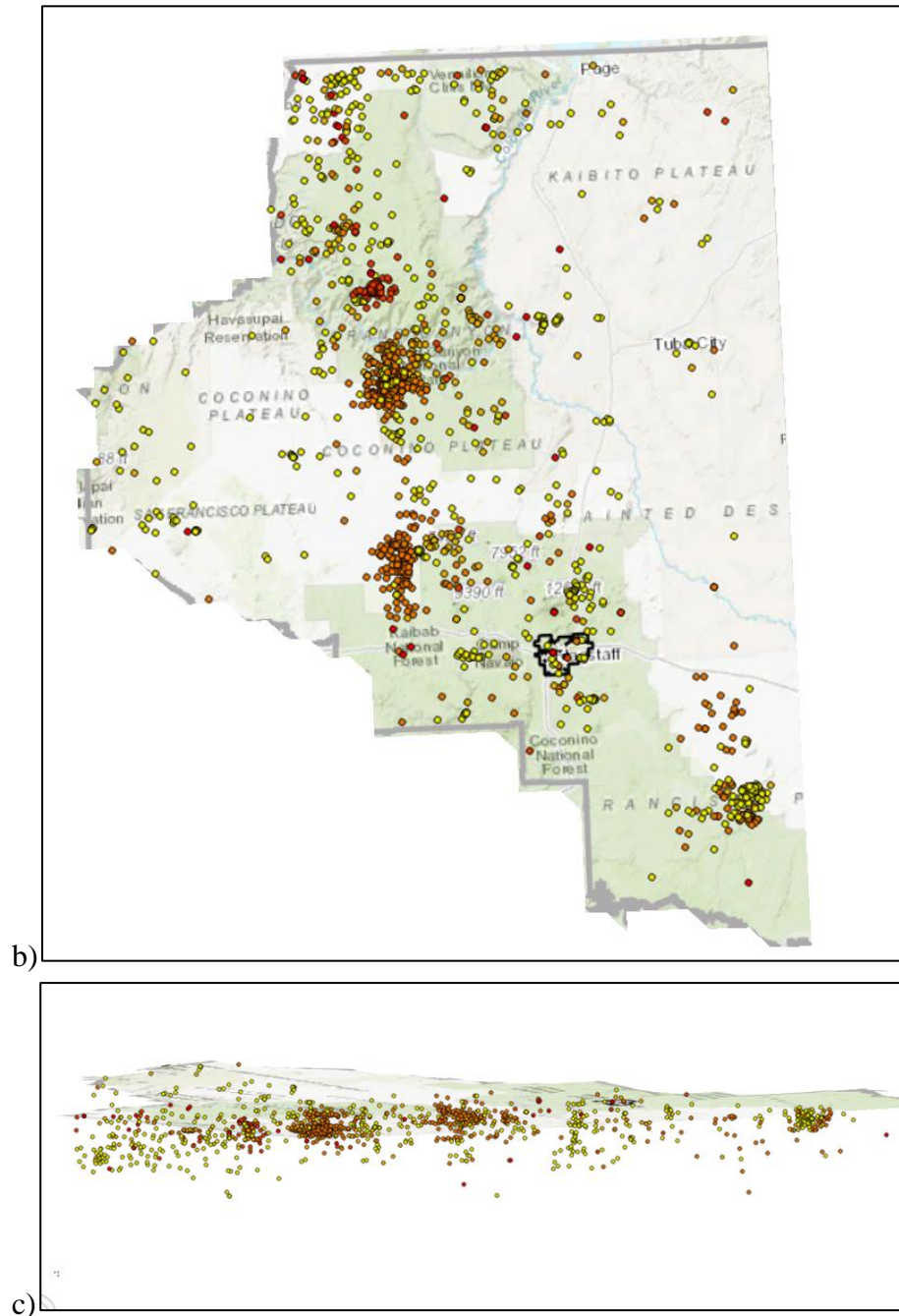
Figure 74 b, c) 3D views of geospatial relationship between earthquake time and depth displayed above and below the surface. Yellow represents younger earthquakes and red represents older earthquakes.

- Hover mouse over EQ_Clip_CC
    - Left click
        - Select Create chart
            - Select Scatter plot
                - Set X to depth and Y to magnitude (Figure 73a)

Question 19a) According to earthquake data in Coconino County that has both year and depth recorded, from viewing the mapped data, is there a correlation with depth and year that you can quantify from viewing geospatial relationships in 3D?

It is difficult to say at this scale purely from viewing the geospatial relationships, however, we can use other features in Pro to help us quantify this.

☐ To determine if there is a correlation that can be drawn from earthquake time of occurrence and depth we can explore the use of charts.

- Set up a chart to display the relationship between year and depth as in Figure 75a
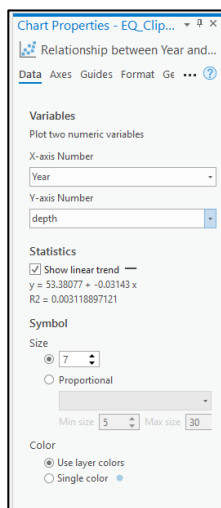
Figure 75a) Chart properties for setting up a chart to display the relationship between year and depth.
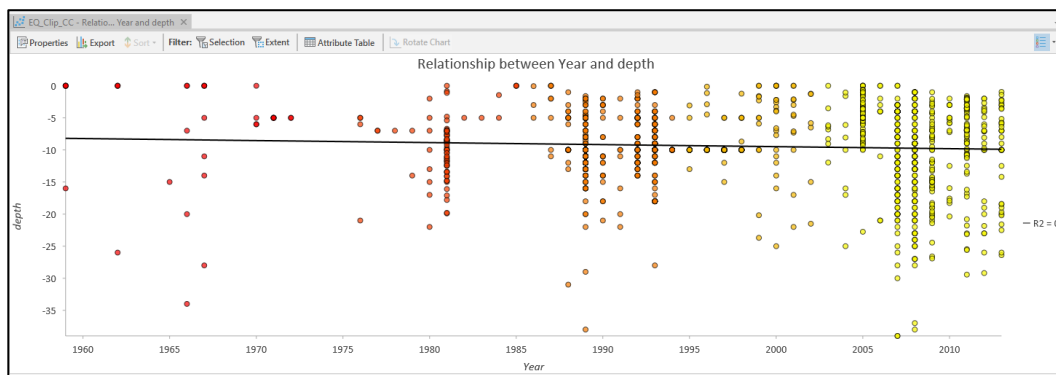
Figure 75b) Chart display of the relationship between earthquake year and depth.

Question 19b) According to earthquake data in Coconino County that has both year and depth recorded, from viewing Chart data, is there a correlation with depth and year that you can quantify from the chart?

Yes, from the negative slope of the regression trend line and the negative value of the equation of the line as calculated in Figure 75a, a correlation can be drawn that earthquakes are getting deeper with time. That is there is more earthquakes at higher depths in more recent time categories as compared to the depth of earthquakes at older time categories.

Question 19c) If you apply critical geoscience thinking to this geospatial question 19b, does this make sense?

Probably not, in fact it is likely due to having more advanced sensors and a larger seismic network in more recent times compared older times that can detect more earthquakes and at greater depths.

Appendix 2: Module 2) Investigation of Flagstaff geologic hazards module

   Flagstaff may not come to mind first on the topic of earthquakes, however, it is a very seismically active place residing within the Northern Arizona Seismic Belt (NASB) (Brumbaugh et al., 2016). This provides a great learning opportunity for place-based geoscience study for schools in Northern Arizona. The NASB can provide a great geospatial awareness exercise with several possibilities for geoscience and GST modules such as mapping historical earthquakes relative to active faults and identifying patterns. A learning outcome we will investigate here is to actively engage student learning of Flagstaff's three greater than 6.0 magnitude earthquakes from 1906-1912 (Brumbaugh, 2014) by mapping the epicenter location to see what damage they could potentially cause if they were to happened today. Students could then apply critical geospatial thinking to identify where large earthquakes have occurred relative to the current city limits. Also, students can apply the use of GST tools in GIS to determine the zones and rates of P-waved and S-waves as they travel from the epicenter to determine where a seismic station should be located to detect a P-wave first to provide an early warning system before an impending S-wave would arrive (Young and Conway, 2012). Students could also do an interpolation of all past earthquakes to determine where a future earthquake may occur exploring raster datasets as well as vector. Also, students can learn to use ArcGIS Pro to display a depth component of 2D spatial data as 3D to visualize the depth of earthquakes below the surface and determine correlations to hypocenter, epicenter and magnitude.

Part 1: Investigation of earthquakes hazards and geospatial relationships

This section is designed to highlight some capabilities that can be done in ArcGIS Pro to explore geologic hazards in Flagstaff without necessarily providing a tutorial. For this part we will investigate what would happen if the 1906 earthquake with 6.1 magnitude that occurred in historic Flagstaff occurred in present-day modern 2019 Flagstaff. We will use ArcGIS Pro to assess damage zones and produce visually appealing maps with an impact that will be easy to visualize neighborhoods that would be affected.

Task 1: Identify largest magnitude historic earthquakes in Coconino County

- Display earthquake data in 2D categorized by magnitude to identify where highest magnitude earthquakes have occurred in Coconino County.
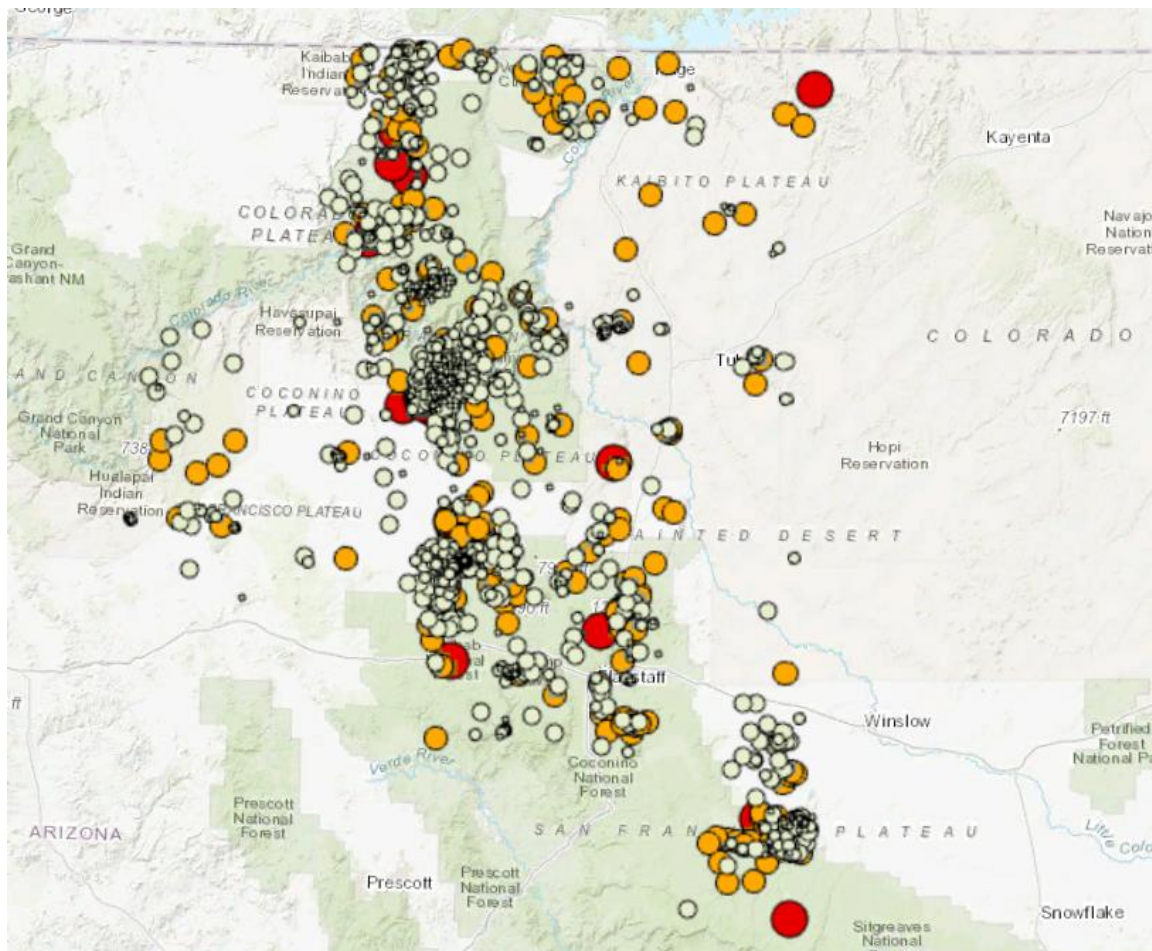
Figure 1) Map of categorized earthquake magnitude in Coconino County.

Task 2: Identify largest magnitude historic earthquakes in Flagstaff

- Identify location of 1906 6.1 magnitude earthquake that occurred within Flagstaff to assess geologic hazards. Change symbology to red triangle to stand out.
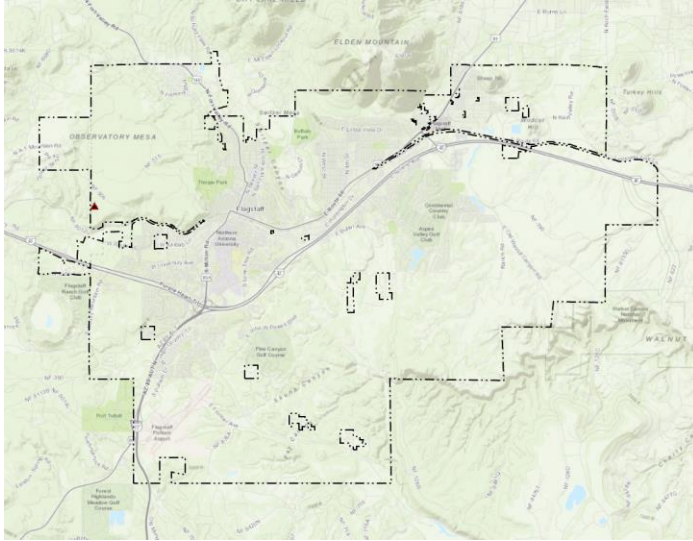
Figure 2) Map displaying location of 6.1 Magnitude 1906 earthquake epicenter within City of Flagstaff.

Part 2: Investigation of earthquake neighborhood damage geospatial relationship

Task 3: Assess geospatial relationship of neighborhoods in Flagstaff

- Add map of Flagstaff neighborhoods to assess geologic hazards in Flagstaff.
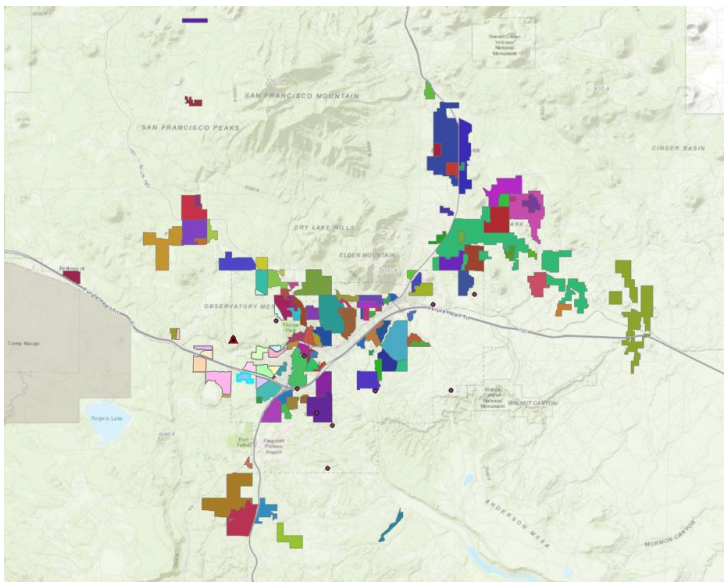
Figure 3) Map of county neighborhoods to assess geologic hazards in imported from Portal.

- View at different scales in 2D, turn on City of Flagstaff boundary to investigate geologic hazards in Flagstaff
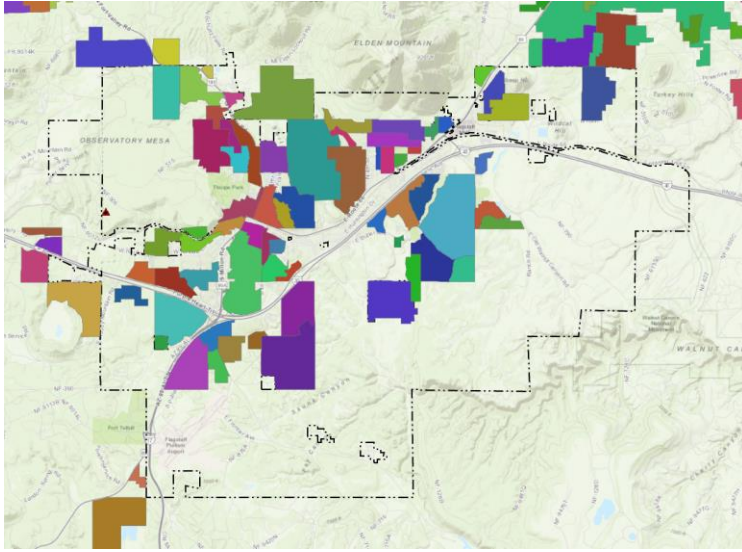
Figure 4) Map of Flagstaff neighborhoods to assess geologic hazards in imported from Portal.

Part 3: Investigation of earthquake P & S-wave zone geospatial relationships

Task 4: Map multiple ring buffers to represent P and S waves from 1906 earthquake

- **Apply Critical Geospatial Thinking 1)**

- Use a multiple ring buffer to determine the distance a P-wave would travel from the epicenter in the first second, 5 seconds, and 10 seconds.
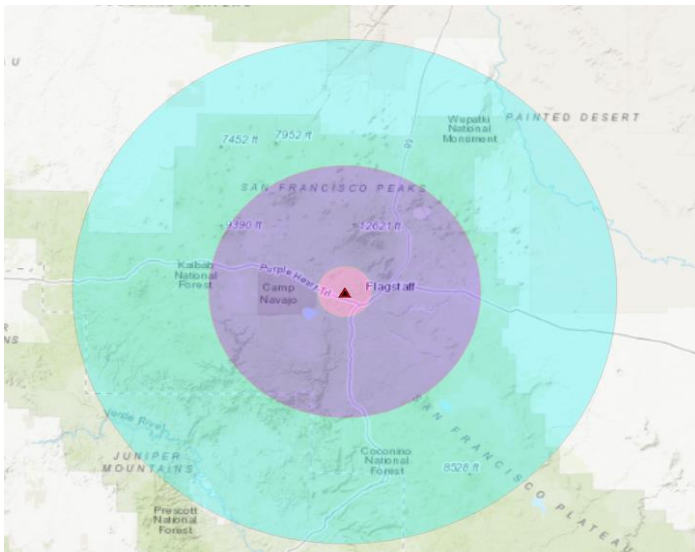
Figure 5) Map of P-wave distances at time intervals emanating from 1906 earthquake epicenter.
- Use a multiple ring buffer to determine the distance a S-wave would travel from the epicenter in the first second, 5 seconds, and 10 seconds.
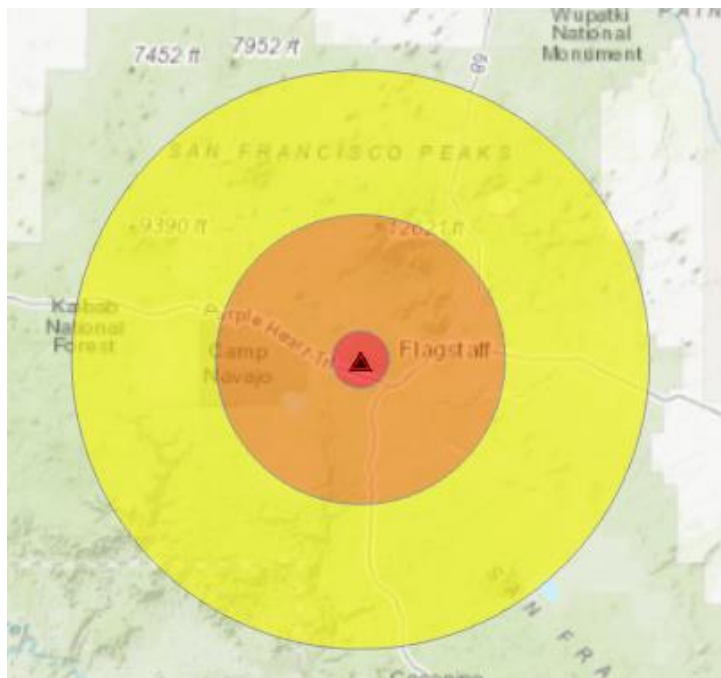
Figure 6) Map of S-wave distances at time intervals emanating from 1906 earthquake epicenter.

Part 4: Investigation of earthquake P & S-wave zones relative to neighborhoods

Task 5: Map geospatial relationship of neighborhoods in damage zones

    - Apply Critical Geospatial Thinking 2)

- Overlay neighborhoods on map of p-waves
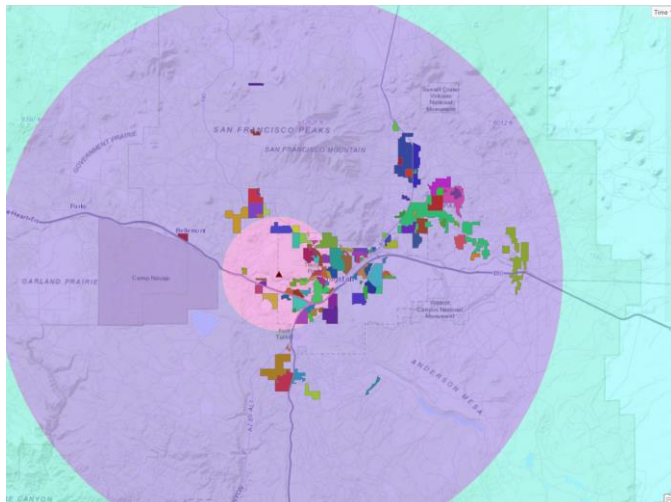
Figure 7) Map of P-wave distances at time intervals emanating from 1906 earthquake epicenter with neighborhoods displayed.

- Overlay neighborhoods on map of s-waves. As s-waves are more destructive and closer to the epicenter has greater potential for damage to occur, what neighborhoods would be most affected from s-waves?
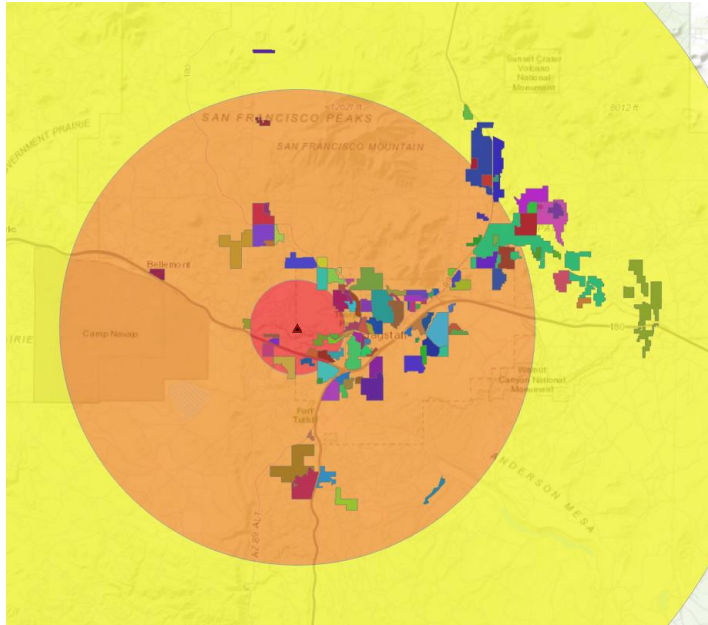
Figure 8) Map of S-wave distances at time intervals emanating from 1906 earthquake epicenter with neighborhoods displayed.

- we can only show neighborhoods that would be most effected in the first second of an earthquake in the path of an S-wave traveling in the first second from its source.
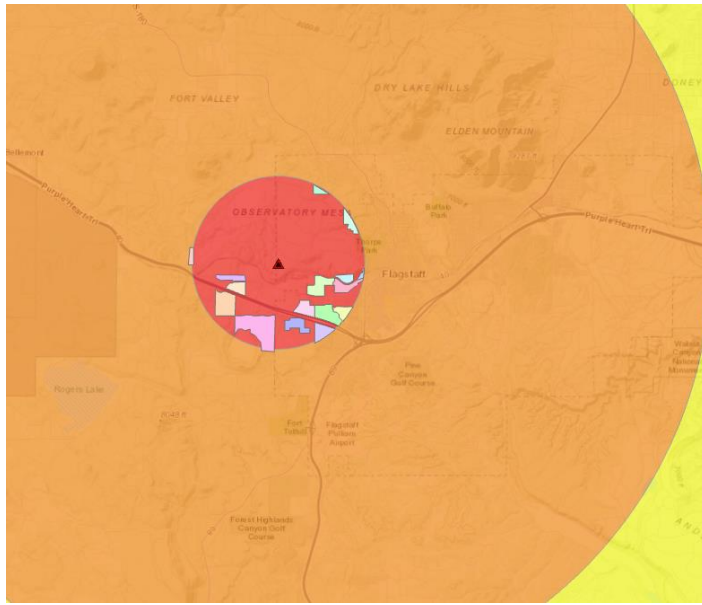
Figure 9) Zoomed in map of S-wave distances at time intervals emanating from 1906 earthquake epicenter with neighborhoods displayed.

- we can display the zone in the biggest path of destruction in the area the s-waves would reach in the first second following an earthquake from the epicenter.
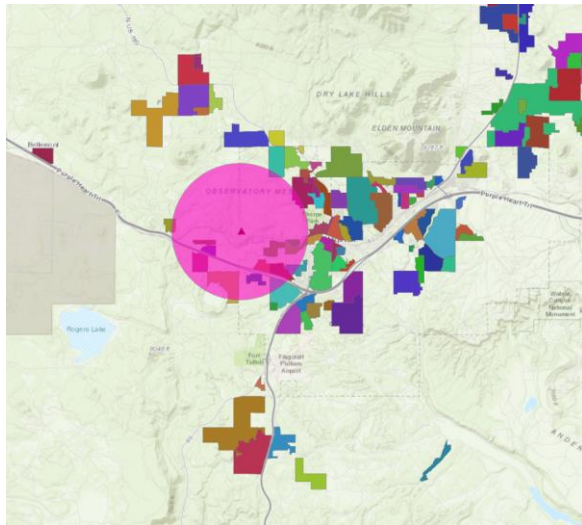
Figure 10) Map only displaying highest damage zone of S-wave 1 second distances emanating from 1906 earthquake epicenter with neighborhoods displayed.

- we can display only the neighborhoods in the biggest path of destruction with the least likelihood of a warning from a preceding p-wave in the area the s-waves would reach in the first second following an earthquake from the epicenter.
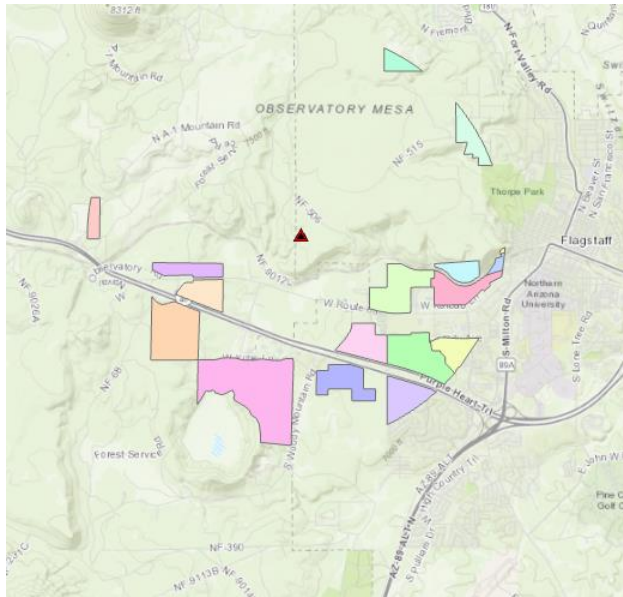
Figure 11) Map only displaying highest damage neighborhoods displayed that would be most affected by zone of S-wave 1 second distances emanating from 1906 earthquake epicenter.

Part 5: Display 3D maps of earthquake S-wave damage zone relative to neighborhoods

- to display this in a more visually appealing way to make more of a visual impact we can first set up elevation features and view in 3D.
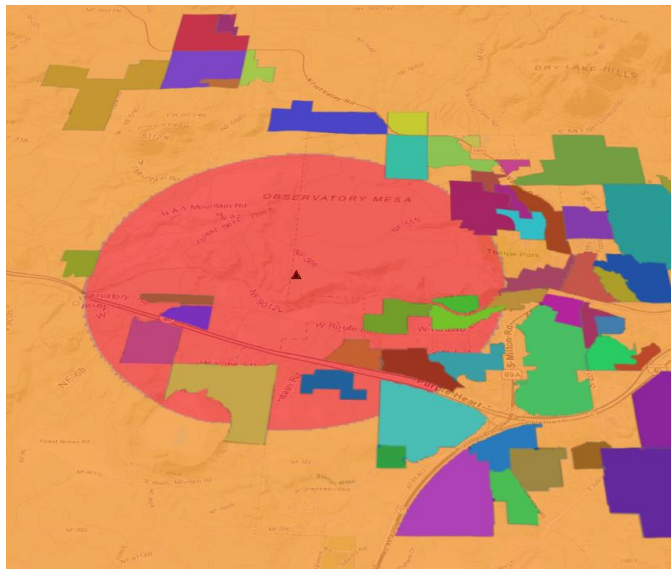
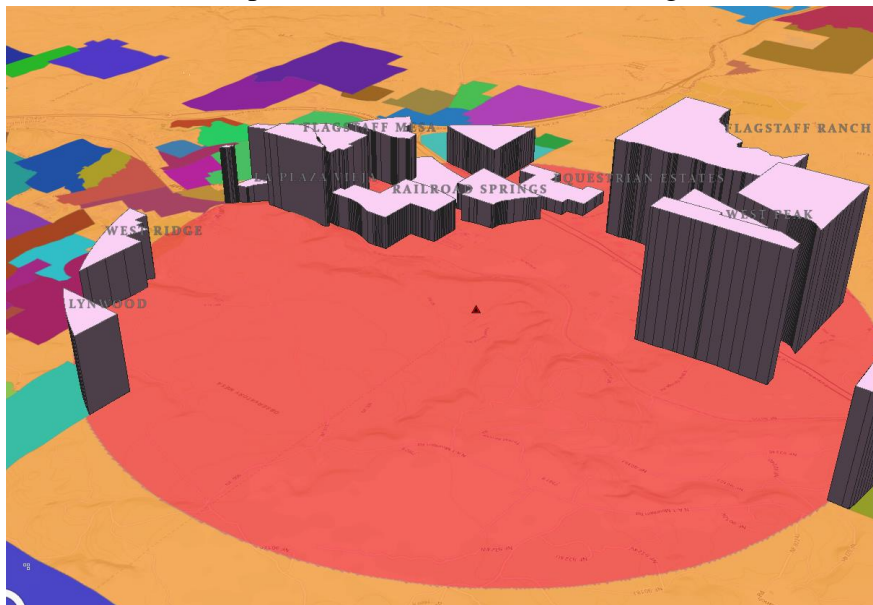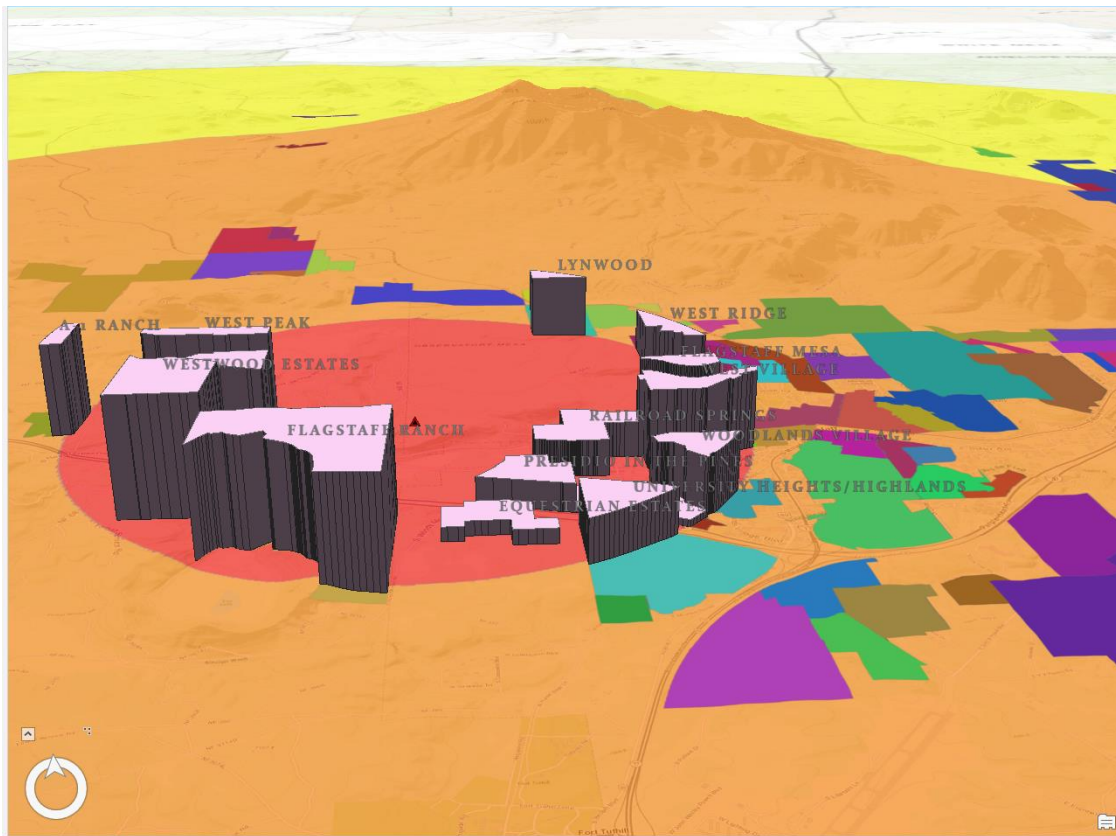**Figure 12)** 3D view of zone of S-wave 1-second distances emanating from 1906 earthquake epicenter with neighborhoods displayed.

Task 6: Map 3D map of neighborhoods in high earthquake damage zones

- Apply Critical Geospatial Thinking 3)

- To make the neighborhoods that would have been most effected by the 1906 Flagstaff earthquake stand out for a visually appealing map that can have a greater impact affect to help get local residents more earthquake prepared we can extrude data and add height to affected neighborhoods.
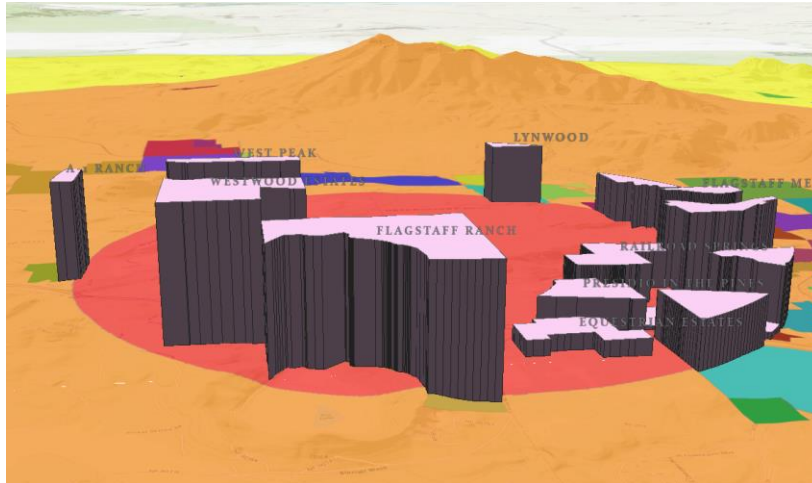
Figure 13a) 3D view of zone of S-wave 1 second distances emanating from 1906 earthquake epicenter with extruded height added to neighborhoods most effected view 1.

- we can explore this at different view settings.

Figure 13b) 3D view of zone of S-wave 1 second distances emanating from 1906 earthquake epicenter with extruded height added to neighborhoods most effected view 2.

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- we can continue to explore this at different view settings.

Figure 13c) 3D view of zone of S-wave 1 second distances emanating from 1906 earthquake epicenter with extruded height added to neighborhoods most effected view 3.

Question 1) What neighborhoods are most affected in the first second zone of the earthquake S-waves?

- To answer this, you can check the attribute table, to display this you can turn on the labels setting. **Some neighborhoods include Lynwood, West Ridge, University Heights, Flagstaff Ranch, and Westwood estates.**

- to determine the difference in distance of P-wave and S-wave travel at the same time interval we can explore the measure tool from the Map Tab. This can be important to determine where a short warning of an impending S-wave may be given by first detecting a p-wave. This can be important even if only a fraction of a second warning for instances as such at a hospital so if a surgeon were performing surgery, she could be warned of an earthquake at the onset of p-wave generation.

Part 6: Measure distance of P & S-wave zones from 1906 6.1 magnitude earthquake

Task 7: Measure distances of S-wave damage zones

    - below are various aspects of using the measure tool for measuring distance of seismic wave travel.
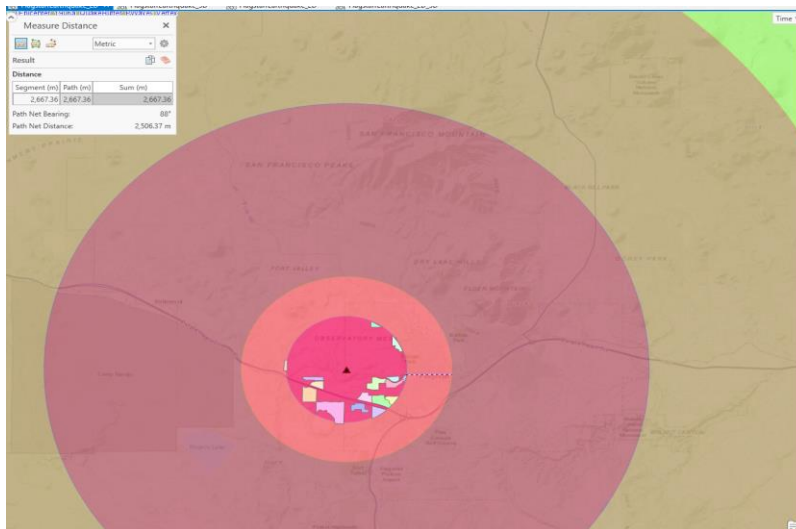

Figure 14) Map displaying P-wave and S-wave distances emanating from 1906 earthquake epicenter.
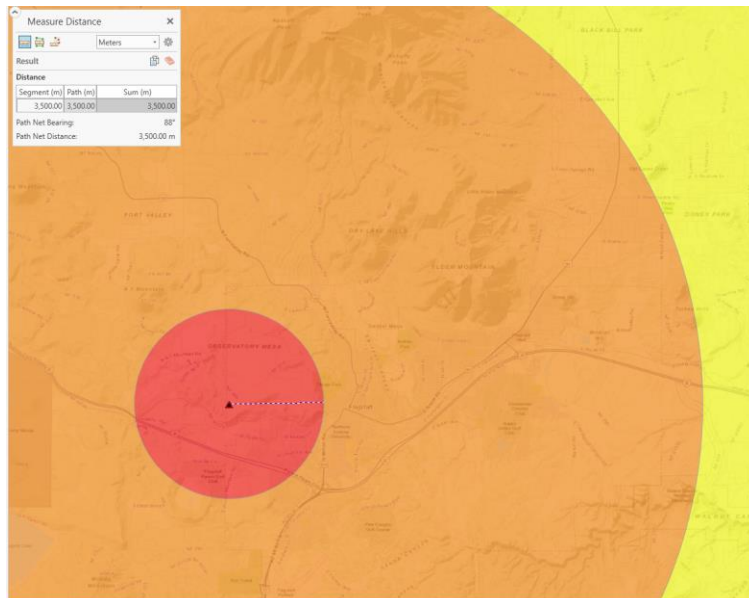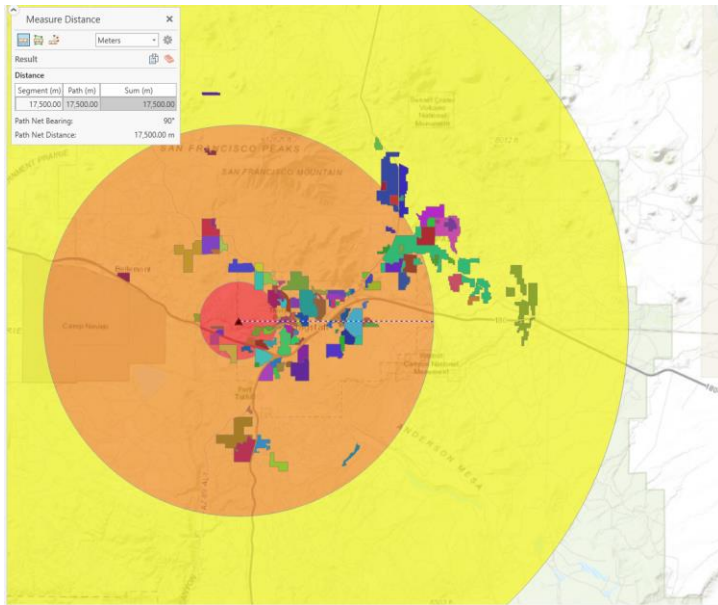

Figure 15a) Map displaying measurement of S-wave earthquake damage distances emanating from 1906 earthquake epicenter version 1.

Question 2) What is the distance that is the S-wave travels through rock in the first second following the earthquake on the surface?

- In this example we have measured a distance of 3,500 m

Figure 15b) Map displaying measurement of S-wave earthquake damage distances emanating from 1906 earthquake epicenter version 2.
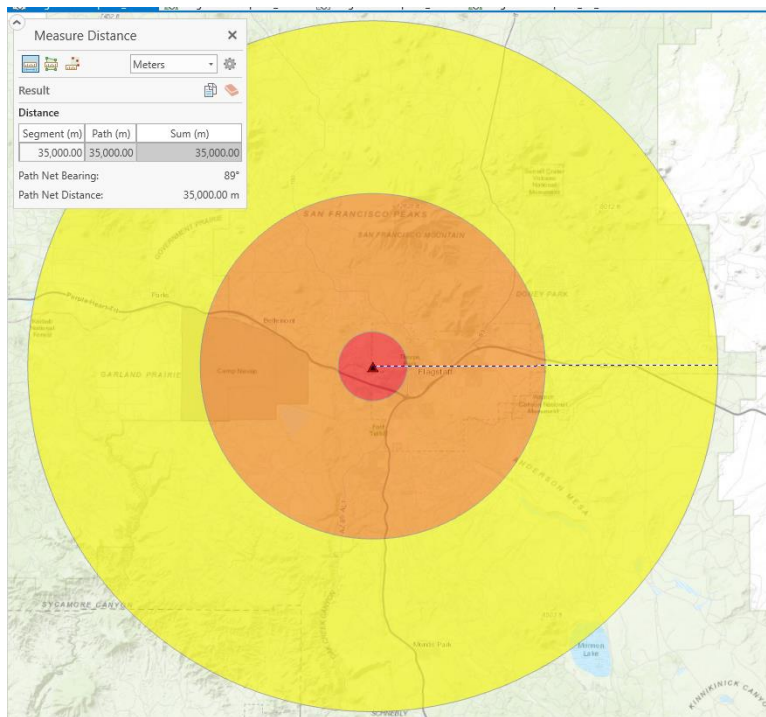
Figure 15c) Map displaying measurement of S-wave earthquake damage distances emanating from 1906 earthquake epicenter version 3.

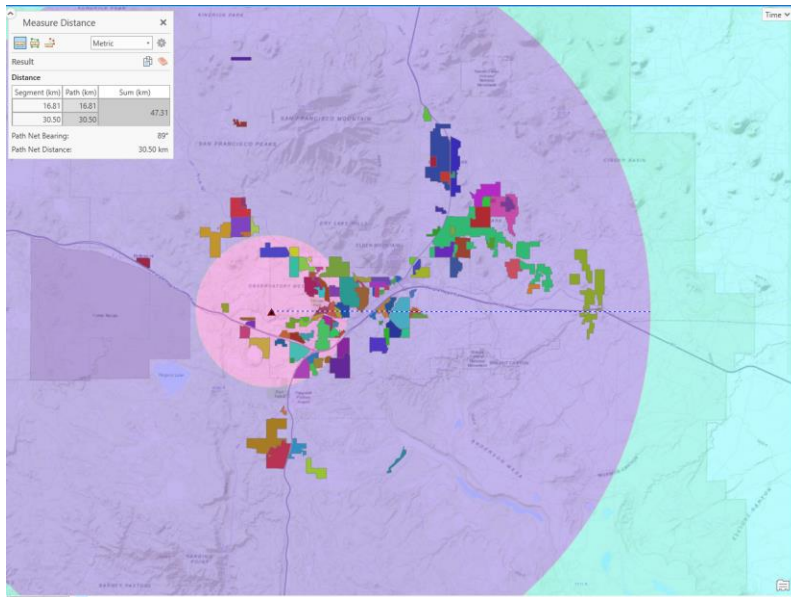## Task 8: Measure distances of P-wave potential short time warning zones

Figure 16a) Map displaying measurement of potential short time warning P-wave distances emanating from 1906 earthquake epicenter version 1.
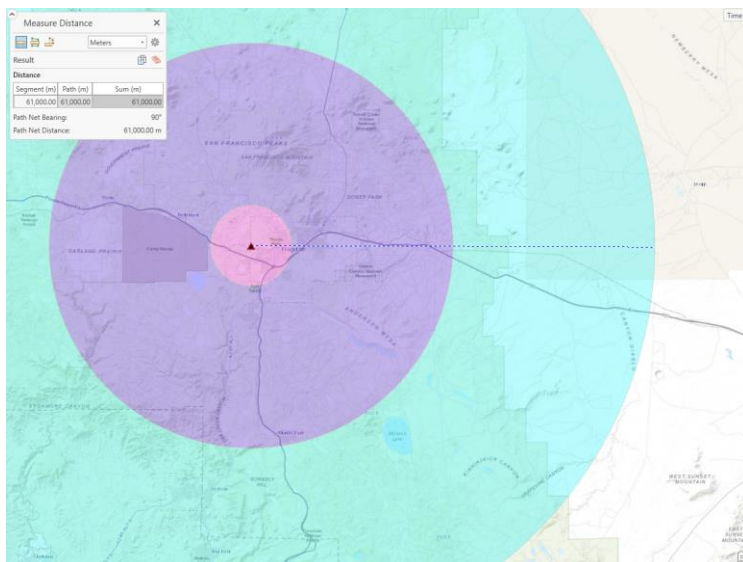

Figure 16b) Map displaying measurement of potential short time warning P-wave distances emanating from 1906 earthquake epicenter version 2.
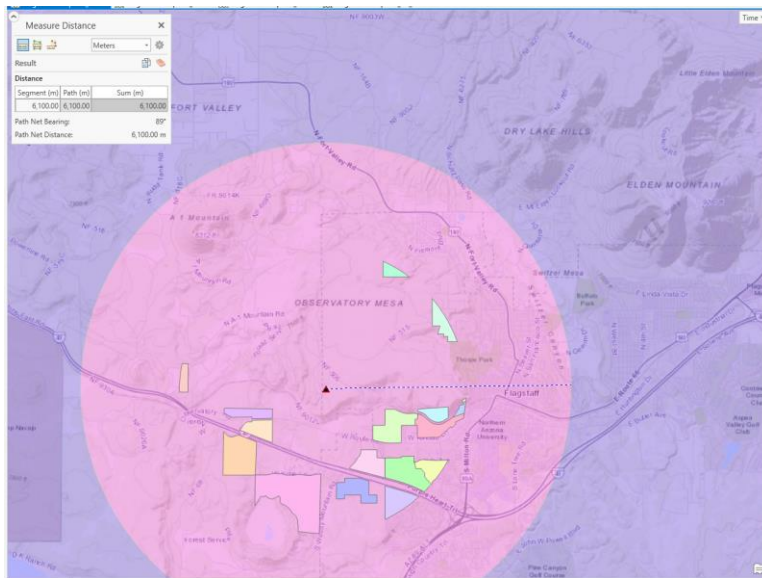
Figure 16c) Map displaying measurement of potential short time warning P-wave distances emanating from 1906 earthquake epicenter version 3.

Question 3) What is the distance that is the P-wave travels through rock in the first second following the earthquake on the surface?

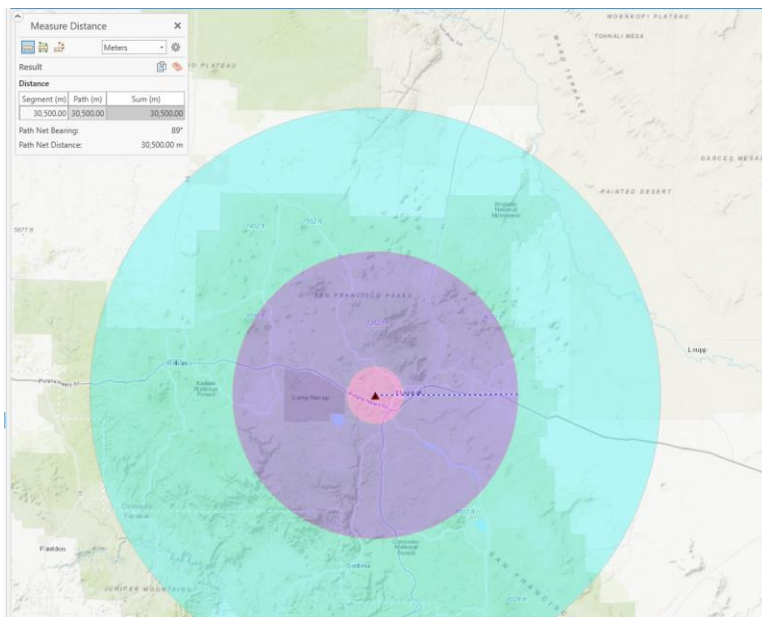- **In this example we have measured a distance of 6,100 m**

Figure 16d) Map displaying measurement of potential short time warning P-wave distances emanating from 1906 earthquake epicenter version 4.