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Geologic Face Mapping Methodology Utilizing Global Positioning Systems and Unmanned Aircraft Systems

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By

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ABSTRACT

Geologic field mapping has traditionally been a low-technology process, limited by time in the field and a delicate balance between data collection and coverage area. Advancements in Global Positioning Systems (GPS), Unmanned Aircraft Systems (UAS), and software packages offer new tools and techniques for collecting high volume, accurate geologic information. These tools can provide geologists with safe and efficient ways to collect and process greater volumes of field data.

Field data for this study was collected from three open pit mines using a Trimble Geo 7X GPS unit with Geo 7 Series Rangefinder module and a Phantom 4 Pro V2.0 UAS. The GPS was used to collect survey data from bedding contacts and other geologic features along the highwalls with centimeter-level accuracy. UAS flight data generated a detailed 3-dimensional (3D) model of the rock faces at each mine. A composite model was created using geologic survey data and 3D models that could then be used by mine personnel to identify potential hazards, calculate volumes, predict ore quality, and plan production. These results demonstrate efficient, effective, and safe methods of collecting, analyzing, and communicating geologic data using GPS and UAS technologies in geologic investigations.

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LIST OF ABBREVIATIONS

.cor – Corrected Standard Storage Format File

.obj – Object file

.tif - Tag Image File Format

AGL – Above Ground Level

AOI – Area of Interest

GCP – Ground Control Point

GIS – Geographic Information System

GPS – Global Positioning System

LiDAR – Light Detection and Ranging

INTRODUCTION

Face mapping is the process of researching a section of rock (outcrop) by studying and describing the visible geologic characteristics present, making observations, and developing conclusions about the geologic data present on the face of the outcrop. It is important because it provides tangible evidence of the rock layers in each area. Evidence in the form of geologic structures, stratigraphy, mineralogy, and geologic history can be studied for a wide range of commercial and research purposes using face mapping techniques.

The process of face mapping has been in practice since the birth of geologic study and was used by James Hutton as he studied and described outcrops in the mid-1700s in Scotland. The primary method for face mapping has traditionally consisted of collecting rock specimens, drawing sketches, and recording geologic descriptions and measurements in a field notebook. What has changed about this method are the processes in which data are collected and used. The advancement of technology provides mechanisms to update older methods to improve the geologic understanding of face mapping, expand the accuracy and efficiency of geologic modeling within the scientific community, and practice safe and efficient ways to gather data from quarry highwalls.

Facies analysis and geologic mapping have been crucial to understanding outcrops of rock bodies. With the advancement of survey techniques, using unmanned aircraft systems (UAS), image collection, and modeling software, modern geologic face mapping can improve data accuracy, safety, and collection efficiency. This study utilized modern face mapping techniques on open pit mine highwalls, sections of rock faces where the rock is discernable, accessible, and mappable, to evaluate geologic features and structures in surface mines and quarries.

LITERATURE REVIEW

Pre-Technological Methods

Spatial geologic maps and cross sections emerged in the early 19th Century with European works from Cuvier and Brongniart who developed a map and report in 1811 of the Paris Basin (Rudwick, 1996). In 1815, William Smith produced a geologic map of England and Wales (e.g. Whitmeyer et al., 2010). These works developed the basic processes of geological interpretation that future geologists would expand upon.

Work in the 19th Century was also being conducted in the United States to better understand the geologic environments and exploit resources. New Hampshire State Geologist C.H. Hitchcock of the New Hampshire Geological Survey provided the methods, insights, and plans used in the late 1800s to geologically delineate large areas of uninhabited land. The pace at which fieldwork could be conducted was dictated by the challenging terrain; some requiring the surveyors to traverse the mountainous forests on foot with few paths to follow (Hitchcock, 1896). Similarly, the quality and quantity of the data relied on the availability of exposed outcrops; accessibility to the outcrop area can be challenged by various natural and anthropogenic obstacles such as vegetative cover, hazardous terrain, weather, and infrastructure.

Mapping techniques were improved and standardized as understanding of geologic history improved. Work by Brimhall et al. (2006) described the historical geologic mapping techniques standardized by the Anaconda Company for mapping underground ore veins, describing the map and compass methods used to delineate the subsurface geology as compared to modern tools used for the same purposes today. Tools like the Brunton Pocket Transit patented by D.W. Brunton in 1894 provided geologists, surveyors, and engineers with a compass that could determine direction or inclination (Merriam and Youngquist, 2012). The Jacob's staff has been used in tandem with the Brunton Pocket Transit to measure stratigraphy in outcrops (e.g. Holland and Regan, 2020). These methods, while productive for basic analyses, lacked modern qualities that can now be achieved using information technology.

Information could not quickly be shared or verified between geologists. The process for researching the face of a rock formation was to first view the area of interest (AOI) to understand the lithology and identify

Modern Methods

The onset of the Information Age in the mid-20th century began reconstructing the economy based on the framework of information technology (Castells, 2007). The boom of the Information Age was aided by revolutionary technological developments, such as the creation of the World Wide Web in 1989 by Tim Burners-Lee. In 1995, almost 5 million users were connected to the internet, and that number nearly doubled in 1996 (Eighmey and McCord, 1998). Navstar Global Positioning Systems (later GPS) became fully functional in 1995, and over the following decades has become relevant in everyday life (Baker, 2017). Geographic Information Systems (GIS), first developed in 1963 by Roger Tomlinson, revolutionized the digital mapping industry.

Geomatics is defined as the branch of science that deals with the collection, analysis, and interpretation of data, especially instrumental data, relating to the earth's surface (Oxford English Dictionary). Dr. Roger Tomlinson's development of the GIS platform allowed scientists to interpret spatial information provided by data collection devices that could be manipulated to display specified attributes that pertain to the goal of any given project (Whitmeyer et al., 2010). The value of digitizing the modeling process is that it allows geologic field mapping to incorporate a wealth of information in digital base maps in real time at any scale (Brimhall et al., 2006). As new mapping methods are developed, traditional techniques are used alongside new technology to validate the data.

The impact of this information becoming widely available within the past 30 years has changed the way data is understood, used, and protected by being continuously upgraded and adapted to benefit the users. Global positioning systems (GPS) have become a staple in the 21st Century for collecting spatially accurate location data. Radionavigation uses one-way signals to transmit data from <31 satellites to receivers on Earth that calculate a receiver's current position, providing users with accurate GPS information (GPS: The Global Positioning System). These satellites have been sent into orbit to develop a worldwide, all-weather navigation, and timing system (Goad, 1985). Satellite data can be uploaded to an array of resources, one being GIS software, where the data can be stored, analyzed, manipulated, and interpreted to develop solutions regarding geologic questions.

The ability to obtain an accurate reference point requires little effort on the part of the user due to the simplicity in which the point can be collected. Conducting geological surveys using technology integrated with GPS units is reshaping the way geologic data is gathered and used. Images that are geographically referenced (georeferenced) provide visual information and geospatially accurate locations. The technology and methods available to collect geologic data has rapidly advanced because of the Information Age. Systems such as manned/unmanned vehicles, unmanned aerial systems (UASs), pushcarts, backpacks, and other methods are being used to collect more data in less time by allowing the user to work more efficiently.

Drone technology offers a cost effective, portable, timesaving, user-friendly, and safe way to collect imagery and videography of targets of interest (Kong, et al., 2021). Cameras and sensors are connected to UASs to provide a wide array of technical services capable of operating in a variety of climates, terrains, environments, and weather conditions. The main components that affect the quality of each image are the spatial resolution and the accuracy of photogrammetric products (Honarmand and Shahriari, 2021). Some examples include a geologic study on landslides in the Lantai area in Taiwan successfully utilized a UAS with LiDAR to investigate geological settings and structures by mapping the area of interest to identify lineaments (Lin, et al., 2021). Aerial imagery is the most commonly applied use for UASs because they can work in inaccessible areas and areas too large to effectively study on foot or by vehicle (Saadatseresht, et al., 2015).

Light Detection and Ranging (LiDAR) data can be utilized to create different types of 2D and 3D data that can be applied to geologic research. Terrestrial ground surveys provide another way of collecting GPS data. This process creates a point cloud of all of the objects within the active sensor’s range. Thousands of signals are projected every second, providing thorough coverage of the area. LiDAR has been used in a variety of geologic investigations and the ability to extract a bare-earth model, or digital terrain model, is what makes LiDAR so valuable to the geologist (Allmendinger and Karabinos, 2023).

GPS technology can have limitations when collecting and verifying data in areas with steep walls and excessively dense tree cover (Brimhall et al., 2006). Factors like shadows, light, and movement of trees and water will significantly impact the quality of each image and the rendered model (Agarwal et al., 2020; Burdziakowski and Bobkowska, 2021). In surface mines, the Sun will obstruct certain angles of highwalls depending on the time of day and season, as the angle of the Sun changes as it passes from east to west.

OBJECTIVES

The primary objectives of this research were to develop a suite of technology-based methods for mapping geologic features on highwalls that can be incorporated into industry standard operating procedures. These methods will provide an effective way for professionals to collect highwall data safely and efficiently, identify potential safety hazards and design workflow for operators to maximize production.

These objectives were accomplished by:

- Creating a personalized data dictionary for each mine site in Trimble® GPS Pathfinder® Office to facilitate data collection in the field;
- Establishing AOIs at each mine site to collect relevant data including a visual assessment of highwalls and surrounding environments, ground control points, and safety protocols;
- Conducting UAS flight(s) to obtain photogrammetric imagery of each study area;
- Surveying and describing geologic features and safety hazards within the AOIs using the Trimble™ Geo 7X GPS unit;
- Processing the geologic point data gathered by the Trimble™ Geo 7X GPS unit;
- Rectifying UAS imagery with Agisoft Metashape Professional modeling software to develop spatially accurate 3-dimensional (3D) models;
- Constructing geologic block models in Leapfrog Geo by overlapping the 3D models and surveyed data points; and

- Developing and refining this methodology for research and commercial applications for geologic face mapping.

METHODOLOGY

Pre-survey Methods

Development of Personalized Data Dictionary

A personalized data dictionary was created for each mine based on the literature review and information provided for each mine site's structure and lithology. The data dictionary was constructed in Trimble® GPS Pathfinder® Office, processing software designed to develop GIS information that is consistent, reliable, and accurate from global navigation satellite system (GNSS) data collected in the field (Trimble® GPS Pathfinder® Office Software). The dictionaries contained fill-in-the-blank, numeric, and drop-down-menu fields for data collection. The Trimble™ Geo 7X GPS unit was connected to the computer hosting the processing software and then the dictionary was uploaded and stored on the Trimble™ Geo 7X which was then used and applied in field research (Figure 1).

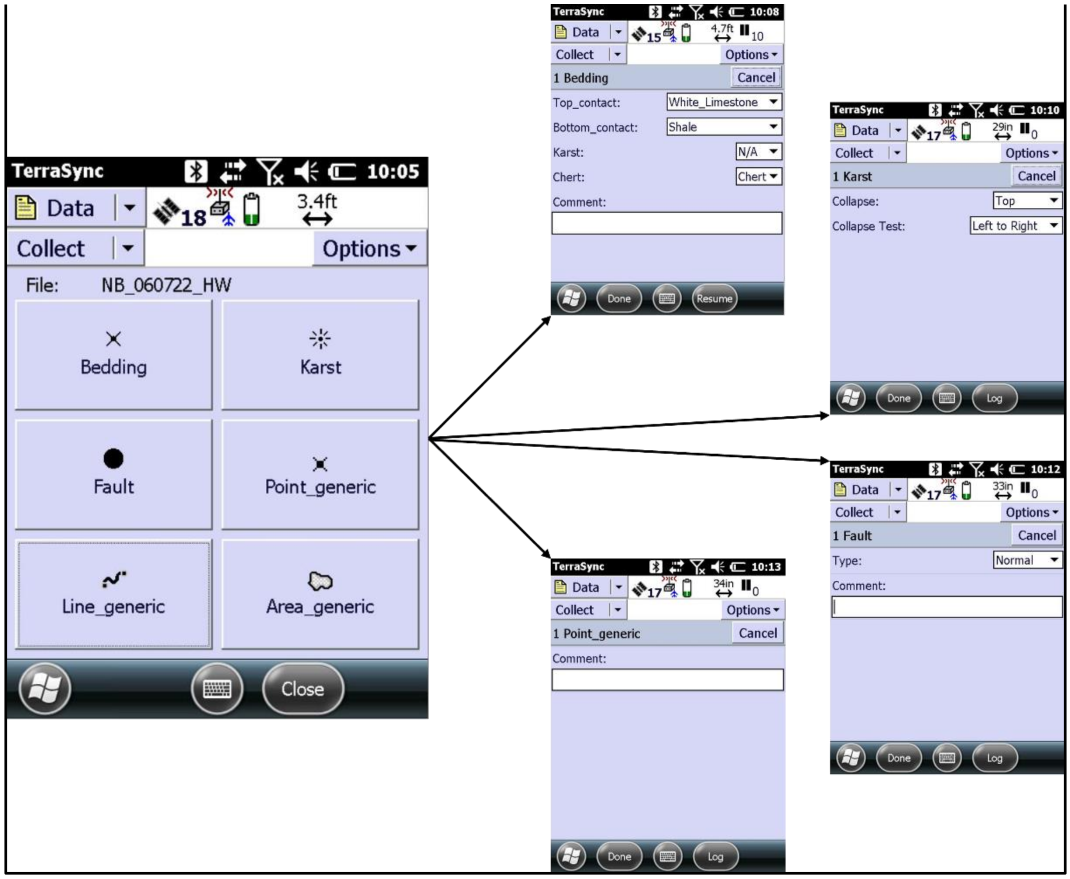


Figure 1: The feature selection system developed from the data dictionary for collecting data with the Trimble^{TM} Geo 7X along with the menus of each selection.

Establishing an Area of Interest and Safety Briefing

Upon arrival at each mine, a safety briefing was held in accordance with the mine's safety officer and Mine Safety and Health Administration (MSHA) guidelines, the organization that dictates all safety measures within every mine in the United States. The area of interest (AOI) was established at each study site based on safety, the prevalence of geologic structures and variations, accessibility, and dimensions of the highwall. Per MSHA standards, in surface operations no individual is allowed within a quarter of the height of the base or peak of a highwall. This mitigates the risk of injury or death from rockfalls.

When the desirable highwall was chosen, the highwall and surrounding environment were visually and audibly assessed to identify safety risks to the researchers by observing and documenting the features on the highwall including joints, collapse structures, faults, karst, bedding, vegetation, and safety hazards. These data were compared to the final models to determine if other features were present but not visible during the initial inspection.

Multiple ground control points (GCPs) were spray painted on the highwall in order for the unmanned aerial system (UAS) camera to capture one or more GCPs at a time. Four to six GCP squares were installed, two or three each at the base and the top, behind the MSHA mandated safety berms (Figure 2). Each GCP was surveyed in the center of the square with the Trimble™ Geo 7X GPS unit which was then used to georeference the UAS imagery to each GCP in Agisoft Metashape Professional modeling software.

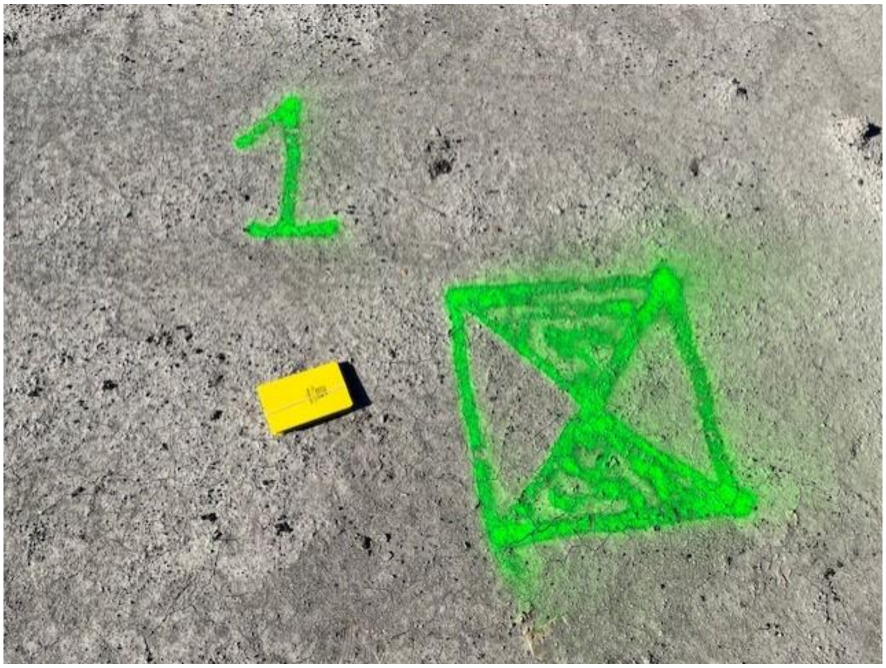


Figure 2: Spray painted ground control point at the South Hallsville No.1 Mine.

Mine Survey

UAS Flights

UAS flight(s) were conducted with a DJI Phantom 4 Pro V2.0 to obtain photogrammetric imagery of the AOI (Figure 3). Before takeoff, a programmed flight plan was set up on the Pix4DCapture application where the following details were arranged: flight area and paths, front and side overlap, duration, camera angle, speed, altitude, ground sample distance (GSD), and white balance. Next, a test flight was manually flown around the perimeter of the mission area to verify that the drone would not collide with obstacles. After the test flight, the programmed mission was launched. If needed, a mid-mission battery change occurred depending on the size of the AOI, flight duration, and weather conditions. Once the battery was changed, the UAS continued the mission and then landed at the home point when the flight was complete. The imagery was saved on the UAS and the flight plan was saved on the Pix4DCapture application.

Surveying Geologic Features

Individual data points along the AOI were recorded using the Trimble^{TM} Geo 7X GPS unit attached to a monopole (Figure 4) to increase stability and point accuracy. The points were surveyed by maintaining a safe distance from the base of the highwall and observing geologic features such as joints, collapse structures, faults, karst, bedding as well as vegetation and safety hazards. When a data point was collected, a log interval of one position per second collected a total of 10 positions and took the average of those positions and created one point at the base of the monopole. The laser rangefinder was

Figure 3: Preparing the DJI Phantom 4 Pro V2.0 for conducting a preprogrammed flight of the study area at the Alabama Mine in Saline County, Arkansas.

then used to collect one point on the highwall of the feature of interest, and a description of the feature was recorded based on visible information. This process was repeated along the entire highwall and the saved points were used in the final model.

Hand samples were safely gathered from the base of the highwalls that were correlated to specific rock layers. If it was not safe to approach the highwall, mine equipment was used to collect samples to abide by MSHA safety regulations. The samples were labeled with a description of the specimen and its collection location.

Figure 4: The Trimble[TM] Geo 7X GPS unit with monopole was used to collect point data along the South Hallsville No.1 Mine highwall in Rusk County, Texas.

Post-survey Processing

Rectifying UAS Imagery

Once the UAS imagery was downloaded onto a drive, the raw images were uploaded to Agisoft Metashape Professional. The raw pictures were stitched together using key points which determined how detailed each image needed to be by identifying individual features on the 2D images; then tie points were established, which identified the key points in each image (i.e., the corner of a distinct rock or cliff). that could be spatially tied together to help align the photos. A set number of points were tied together between images that were then grouped into a sparse point cloud. Next, excess and erroneous tie points that populated the outer edges were deleted from the sparse point cloud to improve the model. From there the cameras were realigned to create a more accurate directional image representation. After this, the depth maps were formed from overlapping images to create the dense cloud model. A mesh was created based on the dense cloud model, then a texture was overlaid on the mesh to increase the detail and create a textured model. The GCPs were identified by manually clicking on the center of each numbered control point in order to georeference the model to the coordinate system. Once the same numbered GCP was identified in multiple images, machine learning preselected the GCPs in the rest of the images, but they were also manually confirmed to verify accuracy. The model was then ready to be exported in two packages, first as a tag image file (.tif) for the imagery, then as an object file (.obj) for the 3D block model. The model was then ready to be exported to Leapfrog Geo geologic modeling software.

Processing Geologic Point Data

Trimble® GPS Pathfinder® Office was used to rectify the point data gathered by the Trimble™ Geo 7X GPS unit. Data was downloaded to a drive and then uploaded into the software. These points were initially corrected by connecting all of the points to a nearby base station or a continuously operating reference system (CORS). It connected the exact location of each surveyed position to the verified location of the base station or CORS, which increased location accuracy. Once the corrected points were saved, their latitude/longitude coordinates were manipulated into a comma-separated value (.csv) file along with the spatial and geologic information required for the final models. Once the point data was in its proper configuration, the files were exported to Leapfrog Geo.

Geologic Block Models

Constructing the Leapfrog Geo model was the last step of this methodology where the textured 3-Dimensional (3D) model from Agisoft Metashape Professional and the corrected point data from Trimble® GPS Pathfinder® Office were combined into one interactive model. The textured model, when imported into Leapfrog Geo, was displayed as a solid color block model and the imagery associated with that model was draped over to populate the block model. The final step of this process was importing the georeferenced point data as well as the geologic description of each feature point. After this, the spatial data of the combined model was verified to ensure all features were in the correct locations.

The final output from Leapfrog Geo was a spatially accurate 3D geologic model made up of a block model obtained from the preprogrammed unmanned aerial system (UAS) flight imagery and individual point data made up of geologic features, vegetation, and safety hazards collected from the Trimble™ Geo 7X unit. The point data is visible and accessible so that any point can be selected and a pop-up menu will appear with a description of the feature and the latitude and longitude coordinates. The workflow of this research can be viewed below (Figure 5).

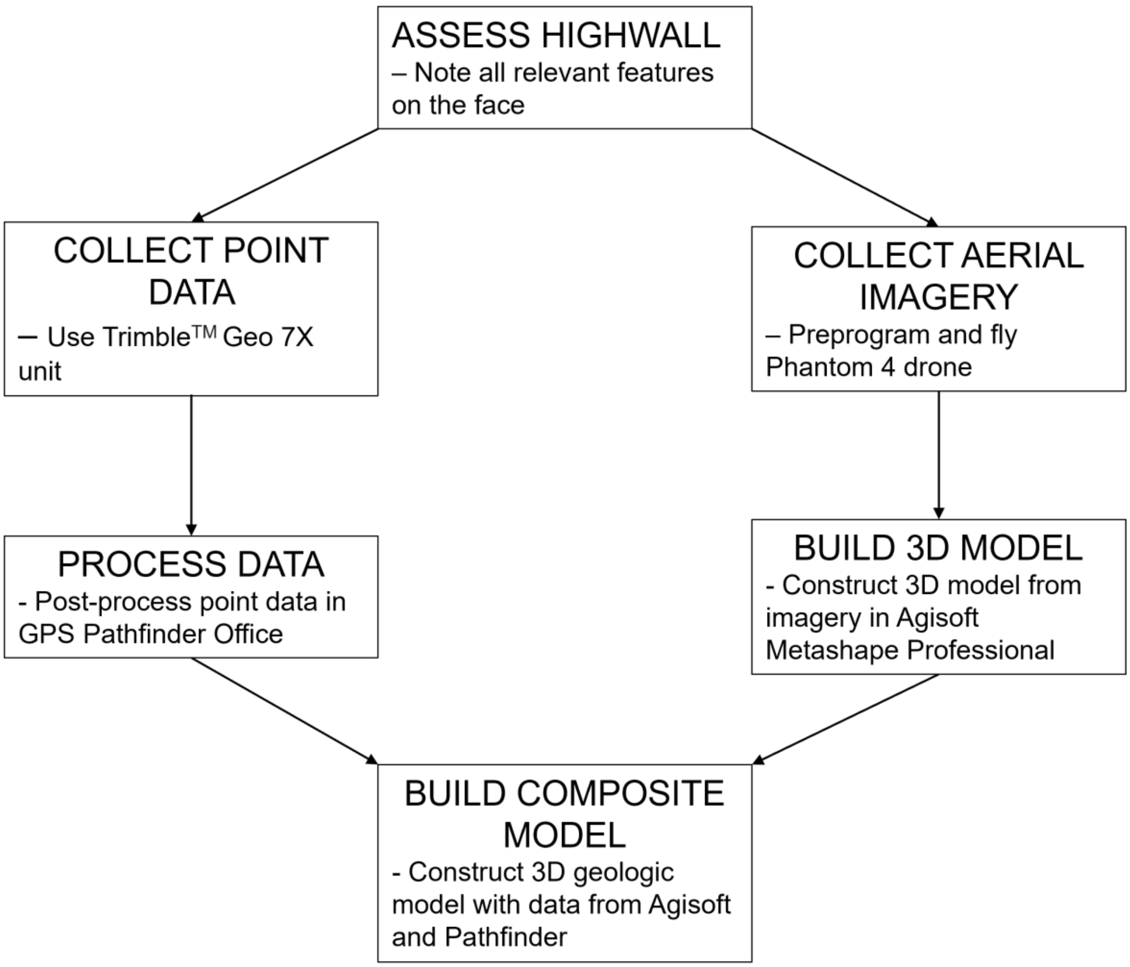


Figure 5: Flow chart depicting the primary working components and outcome of this research.

STUDY AREAS

This research was conducted at three active mine locations in Central Texas, East Texas, and Central Arkansas. Each site is geologically unique which provided an opportunity to utilize this face mapping methodology in a variety of geologic environments.

Lhoist North America, New Braunfels Mine, Comal County, Texas

The Lhoist North America quarry is located in Comal County, Texas (Figure 6). Lhoist mines chemical-grade limestone (96%< $CaCO_3$) at this location. The limestone is extracted by blasting sections of benches, after which haul trucks are loaded to take the product to be crushed and cleaned to remove contaminants. The rock is sorted and processed based on rock size and chemical quality, and then calcinated in a kiln until quicklime is produced. From here the lime is broken down into pebbles, grain, and fine sizes. The plant also manufactures milled lime (CaO), hydrated lime ($Ca(OH)_2$), and milk of lime ($Ca(OH)_2$). Lime from the mine is used in a variety of products, including glass, emulsion paint, water treatment, and others.

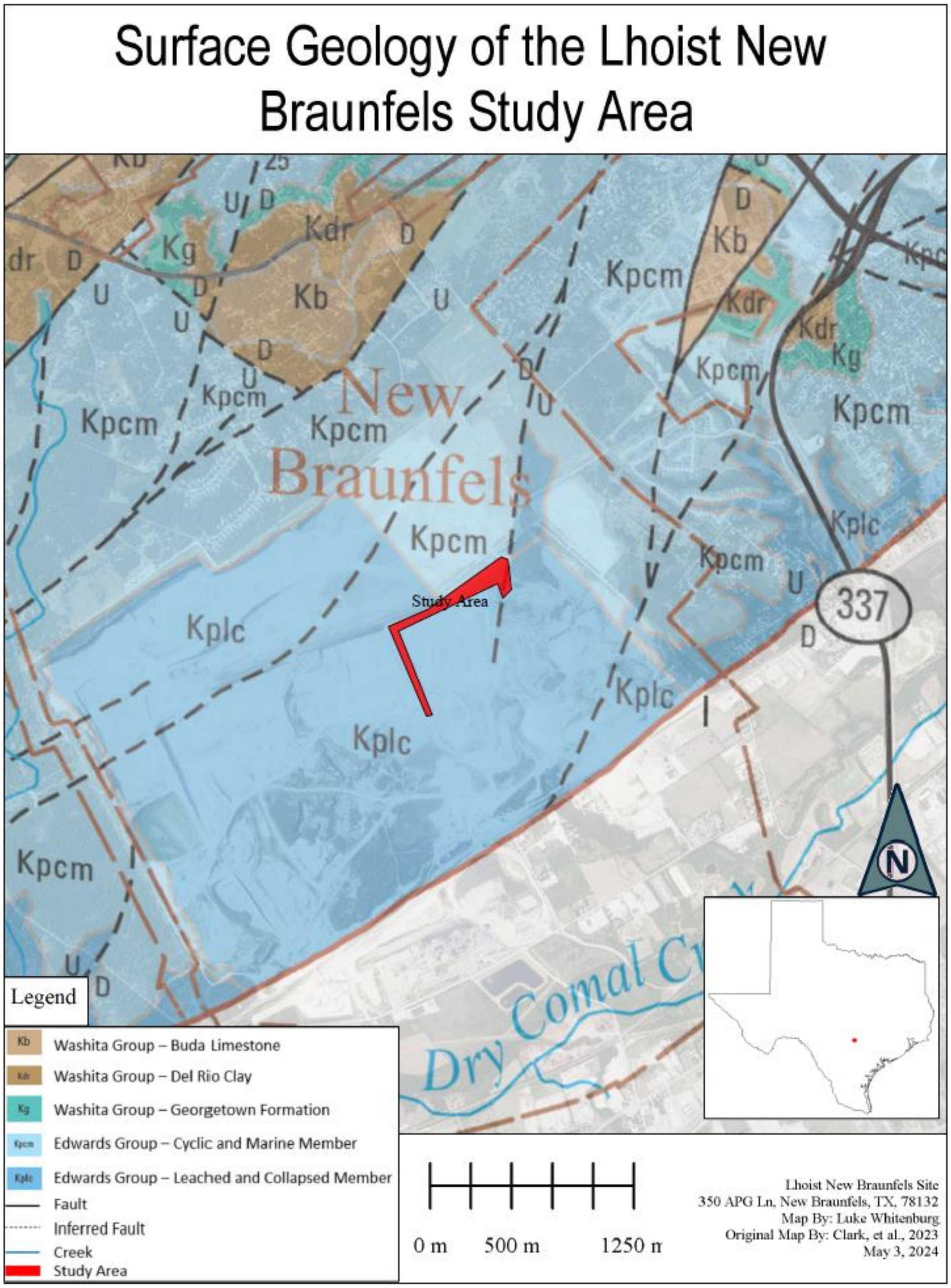


Figure 6: Surface geology map of the Lhoist New Braunfels limestone mine study area in Comal County, TX. Geologic information from the USGS (Clark, et al., 2023), roadway information from the Texas Department of Transportation.

At the New Braunfels quarry, the chemical limestone layers are covered by overburden of non-chemical-grade limestone and shale units. These layers are removed by the neighboring mining company Cemex, an associated multinational aggregate mining and distribution company. A symbiotic relationship between Cemex and Lhoist allows both companies to enter the other's site so that they can remove their respective ore.

To date, the New Braunfels quarry covers 969.3 acres, and is 78m deep. The mine is comprised of four benches and nine mining units. From bottom to top, the mining units are: Bottom Rock Lower, Bottom Rock Upper, Bottom Strip, Pit Rock, Pit Strip, 31, Shale, White Limestone, and Top Strip. The listed units are comprised primarily of limestone along with inclusions of clay seams, shale, ribbon chert, chert nodules, iron-staining, and collapse features. The research conducted at this site entailed developing a 3-dimensional model of the third and fourth benches from the bottom of the pit using drone photogrammetry and the Trimble™ Geo 7X GPS unit to collect highwall data from the main pit of the mine.

New Braunfels Quarry Stratigraphy

Some members of the Person and Kainer formations of the Edwards Group are visible from the deepest point in the mine (Figure 7). The rocks represent transgressive and regressive cycles during the Cretaceous, and host characteristic fossil assemblages and features of both shallow and deep-water environments. The mining units are made up of the Kirschberg Evaporite and Grainstone members of the Kainer Formation (Small and

Hanson, 1994), micritic and grainstone facies from the Regional Dense and Leached and Collapsed members of the Person Formation. Karst formed within the deposited units when a large part of the Central Texas Platform was sub-aerially exposed (Barker, et al., 1994).

Hydrogeologic subdivision			Group, formation, or member			Hydro-logic function	Thickness (feet)	Lithology
Upper Cretaceous	Upper confining units		Navarro and Taylor Groups, undivided			CU	600	Clay, chalky limestone
Upper Cretaceous	Upper confining units		Austin Group			CU; rarely AQ	130 - 150	White to gray limestone
Upper Cretaceous	Upper confining units		Eagle Ford Group			CU	30 - 50	Brown, flaggy shale and argillaceous limestone
Upper Cretaceous	Upper confining units		Buda Limestone			CU	40 - 50	Buff, light gray, dense mudstone
Upper Cretaceous	Upper confining units		Del Rio Clay			CU	40 - 50	Blue-green to yellow-brown clay
Lower Cretaceous	I	Edwards aquifer	Georgetown Formation			CU	Less than 10	Gray to light tan marly limestone
Lower Cretaceous	II	Edwards aquifer	Edwards Group	Person Formation	Cyclic and marine members, undivided	AQ	80 - 100	Mudstone to packstone; *miliolid* grainstone; chert
Lower Cretaceous	III	Edwards aquifer	Edwards Group	Person Formation	Leached and collapsed members, undivided	AQ	80 - 100	Crystalline limestone; mudstone to grainstone; chert; collapsed breccia
Lower Cretaceous	IV	Edwards aquifer	Edwards Group	Person Formation	Regional dense member	CU	20 - 24	Dense, argillaceous mudstone
Lower Cretaceous	V	Edwards aquifer	Edwards Group	Kainer Formation	Grainstone member	AQ	50 - 60	*Miliolid* grainstone; mudstone to wackestone; chert
Lower Cretaceous	VI	Edwards aquifer	Edwards Group	Kainer Formation	Kirschberg evaporite member	AQ	50 - 60	Highly altered crystalline limestone; chalky mudstone; chert
Lower Cretaceous	VII	Edwards aquifer	Edwards Group	Kainer Formation	Dolomitic member	AQ	110 - 130	Mudstone to grainstone; crystalline limestone; chert

Figure 7: A stratigraphic column of the Edwards Group in Central Texas (from Small and Hanson, 1994).

Kainer Formation

Kirschberg Evaporite Member is the older member of the Kainer Formation, an altered crystalline limestone and chalky mudstone unit around 12.2m - 18.3m thick (Small and Hanson, 1994). The member contains chert lenses and nodules, collapse breccia from earlier dissolution, significant karst features, boxwork alteration patterns, and travertine cave deposits (Maclay and Small, 1976).

Grainstone Member is a dense limestone unit comprised of primarily milliolid grainstone, as well as wackestone, and mudstone layers that range from 12.2m - 18.3m thick (Small and Hanson, 1994). This member is characterized by crossbedding and ripple marks located near the upper contact with the Regional Dense Member (Clark, et al., 2023) along with chert beds and nodules. Karst located near the middle of the member is a honeycomb-shape network that can be a stratigraphic indicator for the Edwards Group (Maclay and Small, 1976).

Person Formation

The Person Formation is separated into three members. From the stratigraphic bottom to the top these are: Regional Dense Member, Leached and Collapsed Members (undivided), and Cyclic and Marine Members, (undivided). These members represent shallow marine depositional environments.

Regional Dense Member is an argillaceous, shaly limestone that is commonly 6.1m - 7.3m thick. This layer is characteristically a light tan color, it contains iron-oxide staining, fossils, and chert nodules (Clark, et al., 2023). This member is a stratigraphic marker for the Edwards Group (Small and Hanson, 1994) because of its smooth, clay rich texture compared to the thick limestone of the other members of the Person Formation.

Leached and Collapsed Members (undivided) are thickly bedded recrystallized limestone, grainstone, and mudstone, between 21.3m - 30.5m thick. They are comprised of collapse breccia, chert lenses, marine fossils, iron-stained bioturbation, and karst (Small and Hanson, 1994). Fossils including *Montastrea roemeriana*, *Toucasia* sp., and oysters have been identified in these members (Clark, et al., 2023). The member has been lumped together with the overlying

Cyclic and Marine Members (undivided) are a thickly bedded mudstone to packstone to miliolid grainstone that ranges between 24.4m - 30.5m thick in the Central Texas region. Similar fossils found in the underlying Leached and Collapsed Members (undivided) have been found in this undivided member.

South Hallsville No.1 Mine, North American Coal, Sabine Mining Company, Harrison County, Texas

The South Hallsville No. 1 Mine, located at 6501 Farm Road 968 West, Hallsville, TX 75650-7413 is a lignite open pit mine operated by the Sabine Mining Company, subsidized by North American Coal Corporation (Figure 8). The mine began production in 1984 and opened three pits. The South Hallsville No. 1 Mine ended operations in April 2023 with remediation processes underway. When the mine was operational, drag lines were used to extract the coal by scraping it from the surface, not requiring explosive blasts to break up the already loosely lithified lignite. After the coal is excavated, wheel loaders fill haul trucks which then transports the lignite to the buyers. This pit produced an average of 4,000,000 tons of lignite annually. Production came from three continuous lignite seams (from lowest to uppermost) L RED, L BRN, and L TN (Figure 9; Wheeler, 2009). Some smaller isolated seams such as L RS and L SIL can be mined depending on the thickness and quality of the coal. The production seam thicknesses of coal change along the highwall because of differential compaction from the overriding units and effects of the Triassic to Cretaceous-age Sabine Uplift.

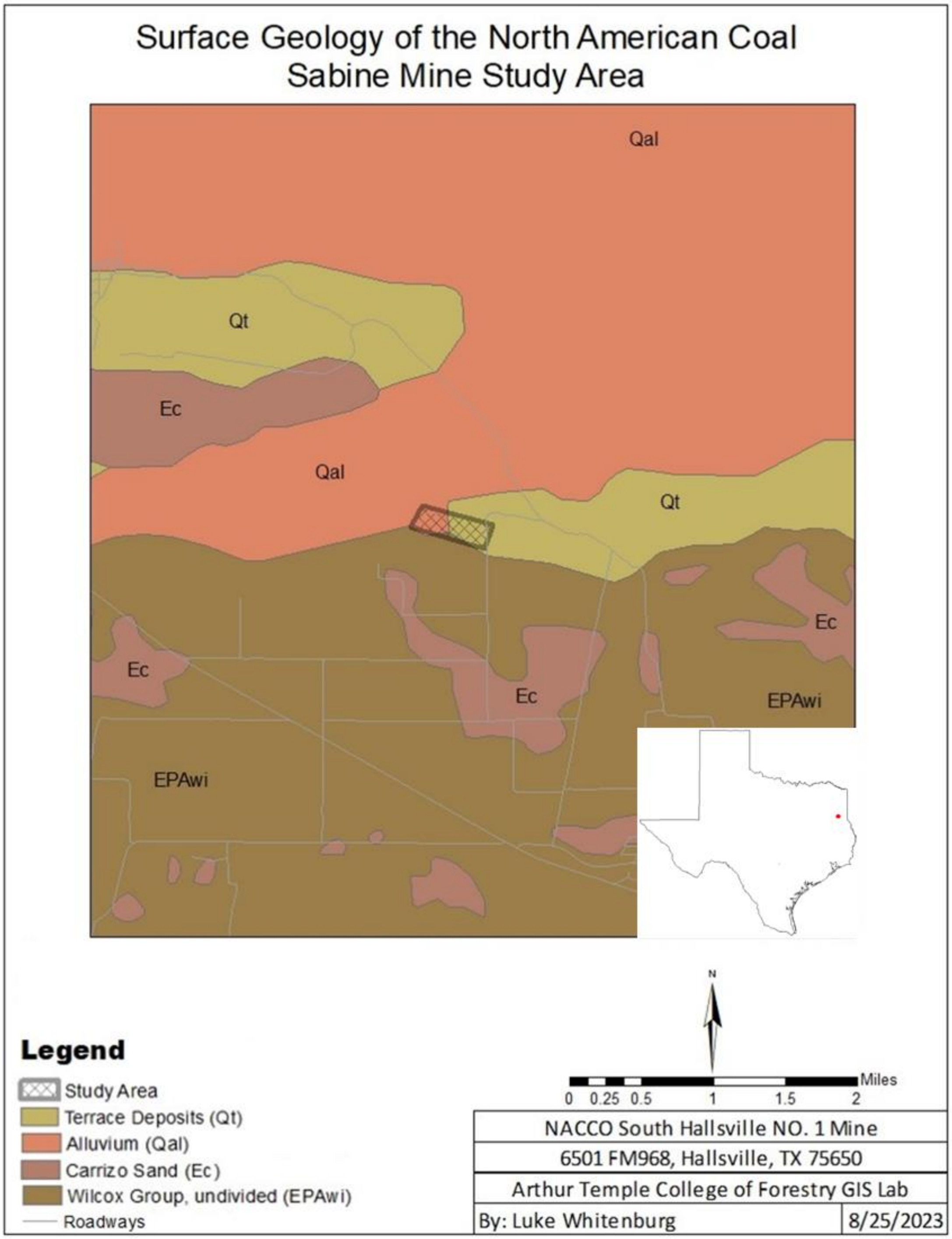


Figure 8: Surface geology map of the NACCO South Hallsville No. 1 lignite mine study area in Rusk County, TX. Geologic information from the USGS, roadway information from the Texas Department of Transportation.

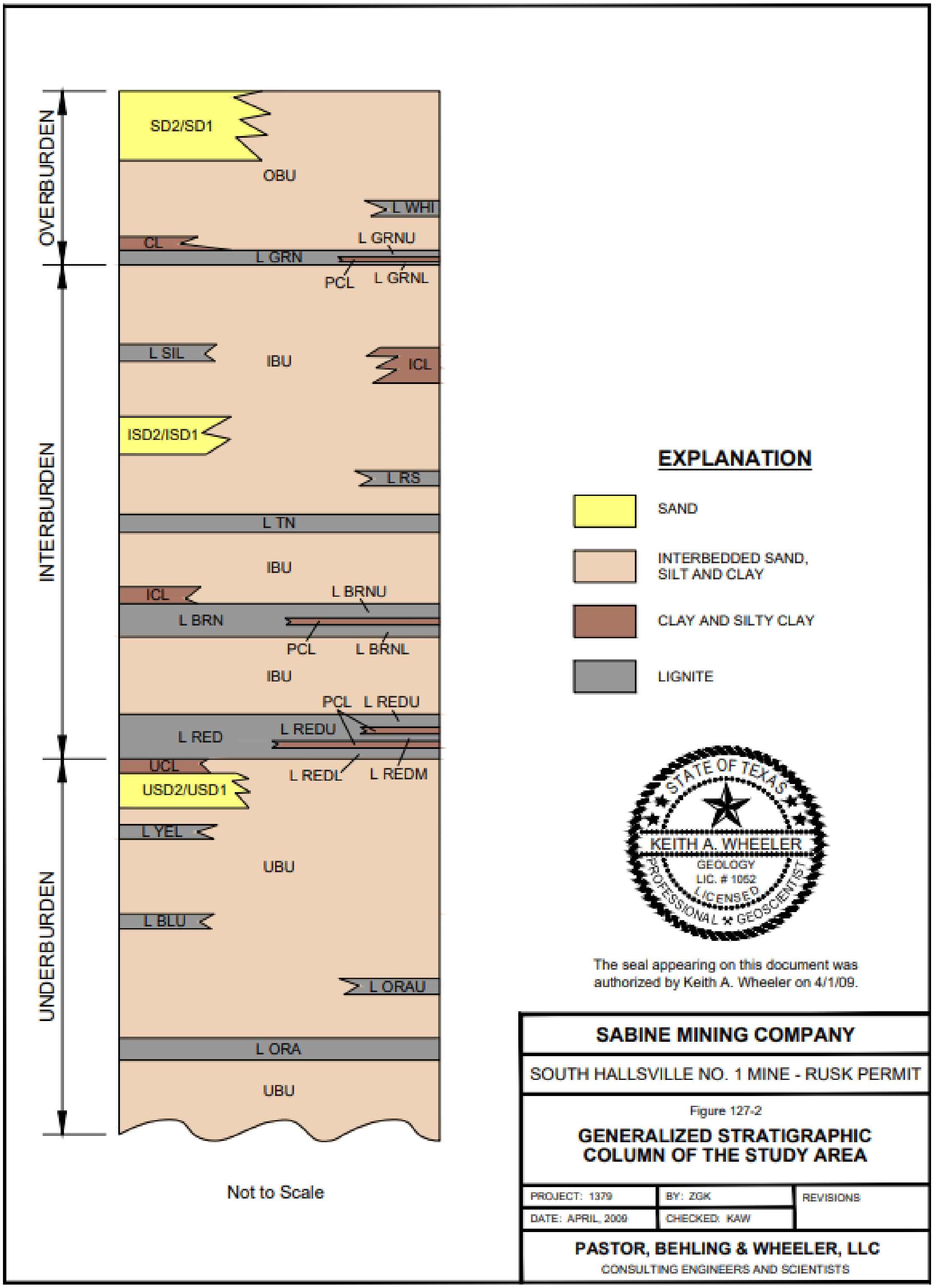


Figure 9: General stratigraphic column of the South Hallsville No. 1 Mine (Wheeler, 2009).

Wilcox Group Description

The mine exposes the undivided Wilcox Group and overlying Reklaw Formation, which are overlain by Quaternary sands and terrace deposits (Figure 10). Regional deformation that developed the East Texas Basin and the Sabine Uplift comes from salt creep that has caused faulting (Jackson, 1982). In this region, large-scale structural alteration has occurred from salt pillows, salt diapirs, and turtle structures (Jackson, 1982). This deformation has created minor folding within the study area. Multiple cycles of transgressions and regressions occurred within the region, displayed by the alternating beds of interbedded sand, silt, and clay with the continuous/noncontinuous lignite beds (Bammel, 1979).

Within the mine are multiple non-economic lignite seams that pinch out and are often too thin to extract for profit. The strata are generally horizontal but bedding deformation from the Sabine Uplift and local differential compaction have caused undulation and soft sediment deformation.

South Hallsville No.1 Mine Stratigraphy

The stratigraphy of the study site from bottom to top, begins with Eocene-age, marine shales and clays of the Upper Wilcox which were covered with deltaic and fluvial sands and clays, creating a disconformity, indicating a rapid sea regression (Echols and Malkin, 1948; Bammel, 1979). Repeating intervals of sands, silt, sandy clays, ferrous concretions, and lignite were spread out along the coast (Townsend, 1954).

Along the East Texas embayment, the beds are conformable and discontinuous due to regional faults. Locally, this has affected the uppermost units of the Wilcox and the lower Claiborne Group, and caused minor folding through the thin clastic beds. Within the upper Wilcox Group in East Texas, the units are composed of clastic sedimentary layers representing transgressive and regressive cycles that brought deeper waters over the coastal plain. Most recently, thin Quaternary alluvium has covered the study area.

The face of the study area is a part of the upper Wilcox (undivided) that was built up by shallow marine to near inland deposits. Four lignite seams that range from two feet to eight feet are located in the study area, developed in inland swamp environments. Thick sections of mixed sand, silt, and clay make up the layers in between the lignite seams, these units were deposited in shallow marine to beach environments.

Alabama Mine, ALCOA, McGeorge Contracting Company,

Saline County, Arkansas

The Alcoa Alabama Mine located at 1401 Bauxite Cutoff Rd, Bauxite, Arkansas 72011, is an open pit bauxite mine that is owned by the Alcoa Corporation and mined by McGeorge Contracting Company. This section of the mine has been operational since 1952 with <6,000 acres of covered bauxite ore. The primary commodity is aluminum ore, with secondary minerals such as gallium, iron, silica, and titanium. (Alcoa Arkansas Operations). Bauxite ore is benched, where sections of rock are blasted from cliff sides, creating stair-step-like topography.

The study area is an in-situ overburden unit of the Berger Formation, the lowest formation of the Wilcox Group (Figure 11). This area was chosen based on three factors: safety, due to a lack of mine activity at the study site; the abundance of local changes in lithology; and the ability to collect hand samples from each rock unit to validate the methodology.

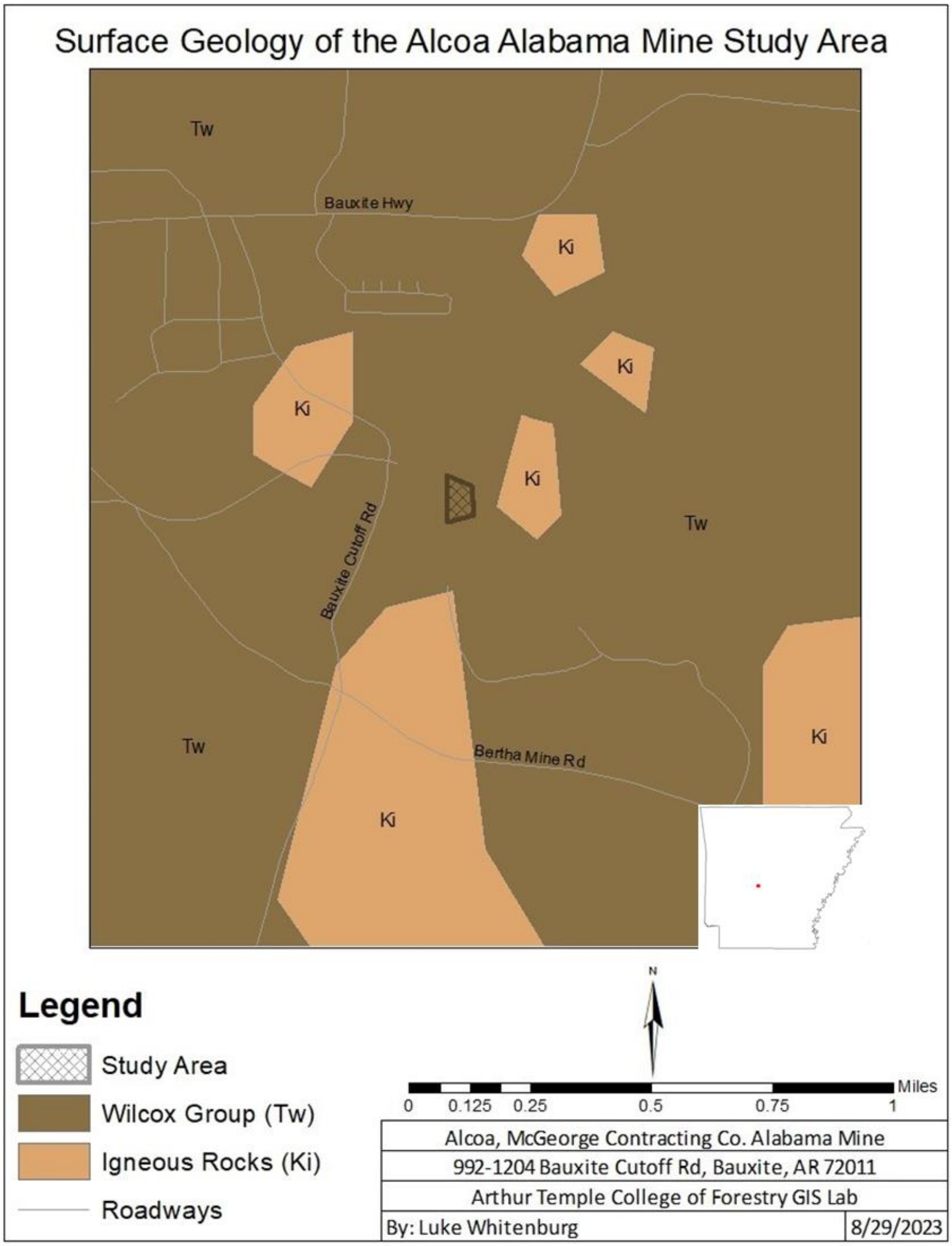


Figure 10: Surface geology map of the Alcoa Alabama Mine study area in Saline County, AR. Geologic information from the USGS, roadway information from the Arkansas Department of Transportation.

Wilcox Group

The Wilcox Group in Central Arkansas is described as a fluvial, deltaic environment in which continentally derived silt and clay were suspended and transported downstream (Arkansas Geological Commission, 1974). After the rivers had regionally dried out, transgressive and regressive sequences deposited sand and lignite as channel-fill (Fogg, et al., 1991; Fisher and McGowen, 1967). Evidence of interfingering shales, sandstones, and lignite, as well as structures such as channel fill, ball and pillow, and differential compaction indicates periods of inland, coastline, and shallow marine environments. Below these clastic deposits lie the bauxite mining unit at the base of the Hooper Formation of the lower Wilcox Group. This unit formed through the weathering and leaching of nepheline syenite minerals as well as secondary leached minerals that are cemented together (Arkansas Geological Commission, 1974; Mahmut, 2023). The bauxite is nonconformable with the underlying Late Cretaceous nepheline syenite that intruded into younger units that later eroded away during the Paleocene and Eocene. Warmer climates in the Eocene helped to create the conditions for bauxite to form in-situ deposits in contact with the nepheline syenite and detrital units which were continuously deposited with other sedimentary units, including the Wilcox Group.

Alabama Mine Stratigraphy

The study area is made up of the lower Berger Formation of the Wilcox Group that overlies the bauxite deposits (Figure 12). The Berger Formation contains thin, alternating layers of claystone, sandstone, and shale that represent shallow marine processes during the Eocene. The lowest exposed bed is a black carbonaceous shale, indicating an inland environment. From there, relative bedding thickness and abundance of four claystone layers indicated that the study site was primarily underwater. Three thin bands of oxidized ironstone were identified, indicating instances of local dewatering. A shallow marine to beach environment occurred on three occasions based on three bedding units along the highwall.

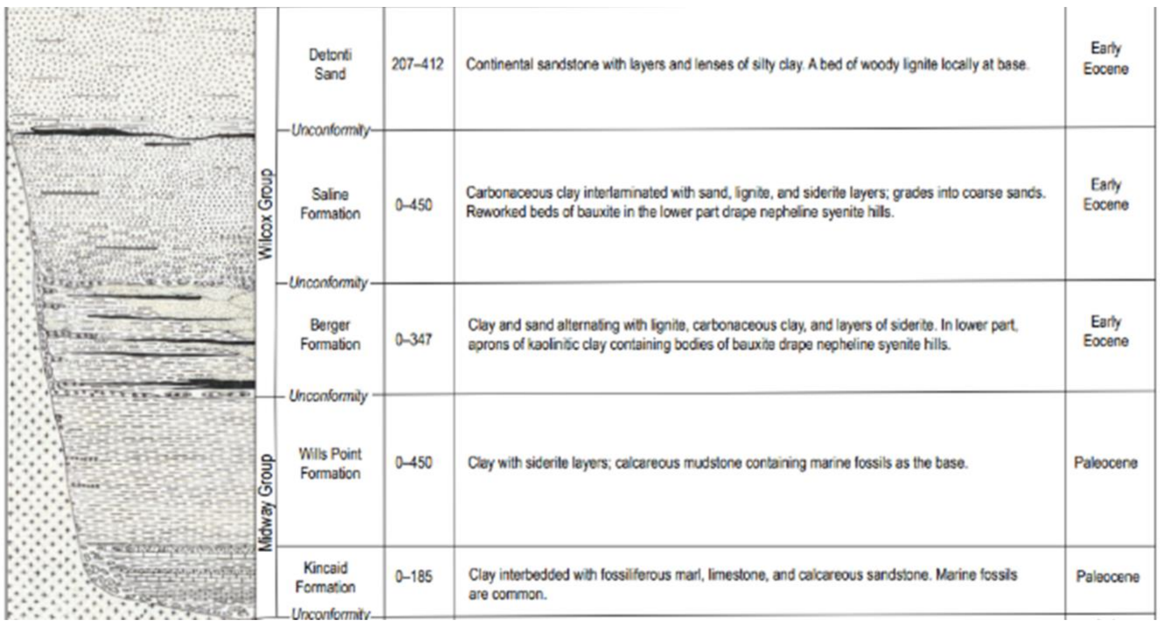


Figure 11: Stratigraphic column of the Wilcox Group in the Arkansas bauxite district (Van Gosen and Choate, 2021). Adapted from Gordon, et. al., 1958.

SIGNIFICANCE

The goal of this research was to develop a safe, efficient, and accurate industry workflow for geologic face mapping that can be replicated and advanced as technology and safety improves. This methodology would provide a consistent process for companies to gather accurate geologic data while keeping employees safe and working in accordance with safety rules and regulations regarding personnel distance from highwalls. The ability to collect closeup aerial imagery of a large area in a short duration provides an efficient way in which users can gather, manipulate, and distribute visible geologic information. Field work can be accomplished by two individuals with one acting as a spotter while the other collects field data. Users will be able to produce spatially accurate 3D models with survey-grade accurate point data without working in hazardous situations. Although this method focuses on geologic interpretation, it can be applied to other fields. The hardware and software used here are publicly available and compatible with a range of operating systems.

RESULTS

The New Braunfels Mine, South Hallsville No.1 Mine, and Alabama Mine were studied using a new geologic face mapping method. Each mine was assessed, surveyed, and modeled without requiring the participants to cross over the safety berm at the base of each highwall or come in contact with any known hazardous environment. Prior to conducting field work at each location, safety protocols were established, site specific training was completed, and weather conditions were checked in order to maintain individual safety and equipment preservation.

All three sites were assessed to determine the study area based on the available geologic information and on-site safety protocols. Each mine had site-specific data dictionaries created to efficiently collect relevant data points. The DJI Phantom 4 Pro V2.0 unmanned aircraft system (UAS) was deployed with preprogrammed missions to systematically collect photos of all three study areas. The Trimble™ Geo 7X global positioning system (GPS) unit was used to survey features along the highwalls to provide accurate locations and descriptions of the features. After field work was completed, the photos were uploaded to Agisoft Metashape Professional and processed to construct a 3D model of each site. The Trimble® GPS Pathfinder® Office software was used to process the point data features collected by the Trimble™ Geo 7X. Lastly, data from Agisoft Metashape Professional and Trimble® GPS Pathfinder® Office were uploaded to Leapfrog Geo geologic modeling software to combine the two datasets into one composite model. The work flow for each mine site and composite models are described in the following sections.

NEW BRAUNFELS MINE, LHOIST NORTH AMERICA, COMAL COUNTY, TEXAS

Pre-Survey Methods

Data Dictionary

The Lhoist North America New Braunfels Mine at 350 APG Ln, New Braunfels, TX 78132 was surveyed on June 7, 24, and July 14, 2022. Three highwalls and benches of the mine were selected for this study. Before conducting research, categories were created in the data dictionary for the Trimble™ Geo 7X GPS (Table 1). Each section underwent a task specific safety assessment to understand the risks and hazards of conducting this work, including safety hazards, their risks, and solutions (Table 2). Information about the geology of the area and a stratigraphic column (Figure 13) were compiled to create a data dictionary of the common geologic features that could be found at this site. Once completed, the dictionary was uploaded to the Trimble™ Geo 7X and tested before being used.

Table 1: Data dictionary created from Trimble® GPS Pathfinder® Office for the Trimble™ Geo 7X GPS for mapping limestone highwalls.

Features	Attributes	Menu
Bedding	Top Contact	Overburden, Top Strip, White Limestone, Shale, 31, Pit Strip, Pit Rock, Bottom Strip, Bottom Rock Upper, Bottom Rock Lower
	Bottom Contact	Overburden, Top Strip, White Limestone, Shale, 31, Pit Strip, Pit Rock, Bottom Strip, Bottom Rock Upper, Bottom Rock Lower
	Notes	Text (200 characters)
Lithology	General Lithology	Limestone, Shale
	Other	Text (30 characters)
	Notes	Text (200 characters)
Structures	Types	Karst, Collapse, Fault, Joint
	Other	Text (30 characters)
	Notes	Text (200 characters)
Hazards	Types	Loose Rock, Fractures, Erosion, Water Drainage
	Other	Text (30 characters)
	Notes	Text (200 characters)
Control Points	Notes	Text (10 characters)

Table 2: Results from the risk assessment of the study areas done prior to conducting field work.

Hazards	Risk	Solution
Heat	High	Sunscreen, protective clothing, water, breaks
Falling	Moderate	Distance from ledge
Tripping	Moderate	Attention
Tall/Aerial Obstacles	Moderate	Attention
Dust/Airborne Particulates	Moderate	ANSI safety sun goggles
Light	Moderate	ANSI safety sun goggles
Moving Equipment	Low	Attention
Rock Fall	Low	Distance from highwall
Noise	Low	Ear plugs (when necessary)

Group	Formation	Member	Layer	Thickness	Lithology	Description
Edwards Group	Person Formation	Leached and Collapsed Members	Top Strip	7		Top soil. Unconsolidated rock.
			White Limestone	26		Massive biomicrite and biosparite limestone layer. Karst features.
		Regional Dense Member	Shale	26		Brittle and platy shale layer. Karst features.
	Kainer Formation	Grainstone Member	31	31		Milliold grain supported limestone layer. Karst features, ribbon chert, and shells.
			Pit Strip	10		Weathered, iron-stained limestone layer. Karst features and a thin chert layer.
			Pit Rock	16		Oosparite fossiliferous limestone layer.
		Kirschberg Evaporite Member	Bottom Strip	19		Recrystallized oosprraritic fossiliferous limestone.
			Bottom Rock Upper	14		Massive bedded, crystallized limestone with pink chert and thin clay seams.

			Bottom Rock Lower	27		Highly recrystallized, coarse, porous limestone.

Figure 12: Stratigraphic column of the exposed mining units at the New Braunfels mine in Comal County, Texas. Compiled from drone imagery and visual analysis of rocks.

Safety Briefing

It was determined that the main hazards while working in this area of the mine were heat, falling, tripping, tall/aerial obstacles (for the UAS), dust/airborne particulates, and light. The most visible geologic features were bedding planes that separated the mining units, small collapse features, and clay seams.

Preparing the Study Area

Ten ground control points (GCPs) with assigned numbers were spray painted at each level of the study area (Figure 14) in preparation for the UAS flight. Each GCP was spread out at different elevations along the benches in order to provide the most accurate spatial data for post processing. The Trimble™ Geo 7X connected to its monopole was used to record the control points at the center of each GCP.

The Weather application on Apple IOS was used to monitor the weather patterns the day of the flight and up to minutes prior to takeoff. Both days were deemed to have acceptable flying conditions (Table 3). The AirMap application was used to submit a notice to nearby manned and unmanned aircraft systems of the flight just before takeoff. This provided information about the location, altitude, radius, and model of the UAS in flight.

Figure 13: Surveying a ground control point in the Lhoist New Braunfels study area.

Table 3: Weather information recorded prior to the UAS flight on June 7, 2022 and July 14, 2022.

June 7, 2022		July 14, 2022	
Weather	**Data**	**Weather**	**Data**
Temperature	90°F	Temperature	87°F
Visibility	5sm	Visibility	10sm
Wind Speed	<5mph	Wind Speed	<5mph
Cloud Coverage	Partly Cloudy	Cloud Coverage	Clear
Humidity	58%	Humidity	60%
Atmospheric Pressure	29.3inHg	Atmospheric Pressure	29.4inHg

Mine Survey

UAS Flight

At the bottom of the pit, two researchers constructed the DJI Phantom 4 Pro V2.0 and programmed a flight plan using a Samsung tablet with the DJI Pilot application. The flying area was set to be greater than the actual study area in order to obtain significant overlap at the edges to produce a higher quality model. The altitude was set at 60.9m above ground level (AGL) which was high enough to pass over the AOI and avoid tall and suspended obstacles, but low enough to collect higher resolution imagery. The flight speed was set to the normal recommended speed to keep the UAS battery from depleting more rapidly than necessary. The camera angle was set to 60° in order to capture the vertical face of the highwall as well as the horizontal bases and ledges of both benches. The front overlap and side overlap were set to 75/75 so as to provide significant image overlap and mitigate poor quality. An overlapping flight pattern was established to provide an opportunity for the best imagery coverage. Once the flight parameters were set, the UAS was manually flown around the perimeter of the mapping area to verify its safe distance from the tall north highwall and other potential obstacles. Next, the area directly around the drone was visually and audibly assessed to make sure the flight was safe to commence. A flight was launched for each of the three sections of the study area. Flight one of the west benches lasted 44 minutes and 35 seconds and collected 280 photos. Flight two of the northeast bench lasted 45 minutes and 23 seconds and collected 287 photos. Flight three of the north benches lasted 33 minutes and 58 seconds and collected 163 photos. A total of 730 images were captured and saved to the Phantom 4 Pro V2.0’s secure digital (SD) card.

Surveying Geologic Features

The Trimble™ Geo 7X GPS unit with the attached monopole was used to collect data along three benches in the mine on three separate dates. Adequate satellite reception (15-20 satellites) was achieved within five minutes of the unit searching. The data module within the unit used the premade data dictionary that contained geologic nomenclature specific to this study area. In preparation for data collection, researchers approached the highwall, maintaining a safe distance (35ft) from the safety berm at the base of each bench. Most information was collected in 30ft wide intervals and spanned from the ledge to the base of each highwall (Figure 15). The interval width between each section was assigned so that even if some sections of the highwall were homogenous, data would still be collected to verify the observations. The Trimble™ Geo 7X with monopole was placed on a solid, stable surface, and a single ground point was collected from an average of ten recorded positions. From there, data was collected systematically, beginning with collecting point data of the geologic bedding contacts, then other geologic information. By doing this, it was easier to identify the data in post-processing by understanding the repeating nature of the information. A total of 117 points were collected along both highwalls (Table 4).

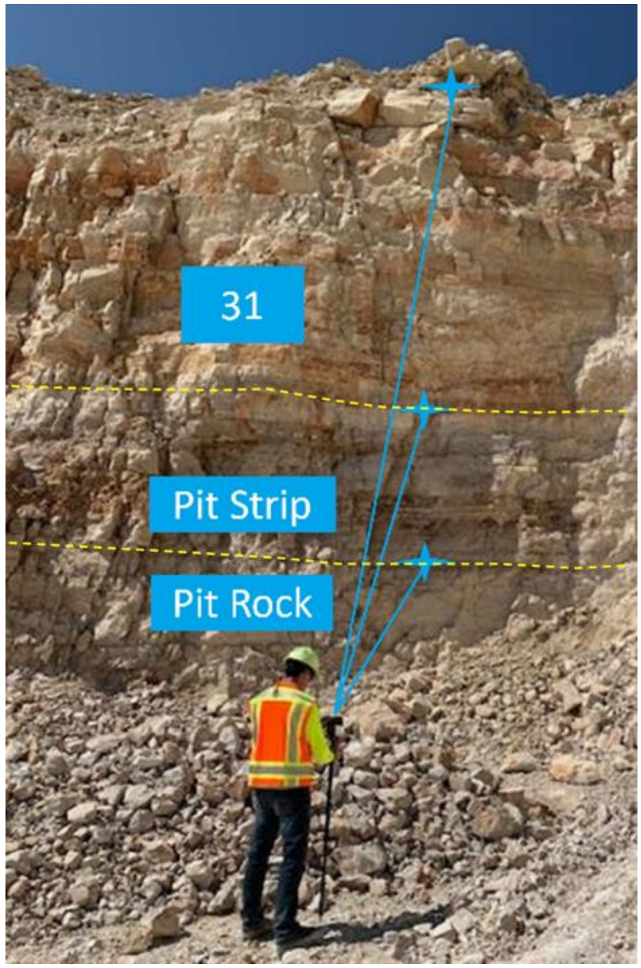


Figure 14: Bedding data point collection process with the Trimble™ Geo 7X on a section of the West bench at the New Braunfels mine.

Table 4: The quantity of points surveyed at the West benches and the Northeast benches within the study area.

Mapping Area	Surveyed Points	Date
West Benches	93	June 7, 2022
Northeast Benches	24	June 24, 2022

Sample Collection

Rocks located on the safe side of the safety berms were collected to represent each bedding unit present in the study area. The distinct color of each bedding unit made it possible to collect samples and classify them in good faith with the units in the study area. The samples, their collection location, and their geologic characteristics are described in Figure 15 below.

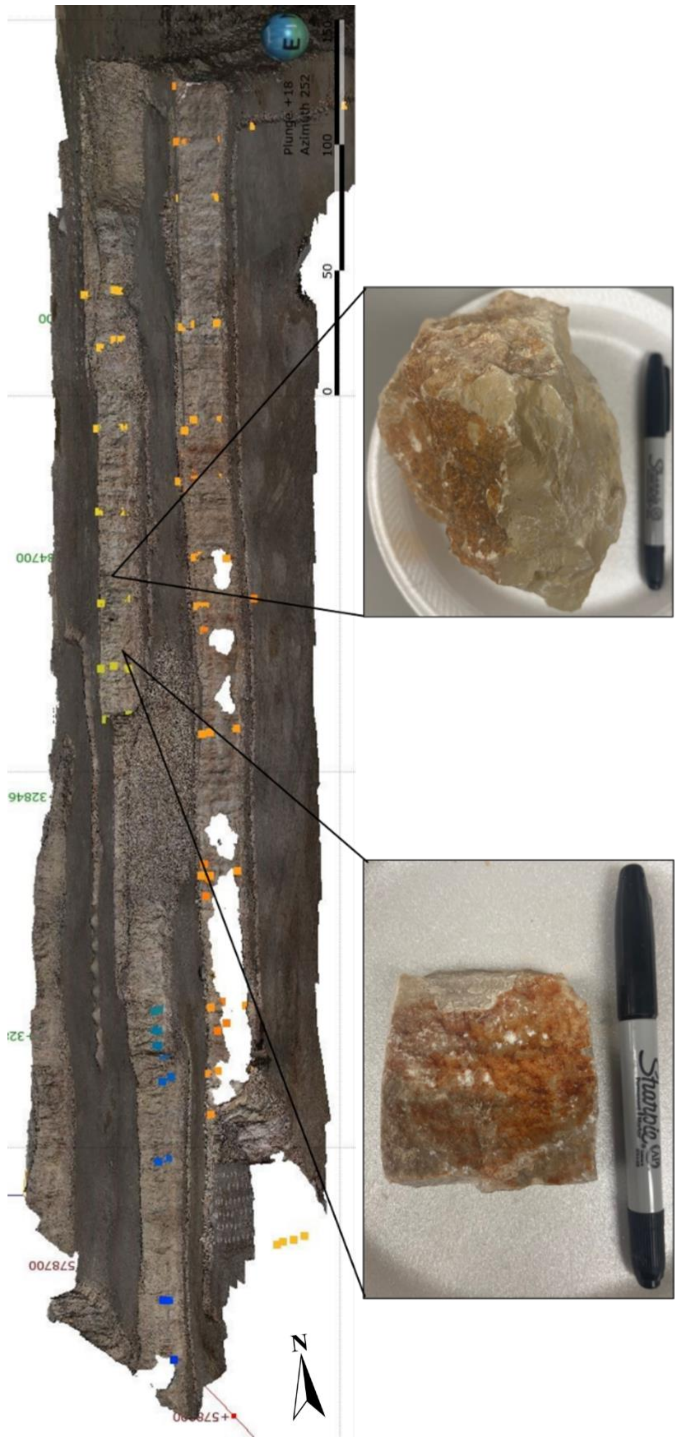


Figure 15: Two hand samples collected from the third bench of the Southwest wall. (Left) is from the middle mining unit, distinctive by its red color iron oxide content. (Right) is from the upper mining unit, distinctive by its yellowish tan color and lack of fossils.

Post-Survey Processing

Processing Geologic Point Data

Point data was uploaded to Trimble® GPS Pathfinder® Office where the data was corrected. This process connected 128 points to the COR station located in Seguin, TX (USA)(offline) base station, located 21km away from the point locations with an integrity index of 94.55 (Table 5). The corrected point data was converted into a .cor file, which contains a corrected standard storage file that has undergone differential postprocessing. The .cor file contains each point's specific identification number, latitude and longitude coordinates, and elevation.

Table 5: The estimated accuracy for 128 points collected with the Trimble™ Geo 7X.

Range	Percentage
0-5cm	100.00%
5-15cm	Null
15-30cm	Null
30-50cm	Null
0.5-1m	Null
1-2m	Null
2-5m	Null
>5m	Null

Rectifying UAS Imagery

The study area from the flight was divided into three datasets so that the software could operate more efficiently. Each area was georeferenced using coordinates collected from the Trimble™ Geo 7X and matched the ground control points with their specific coordinates. Some areas had a lack of point coverage, noticeably the face of the bottom bench in Figure 16. This was caused by clouds that created shadows on the west bench which significantly inhibited the modeling process of those areas. Some of the affected areas contained enough information to fill in surrounding null data in order to build a more complete model, but these filled areas are not supported by adequate point data and the user should exercise caution when interpreting the results.

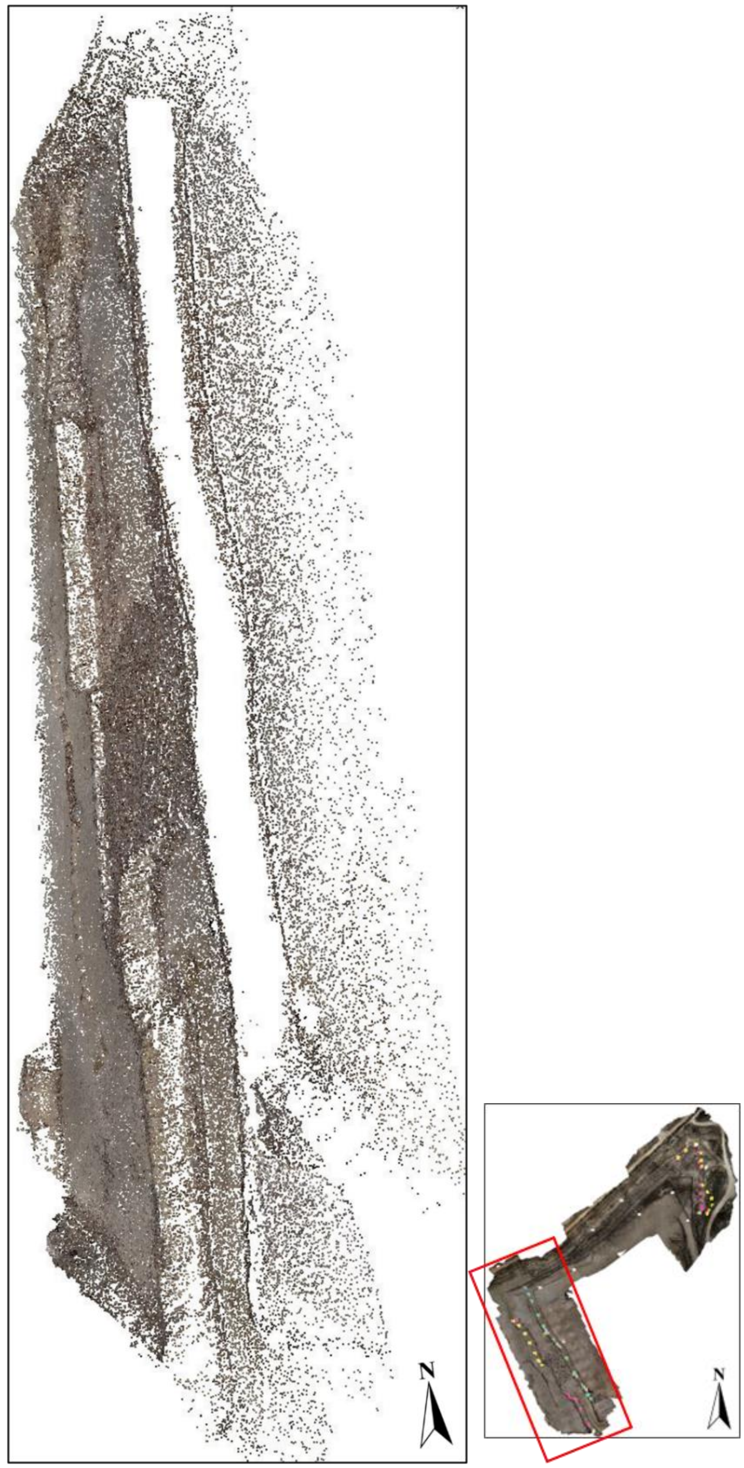


Figure 16: The sparse point cloud model of the Southwest study area, produced in Agisoft Metashape Professional. The first step in the model development process.

The dense cloud model (Figure 17) was less successful at capturing the vertical highwalls, but successfully rendered the tops and bottoms of each bench. The mesh model was then constructed (Figure 18), it altered the model by filling in all areas with limited point data to lessen or remove white space. Model confidence was used for the dense cloud in Figure 19 and for the mesh model in Figure 20 to assess the accuracy of both models. Based on both confidence figures, the bottom bench face was not rendered into the model correctly because of the limited data used to generate the imagery. The rest of the model was assembled correctly based on the model confidence and the clarity of the imagery. The number of points that it took to render each type of model was calculated (Table 6). Once the model was completed, a tag image file (.tif) was exported for the model image. A block model was exported as an object file (.obj), which contained geometric data of 3D objects in a vector format.

Figure 17: The dense cloud model of the Southwest study area produced in Agisoft Metashape Professional. The second step in the model development process.

Figure 18: Mesh model of the Southwest study area in Agisoft Metashape Professional. The third step in the model development process.

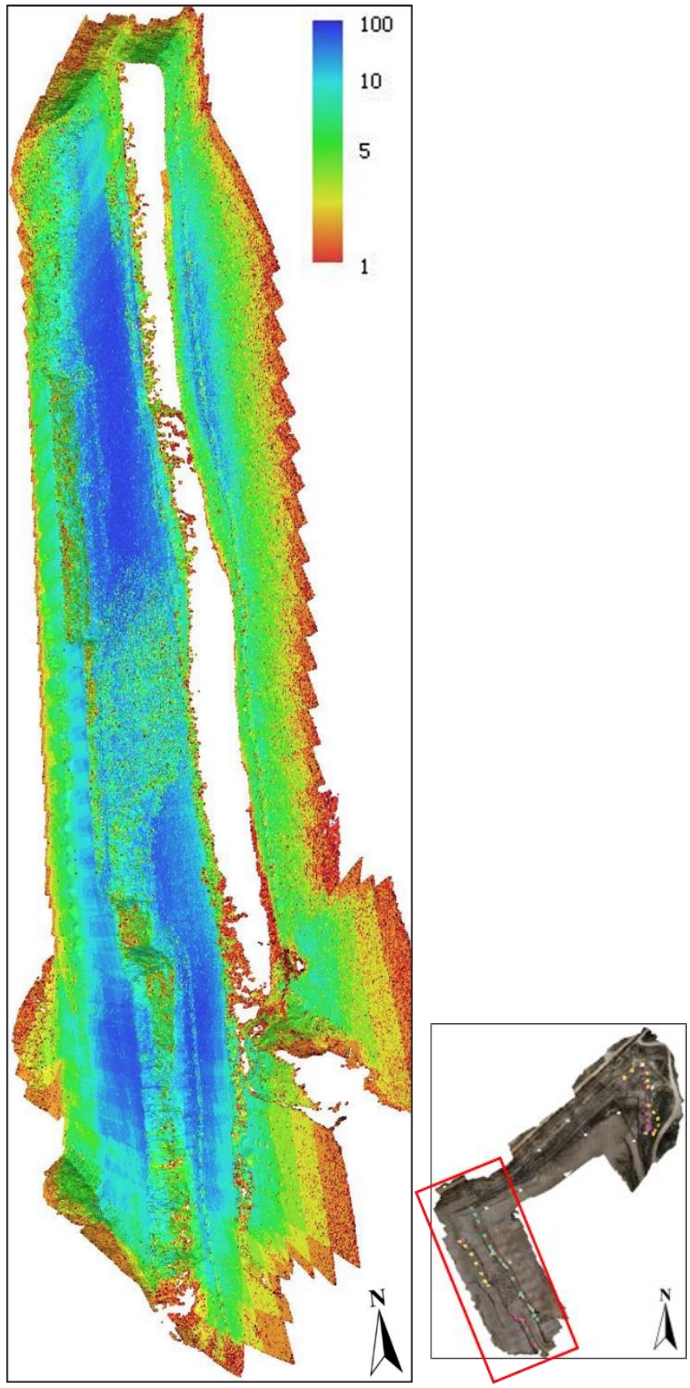
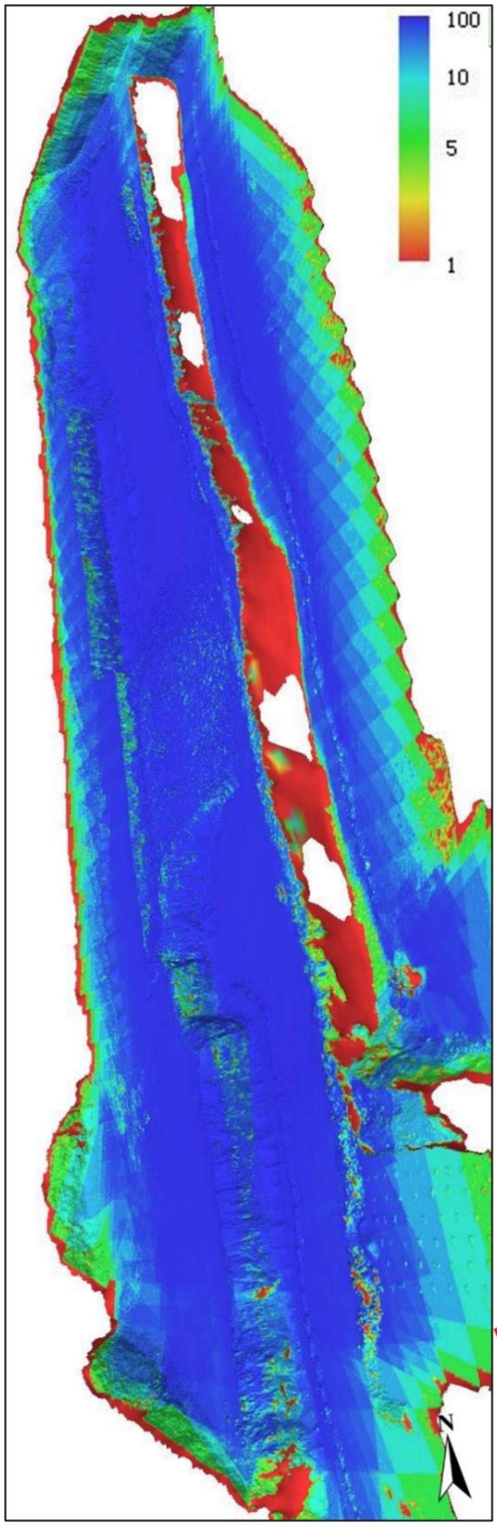


Figure 19: Dense cloud confidence model of the Southwest study area produced with Agisoft Metashape Professional. The color ramp indicates the amount of coverage created by the model, with red being the least and blue being the highest coverage. The higher the coverage the more accurate the model is to the original imagery.



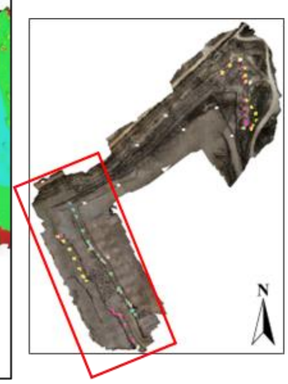


Figure 20: Mesh confidence model of the Southwest study area in Agisoft Metashape Professional.

Table 6: Combined data from all three model sets from the North face, Northeast face, and Southwest face at the New Braunfels mine in Comal County, Texas.

Feature	Results
Sparse Cloud Points	781,947
Dense Cloud Points	105,050,861
Mesh Model Faces/Vertices	18,273,068/7,996,434

Geologic Block Models

A block model, imagery, and data points were exported to Leapfrog Geo geologic modeling software to create an interactive model. The block model and overlayed orthomosaic imagery were exported from Agisoft Metashape Professional. The model was placed in the "Mesh" folder and the orthomosaic was added to a subset of the same folder. The point data was exported from Trimble® GPS Pathfinder® Office into the "Points" folder. Data points were characterized based on their upper geologic contact which helped to distinguish the lithology of each bench as well as the major weathering effects in the AOI. A total of 117 points were collected describing the geologic features including: collapse structures, karst, bedding, and safety hazards that were surveyed within the AOI (Figure 21). After analyzing the model, four survey points were discarded because they were outside of the AOI. The data points were appropriately marked and divided by upper bedding unit contacts, erosion patterns, and control points. The North section (Figure 22), Northeast section (Figure 23), and West section (Figure 24) were combined and overlayed with data points, which finalized the model.

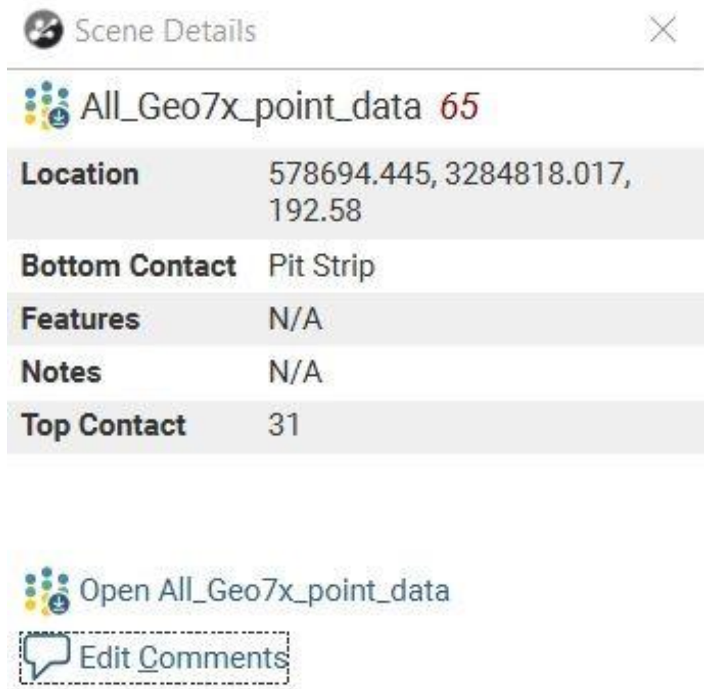


Figure 21: Scene details from data point #65 with bedding information, Northing and Easting coordinates, elevation, features, and notes data from Leapfrog Geo.

Figure 22: New Braunfels mine composite model viewing the North wall from Leapfrog Geo. This shows a portion of the final model with geologic data points collected from the Geo 7X GPS unit.

Figure 23: New Braunfels mine composite model viewing the Northeast wall in Leapfrog Geo.

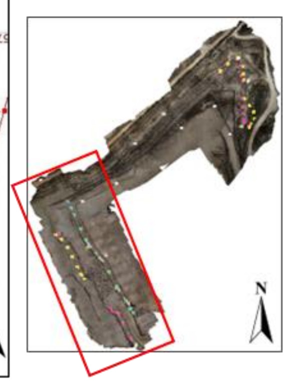


Figure 24: New Braunfels mine composite model viewing the Southwest wall in Leapfrog Geo.

The composite model produced a spatially accurate, interactive model (Figure 25). There was some difficulty overlaying the point data with the model because some points were partially covered by the block model, but this problem was a rarity and primarily occurred where the model was disrupted attempting to render the vegetation. The model has lower resolution when zoomed in within five feet of the surface (Figure 26) due to the loss of resolution when the draped .tif image was exported from Agisoft Metashape Professional to Leapfrog Geo.

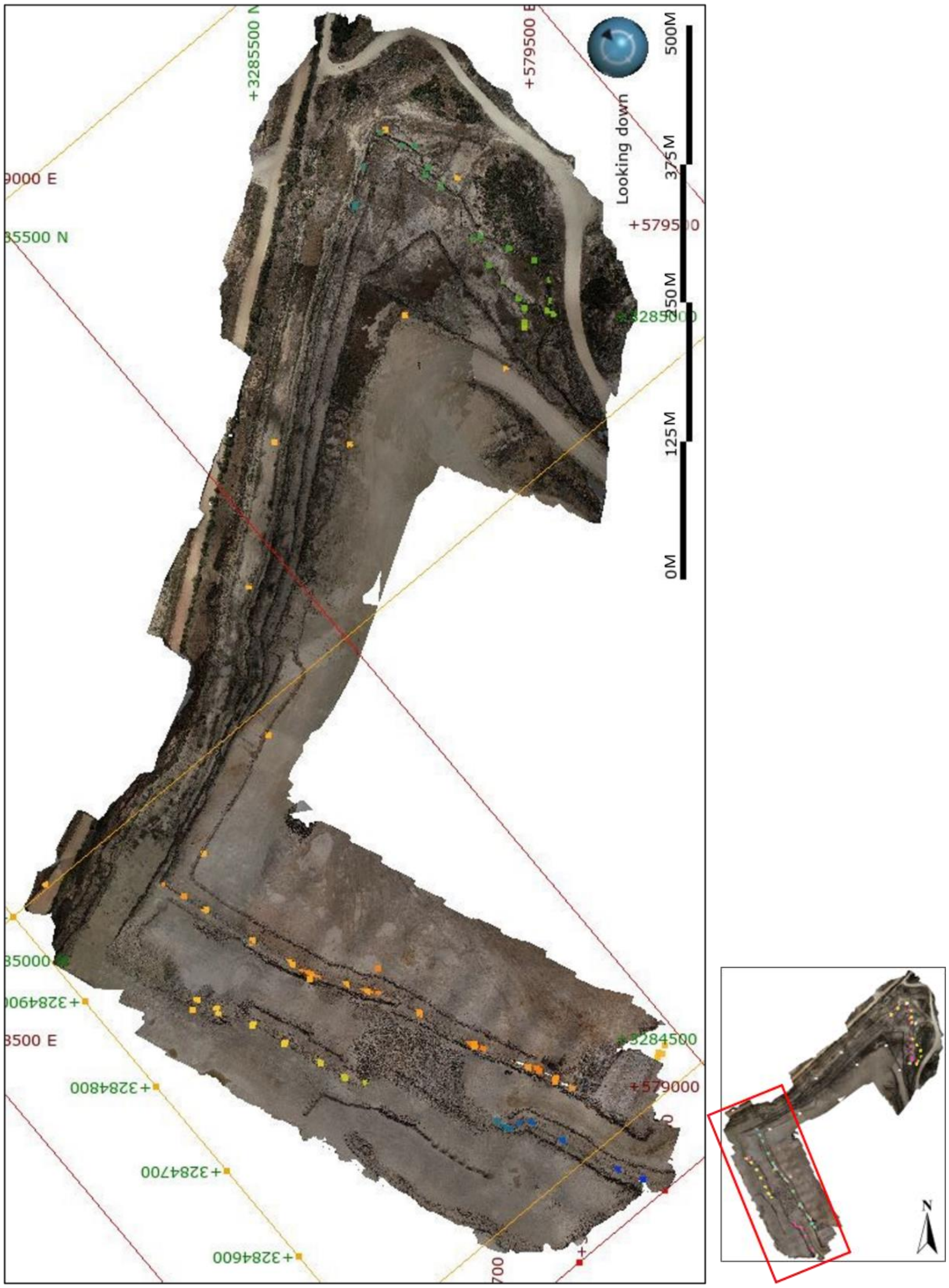


Figure 25: Plan view of the New Braunfels Mine model in Leapfrog Geo.

Figure 26: The model appearance from three feet away. The colors and shapes of the model are blended and distorted showing the minimum distance that the model is accurate to.

SOUTH HALLSVILLE NO.1 MINE, NORTH AMERICAN COAL, SABINE MINING COMPANY, HARRISON COUNTY, TEXAS

Pre-Survey Methods

Data Dictionary

The South Hallsville No. 1 Mine, located at 6501 Farm Road 968 West, Hallsville, TX 75650-7413 is an open pit lignite mine. The mine is owned by the North American Coal Corporation and operated by the Sabine Mining Company. The study area location was chosen based on the light exposure from the sun during the data collection process and because of the variety of data that could be collected in a reasonably sized study area. A data dictionary was created for the Trimble™ Geo 7X as a means of expediting the data collection process by compiling information likely to be found at this site (Table 7).

Table 7: This table displays the contents of the data dictionary created from Trimble® GPS Pathfinder® Office for the Trimble™ Geo 7X for the South Hallsville No.1 Mine.

Features	Attributes	Menu
Bedding	Top Contact	SD1, SD2, OBU, L WHI, CL, L GRN, L GRNU, PCL, L GRNL, IBU, ICL, L SIL, ISD1, ISD2, L RS, L TN, L BRN, L BRNU, L BRNL, L RED, L REDU, L REDM
	Bottom Contact	SD1, SD2, OBU, L WHI, CL, L GRN, L GRNU, PCL, L GRNL, IBU, ICL, L SIL, ISD1, ISD2, L RS, L TN, L BRN, L BRNU, L BRNL, L RED, L REDU, L REDM
	Notes	Text (200 characters)
Lithology	General Lithology	Sandstone, Siltstone, Claystone, Lignite, Interbedded, Silty Clay, Clay
	Other	Text (30 characters)
	Notes	Text (200 characters)
Structures	Types	Fault, Collapse, Karst, Joint, Oxidized Unit, Soft Sediment Deformation, Crossbedding, Seep
	Other	Text (30 characters)
	Notes	Text (200 characters)
Hazards	Types	Rock Fall, Loose Rock, Fractures, Erosion, Water
	Other	Text (30 characters)
	Notes	Text (200 characters)
Control Points	Notes	Text (10 characters)

Safety Briefing

The study area within the South Hallsville No.1 Mine was visibly and audibly assessed for safety concerns before completing any field work. After the site safety briefing, the highwalls were analyzed to identify the main types of geologic features present in the AOI as well as other miscellaneous data that might need to be recorded (Table 8).

Table 8: Potential hazards for researchers and equipment while working within the mine.

Hazards	**Risk**	**Solution**
Rock Fall	High	Distance from highwall
Tall/Aerial Obstacles	High	Attention
Tripping	Moderate	Attention
Cold	Moderate	Layered clothing
Light	Moderate	ANSI safety sun goggles
Falling	Low	Distance from ledge
Moving Equipment	Low	Attention
Noise	Low	Ear plugs (when necessary)
Dust/Airborne Particulates	Low	ANSI safety sun goggles
Heat	Low	Breaks, water

Based on the preliminary assessments, the main safety risks that might be encountered while collecting field data were rock falls and tall objects. The highwalls in the study area contained visible bedding planes, oxidation horizons, and seeps (Figure 27). Multiple hazards were identified on and off the highwall. This information could easily be collected and modeled due to the size of the AOI and the variations in bedding color, bedding composition, and stability of the highwall (Figure 28). After the initial analysis of the study area was completed, data collection began.

Group	Formation	Layer	Thickness	Lithology	Description
Wilcox Group (undivided)	Reklaw	IBU	8		Consolidated sedimentary unit comprised of sandstone, siltstone, and claystone. Wavy bedding. Biological weathering at the surface.
		L RS	1		Lignite coal.
		IBU	13		Consolidated sedimentary unit comprised of sandstone, siltstone, and claystone. Orange iron oxide seep. Some areas of wavy bedding.
		L TN	2		Lignite coal.
		IBU	12		Consolidated sedimentary unit comprised of sandstone, siltstone, and claystone. Wavy bedding and ball and pillow structures.
		L BRN	4		Lignite coal.
		IBU	15		Consolidated sedimentary unit comprised of sandstone, siltstone, and claystone.

Figure 27: Stratigraphic column of the study area face at the South Hallsville No.1 Mine in Rusk County, Texas. Data was compiled from drone analysis and mine information.

Figure 28: The South Hallsville No.1 Mine study area (right side highwall), Rusk County, Texas.

Six GCPs were marked and numbered with green and orange spray paint and then surveyed with the Trimble™ Geo 7X. GCPs one through three were placed at the top of the highwall above the pit while completing the preliminary analysis. GCPs four through six were placed at the bottom of the pit, below the highwall.

Mine Survey

Surveying Geologic Features

The point data was gathered first due to poor sun exposure on the AOI. The Trimble™ Geo 7X with the monopole was assembled and set up with the Sabine Data Dictionary, loaded with specific information to improve the efficiency of the data collection process (Figure 29). Data was collected along the length of the AOI using the laser rangefinder (Figure 30). Each time a point was surveyed on the ground, ten positions would be taken at an interval of one position per second. After the survey was completed, 1110 positions were collected. Point data collection was completed in two hours.

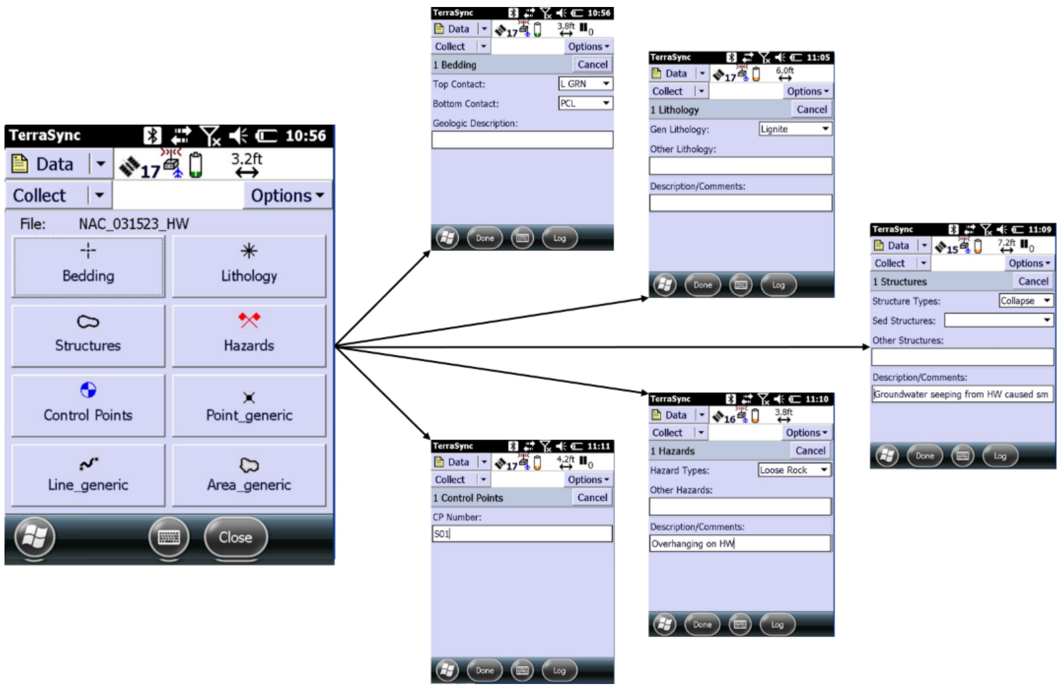


Figure 29: The button layout and associated menu system on the Trimble™ Geo 7X designed for the South Hallsville No.1 Mine.

Figure 30: The laser rangefinder on the Trimble™ Geo 7X being used to collect geologic point data along the quarry highwall.

UAS Flight

By 12:00 p.m., the AOI was determined to be at maximum illumination for the conditions that day, with about 50% of the highwall illuminated by the sun. The environmental conditions were appropriate to conduct the UAS flight so the Phantom 4 Pro V2.0 was assembled and a preprogrammed flight was prepared (Table 9). Poor satellite reception within the pit did not allow the base map to be loaded while planning the flight map, and establishing an Airmap was not possible. The flight was setup to begin a double overlap flight mission at 190ft AGL. Nine flights took place over the area of interest (Figure 31). Prior to each flight, the perimeter of the study area was manually flown to assure that the flight paths were safe and avoided obstacles. Collectively, each preprogrammed flight successfully mapped the AOI with significant coverage to adequately map the faces. Six battery changes occurred during the entire flight process. The total combined flight time was 71 minutes and 50 seconds and collected 248 photos of the study area.

Table 9: Weather data recorded prior to the UAS flight at the South Hallsville No.1 Mine in Rusk County, Texas.

Weather	**Data**
Temperature	55°F
Visibility	5sm
Wind Speed	8mph
Cloud Coverage	Partly Cloudy
Humidity	45%
Atmospheric Pressure	30.2inHg

Figure 31: Phantom 4 Pro V2.0 prior to a preprogrammed flight of the study area.

Sample Collection

Two rock samples were collected from the study area (Figure 32). A displaced piece of petrified wood found at the surface above the pit and lignite from the L Red seam at the base of the pit. Additional specimens could not be collected because they were located behind the safety barrier and there were no available alternatives to collect them. Because of this, it would have been challenging to correlate the displaced rock with its in-situ source due to the number of layers.

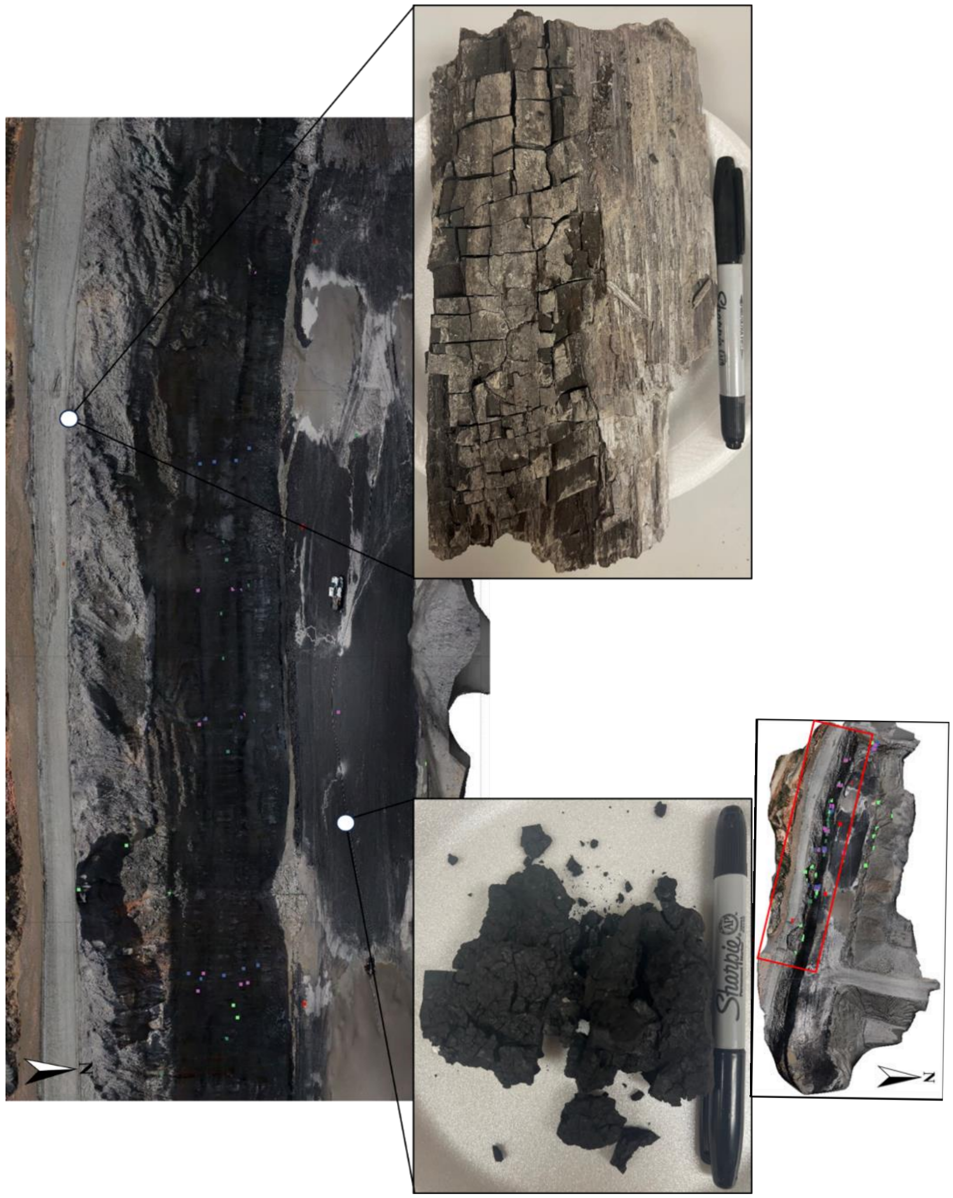


Figure 32: Two samples were collected from the South Hallsville No.1 Mine. (Left) Lignite ore collected at the base of the study area. (Right) Petrified wood with lignite collected from the top of the study area.

Post-Survey Processing

Rectifying UAS Imagery

A total of 248 aerial images were downloaded onto a computer and then uploaded to Agisoft Metashape Professional. Each model below was derived from Agisoft Metashape Professional as the final model was being constructed (Table 10). The sparse point cloud (Figure 33) connected the same feature in multiple overlapping images to create tie points which constructed the initial model. Next, the dense cloud was created by calculating depth information from camera positions (Figure 34). From there the mesh model was constructed to build the full model (Figure 35). The confidence models from the dense cloud (Figure 36) and the mesh model (Figure 37) were then analyzed to verify that the coverage of the UAS flights were enough to build a full model.

Table 10: The tie points, faces, and vertices used to create each type of model for the South Hallsville No.1 Mine in Rusk County, Texas.

Feature	Results
Sparse Cloud Points	360,827
Dense Cloud Points	26,693,472
Mesh Model Faces/Verticies	1,143,158/571,786

Figure 33: Sparse cloud model of the South Hallsville No.1 study area.

Figure 34: Dense cloud model of the South Hallsville No.1 study area.

Figure 35: Mesh model of the South Hallsville No.1 study area.

Figure 36: Dense cloud confidence model of the South Hallsville No.1 study area.

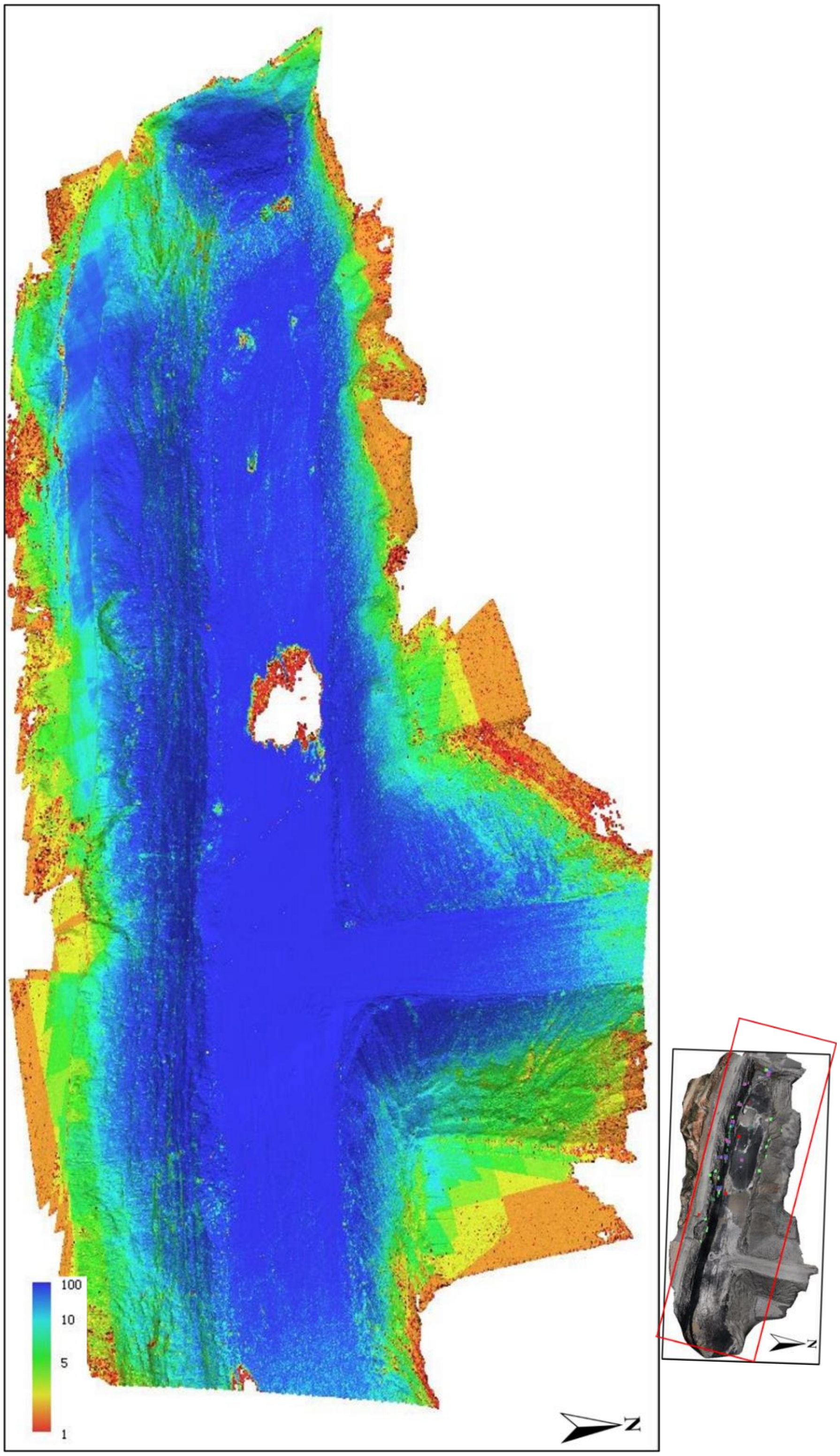


Figure 37: Mesh confidence model of the South Hallsville No.1 study area.

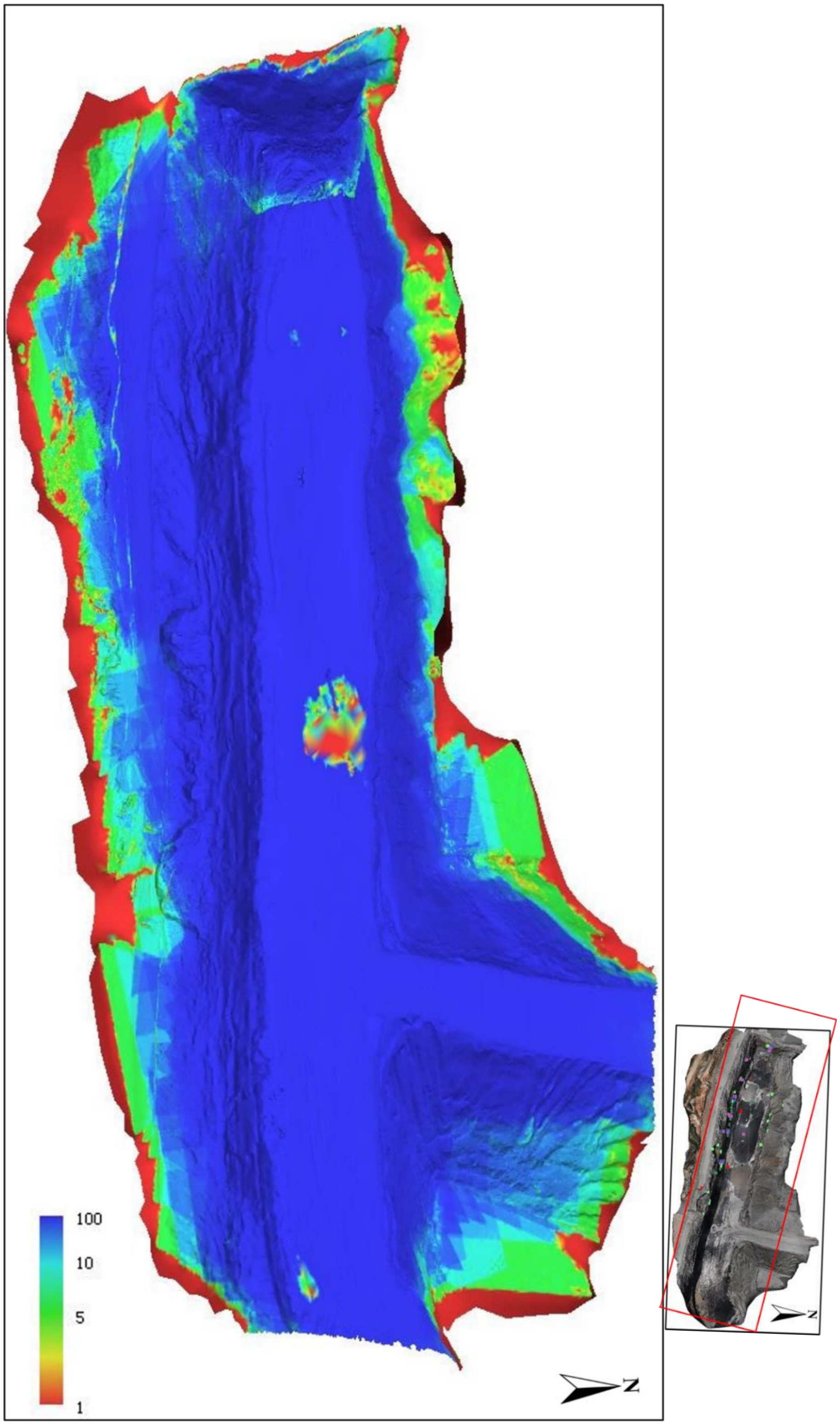


Figure 37: Mesh confidence model of the South Hallsville No.1 study area.

Processing Geologic Point Data

Point data was uploaded to Trimble® GPS Pathfinder® Office and 1,110 positions were processed from 111 survey marks that were collected from the study area. These points were downloaded on a computer and uploaded to Trimble® GPS Pathfinder® Office to be processed and refined (Table 11). The CORS, Marshall, TX (TXMA), Texas (offline) base station was used to process this data. It is located 32km from the study area, has an acceptable integrity index of 94.31, covers 100% of the study area, and is 0.91m from the base provider.

Table 11: The point location accuracy of the 111 surveyed data points captured from the collection process.

Range	**Percentage**
0-5cm	20.36%
5-15cm	68.56%
15-30cm	3.60%
30-50cm	4.77%
0.5-1m	2.70%
1-2m	Null
2-5m	Null
>5m	Null

Geologic Block Models

The block model .obj and the stitched orthomosaic .tif were uploaded to Leapfrog Geo. The model was added to the mesh folder where the orthomosaic was opened as a draped image. From there, the full Agisoft model was dragged and dropped in the scene view where it could be viewed and manipulated.

The corrected data points from *Trimble® GPS Pathfinder® Office* were uploaded to the points folder and categorized by their assigned attributes, such as coordinates, bedding, structures, lithology, hazards, or others. Next, the information was processed and imported into the scene view. The points were color coded based on their attribute, this could be changed later depending on the type of data needed. In the final model, each point can be selected by clicking on it, which opens a menu with information about the geology, location coordinates, and any notes made while collecting the data in the field.

The final composite model retained spatial accuracy with the overlapping point data and model because the same coordinate system was used. The map was analyzed from each direction to assess the quality of the model from the top down (Figure 38), North (Figure 39), and South (Figure 40). Imagery can be blurry when zoomed in very close because image resolution deteriorates when exported from Agisoft into Leapfrog. The point data also acted as validation to the model imagery (Figure 41).

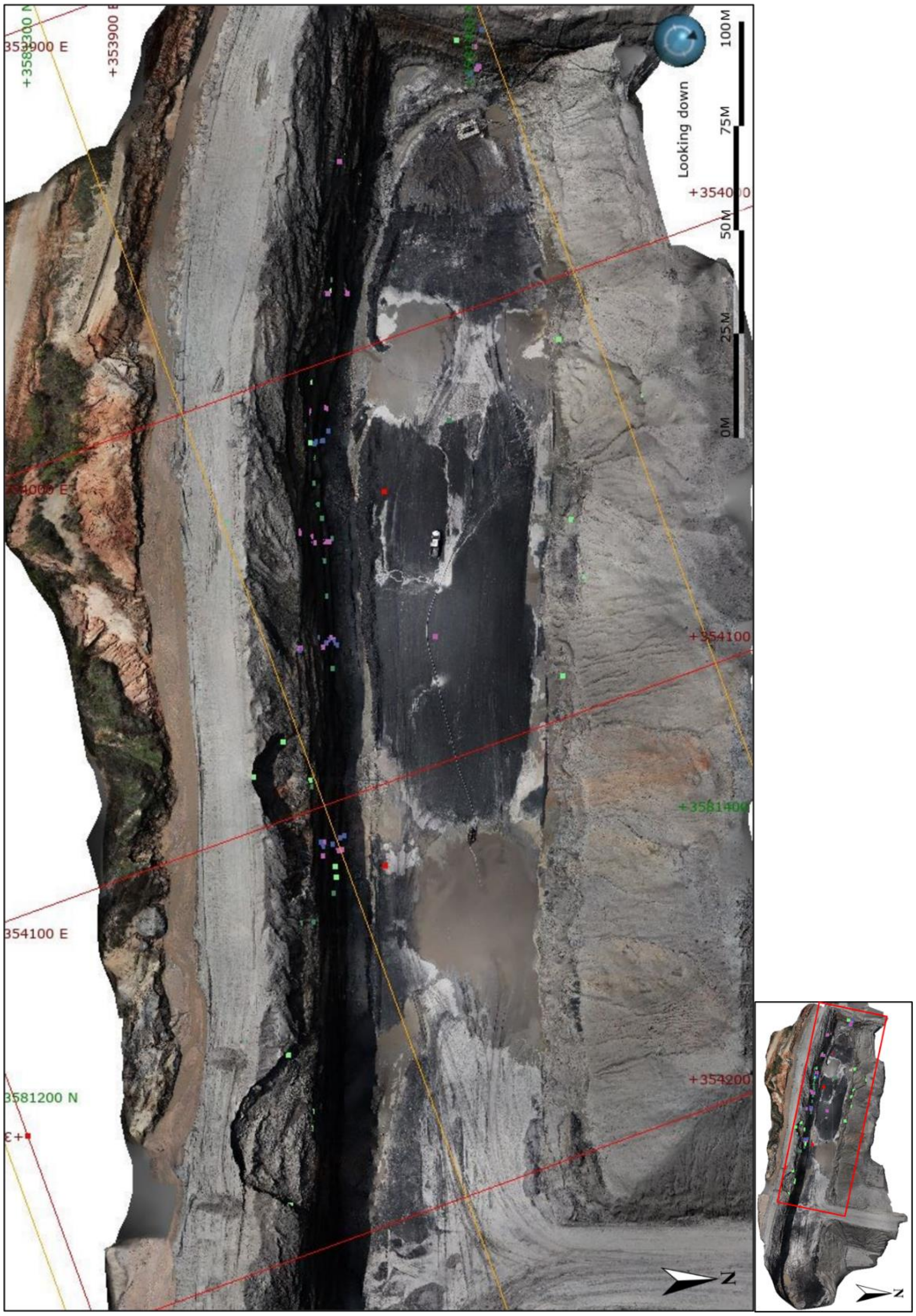


Figure 38: Plan view of the South Hallsville No.1 Mine study area.

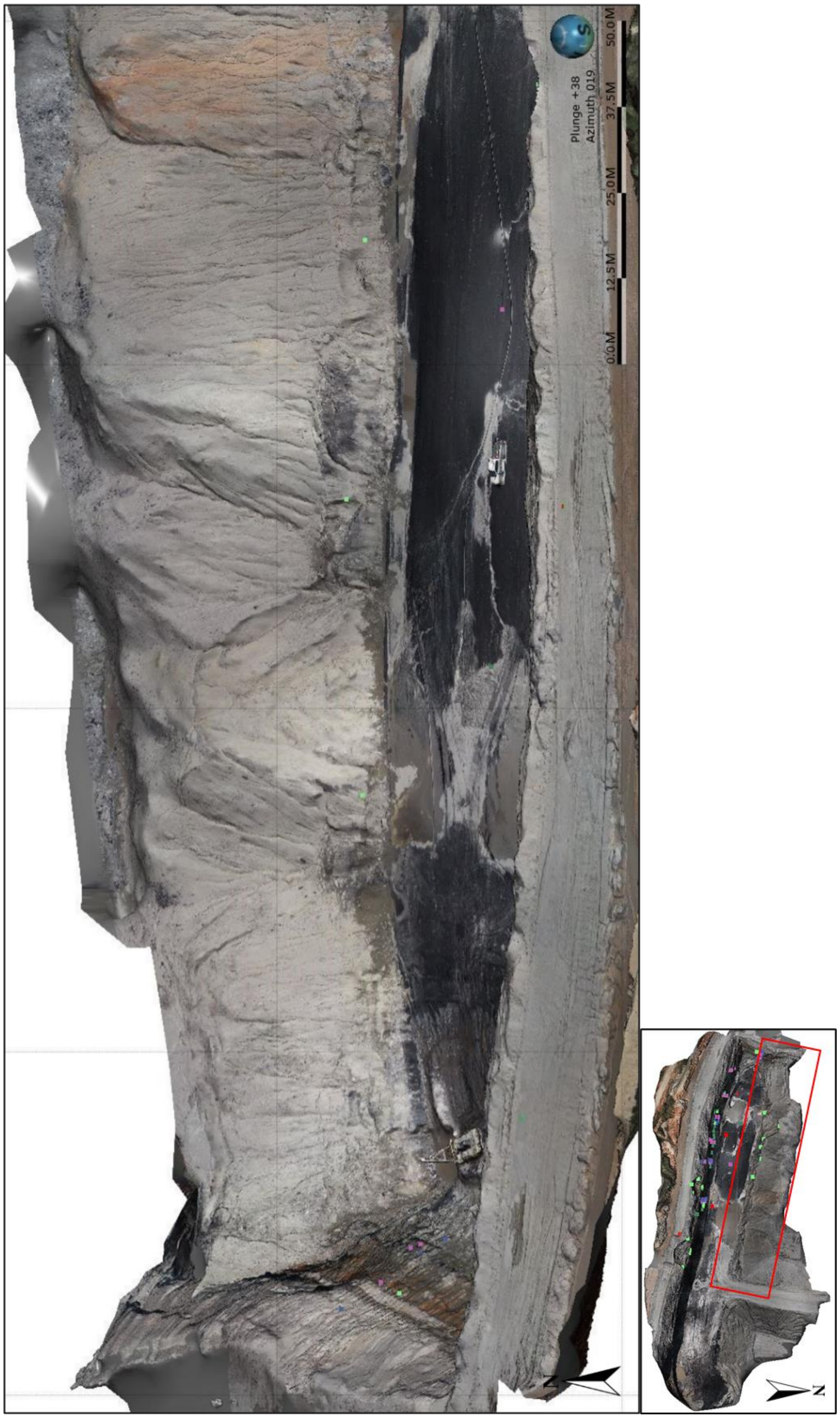


Figure 39: Looking North at the study area at the South Hallsville No.1 Mine.

Figure 40: Looking South at the study area at the South Hallsville No.1 Mine.

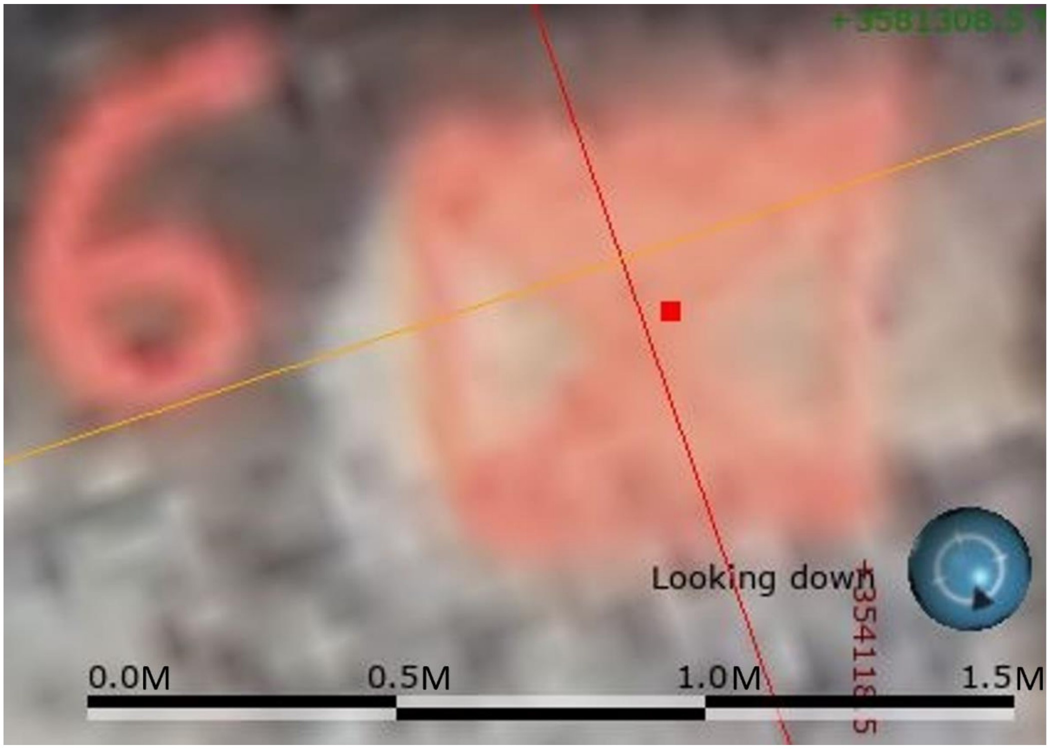


Figure 41: Plan view of control point S06 with the Trimble™ Geo 7X control point data overlayed at the bottom of the South Hallsville No.1 Mine.

ALABAMA MINE, ALCOA, MCGEORGE CONTRACTING CO., SALINE COUNTY, ARKANSAS

Pre-Survey Methods

Data Dictionary

The Alcoa Alabama Mine, located at 1401 Bauxite Cutoff Rd, Bauxite, Arkansas 72011, is an open pit bauxite mine that is owned by the Alcoa Corporation and mined by McGeorge Contracting Co. Prior to conducting research at the site, a data dictionary was set up for the Trimble™ Geo 7X so that some common information could be added to expedite the process of data collection. Preliminary information was accessed from geologic papers, conversations with the mine staff, and analyzing open-source geologic data. From that information, the dictionary was created in Trimble® GPS Pathfinder® Office and uploaded to the Trimble™ Geo 7X GPS unit. The types of data created for this dictionary are seen in Table 12.

Table 12: The features and their subdivided groups programmed in Trimble® GPS Pathfinder® Office for the Trimble™ Geo 7X to map the Alabama Mine in Saline County, Arkansas.

Features	**Attributes**	**Menu**
Bedding	Top Contact	Sandstone, Ironstone, Shale, Claystone, Gravel, Sand, Clay
	Bottom Contact	Sandstone, Ironstone, Shale, Claystone, Gravel, Sand, Clay
	Notes	Text (200 characters)
Lithology	General Lithology	Sandstone, Ironstone, Shale, Claystone, Gravel, Sand, Clay
	Other	Text (30 characters)
	Notes	Text (200 characters)
Structures	Sediment Structures	Soft Sediment Deformation, Oxidized Zone, Crossbedding, Seep
	Other	Text (30 characters)
	Notes	Text (200 characters)
Hazards	Types	Rock Fall, Loose Rock, Fractures, Erosion, Water Drainage, Land Slides
	Other	Text (30 characters)
	Notes	Text (200 characters)
Control Points	Notes	Text (10 characters)

Safety Brief

This area was surveyed on May 2, 2023. The study area was assessed to identify safety hazards that could endanger the researchers or equipment (Table 13). Geologic features and other miscellaneous data in the AOI were assessed to locate primary areas of focus when collecting data. This study area did not have many hazards, the most serious hazard was determined to be fall risks as the benches are not very wide. The most visible geologic features found in the study area were the sedimentary bedding features and soft sediment deformation. Some natural and man-made hazards were visible as well as vegetation which has been growing on the benches due to a prolonged lapse of mine activity at this locality (Figure 42). A stratigraphic column of the AOI was developed prior to conducting the point data or UAS work (Figure 43).

Table 13: Potential hazards for researchers and equipment while conducting research within the study area.

Hazards	**Risk**	**Solution**
Tall/Aerial Obstacles	Moderate	Attention
Tripping	Moderate	Attention
Light	Moderate	ANSI safety sun goggles
Falling	Moderate	Distance from ledge
Heat	Moderate	Breaks, water
Rock Fall	Low	Distance from highwall
Cold	Low	Layered clothing
Moving Equipment	Low	Attention
Noise	Low	Ear plugs (when necessary)
Dust/Airborne Particulates	Low	ANSI safety sun goggles

Figure 42: The Alabama Mine study area, Saline County, Arkansas. The 11 bedding units here make up the five mining benches pictured.

Group	Formation	Layer	Thickness (ft)	Lithology	Description
Wilcox Group	Berger Formation	Sandstone	7		Sandstone. Pebble to fine grain. Interbedded seams of iron rich sandstone.
		Ironstone	1		Ironstone. Wavy bedding.
		Claystone	12		Claystone. Fine to very fine grain. Interbedded iron rich clay lenses.
		Claystone	8		Sandy claystone. Fine to very fine grain. Channel fill structures.
		Claystone	10		Claystone. Fine to very fine grain. Compacted and brittle.
		Sandstone	3		Clay-rich sandstone. Fine to very fine grain.
		Ironstone	0.5		Ironstone. Wavy bedding.
		Sandstone	15		Sandstone. Pebble to fine grain. Channel fill structures and soft sediment deformation.
		Ironstone	0.5		Ironstone. Wavy bedding. Specular hematite.
		Claystone	1		Silty claystone. Medium to fine grain. Wavy ball and pillow structures.
		Carbonaceous Shale	22		Carbonaceous shale. Channel fill structures and soft sediment deformation.

Figure 43: Stratigraphic column of the study area face at the Alabama Mine in Saline County, Arkansas.

Five GCPs were placed in the area of interest. Two were placed near the base of the study area, two were placed on benches halfway up the area, and one was placed at the top of the study area. This was done to provide an accurate representation of the elevation gain in the area for the 3D model.

Mine Survey

UAS Flight

The UAS flight was conducted first because the study area was visible with ambient sunlight, limiting shadows on the highwalls. The environmental conditions were deemed safe for conducting the flight (Table 14). The flight area was spread over the AOI with a double overlap flight pattern. The area was 80.8m by 107m with an estimated flight time of 22min 11s. The flight altitude was set to 42.7m above ground level (AGL) which provided a safe distance from nearby trees, powerlines, and hills. The ground sample distance (GSD) was calculated at 1.65cm/pixel. From here the advanced settings were manipulated to best perform this flight. The camera was set to a 45° angle in order to capture the maximum amount of data on the highwalls. The front and side overlaps were both set to 80% to thoroughly cover the study area and collect accurate data. The picture trigger mode was set to safe mode. The drone speed was set to normal (7.6m/s), with alternatives being slow and fast. The white balance was set to sunny to properly account for the current conditions. The mission was launched and lasted 22 minutes and 55 seconds and collected 153 photos.

Table 14: The weather data recorded prior to flying a UAS mission at the Alabama Mine in Bauxite, Arkansas.

Weather	**Data**
Temperature	72°F
Visibility	10sm
Wind Speed	8mph
Cloud Coverage	Sunny
Humidity	25%
Atmospheric Pressure	29.87inHg

Surveying Geologic Features

The Trimble™ Geo 7X GPS unit was connected to its monopole and used to conduct point data collection along each highwall moving up the hill (Figure 44). Sections of each highwall (6.1m tall) were surveyed at a time, marking one ground position before gathering data on the wall. Bedding plane contacts in between rock units were the most common attributes due to the number of rock layers within the study area. Contacts were marked with a point every 3m unless the contact was considerably deformed, in which case a series of points were marked to adequately map the deformity. Deformation features were identified in some of the sedimentary rock units that were large enough to be surveyed. Crossbedding was identified by marking one or multiple points along the center of the crossbedded planes. Geohazards were marked with single points where the source of the hazard was located in order to mitigate confusion of the location. Vegetation was marked with single points for small or single swaths of vegetation while larger vegetated areas were marked with multiple points circling the perimeter of the group. All features in the study area were documented with 69 data points in 1hr and 41min (Table 15).

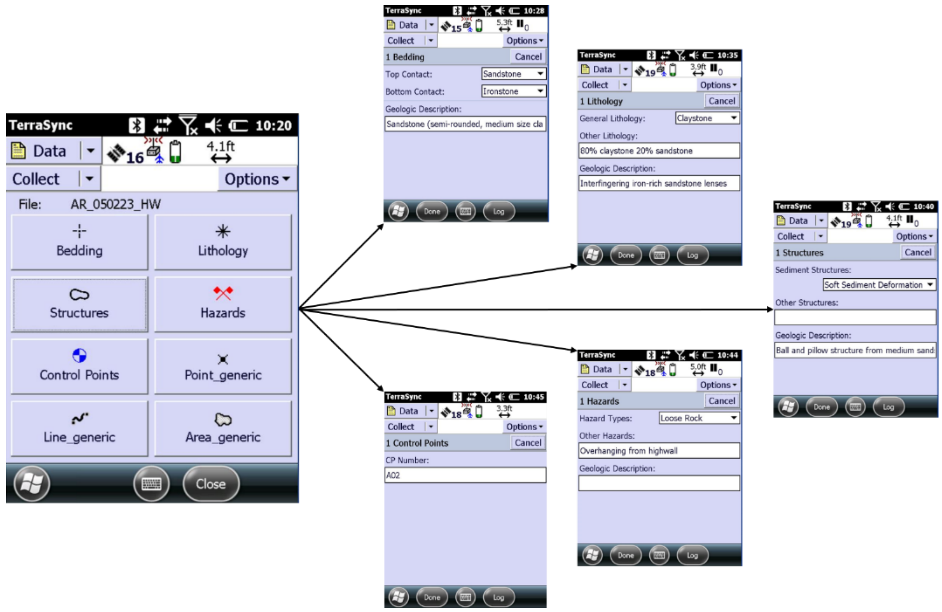


Figure 44: The button layout and associated menu system on the Trimble™ Geo 7X designed for the Alabama Mine.

Table 15: Quantity of data points collected at the Alabama Mine study area.

Point Type	Bedding Contacts	Lithologies	Structures	Hazards	Control Points
Number of Points	38	17	7	2	5

Sample Collection

Hand samples were collected from all lithologic units because the area was safe enough to do so. Eleven samples of sedimentary rock were collected using a rock hammer and plastic bags to store, label, and catalog each sample. The locations of the samples are provided in Figure 45.

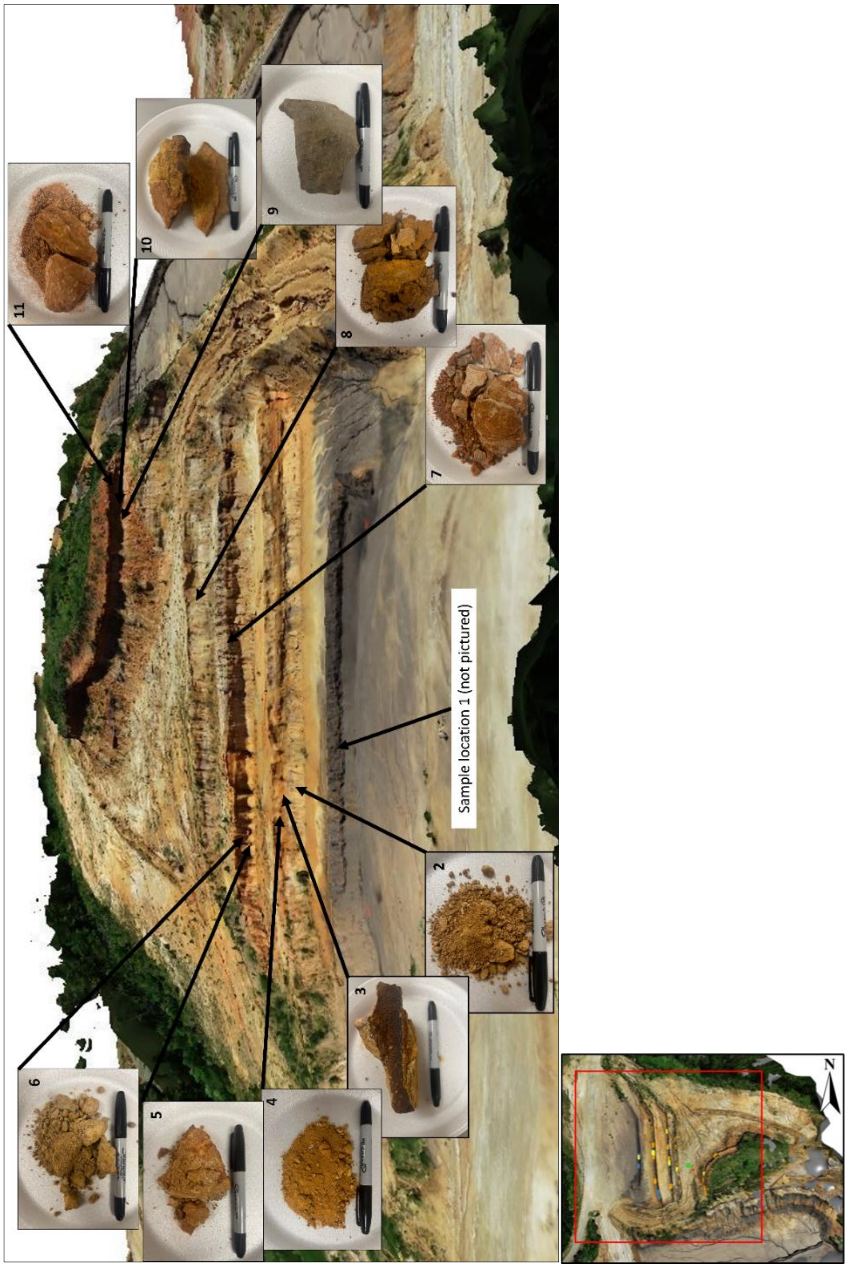


Figure 45: Rock sample collection locations at the Alabama Mine in Saline County, Arkansas.

Post-Survey Processing

Processing Geologic Point Data

A total of 700 positions were uploaded and processed in Trimble® GPS Pathfinder® Office. The data was first connected to the CORS, Little Rock (ARLR), Arkansas (derived from IGS08) base station, which was 17km away from the data points and has a good quality integrity index of 94.53. The base station covered 100% of the points at 0.93m from the base provider. The differential correction process was initiated to rectify the point data (Table 16).

Table 16: The estimated accuracies for 700 corrected positions after differential correction, creating 70 points.

Range	Percentage
0-5cm	39.86%
5-15cm	49.71%
15-30cm	5.29%
30-50cm	5.00%
0.5-1m	0.14%
1-2m	Null
2-5m	Null
>5m	Null

After the data was processed, the .cor file was then opened to export the data and attributes for Leapfrog Geo. The point identification number, northing and easting coordinates, elevation, and collected information about each point were exported into comma-separated value (.csv) files, one for each feature type. From there the data was ready to be imported into Leapfrog Geo.

Rectifying UAS Imagery

A total of 153 aerial images were downloaded from the Phantom 4 Pro V2.0 and uploaded to Agisoft Metashape Professional where the raw images were refined to create a series of models (Table 17). First, tie points were connected to create an initial sparse point cloud from the imagery (Figure 46). The dense cloud was produced and only had blank areas where heavy tree cover was present (Figure 47). Attributes such as leaves and water do not render well in models because in each image, the attributes are moving, making it challenging to connect tie points. Overlap and tie point connections were assessed by looking at the confidence dense cloud (Figure 48), which covered the entire study area. From there the mesh model was developed which filled in any areas with blank spots in the model (Figure 49). Mesh model quality was then examined by looking at the confidence model (Figure 50) to determine how well it rendered the model from the dense cloud. The model and image drape were then exported to Leapfrog Geo.

Table 17: The tie points, faces, and vertices used to create each type of model for the Alabama Mine in Saline County, Arkansas.

Feature	Results
Sparse Cloud Points	288,293
Dense Cloud Points	84,737,829
Mesh Model Faces/Vertices	6,654,612/3,329,854

Figure 46: Sparse point cloud the Alabama Mine study area in Saline County, Arkansas.

Figure 47: Dense cloud of the Alabama Mine study area in Saline County, Arkansas.

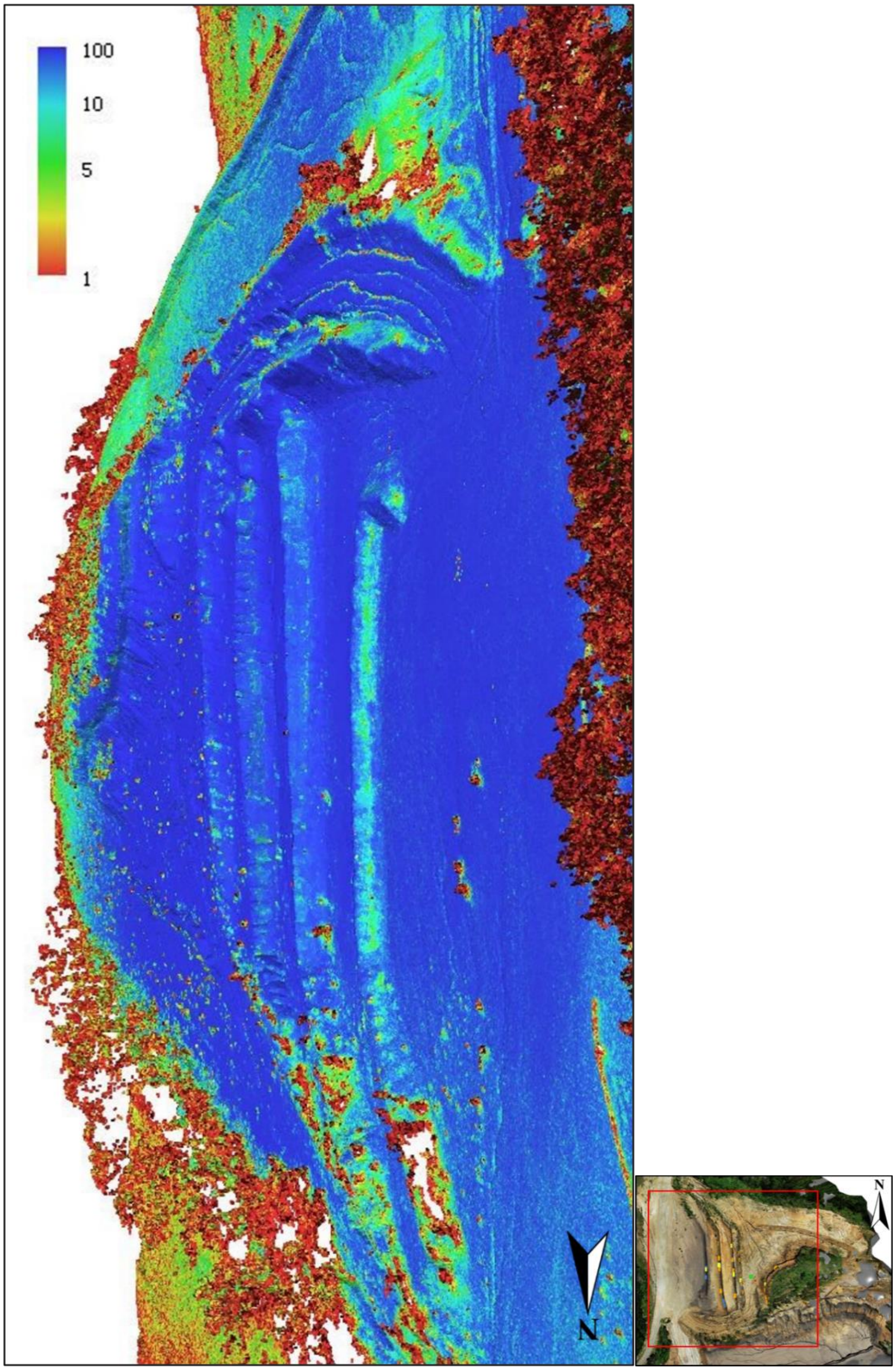


Figure 48: Dense cloud confidence model of the Alabama Mine study area in Saline County, Arkansas.

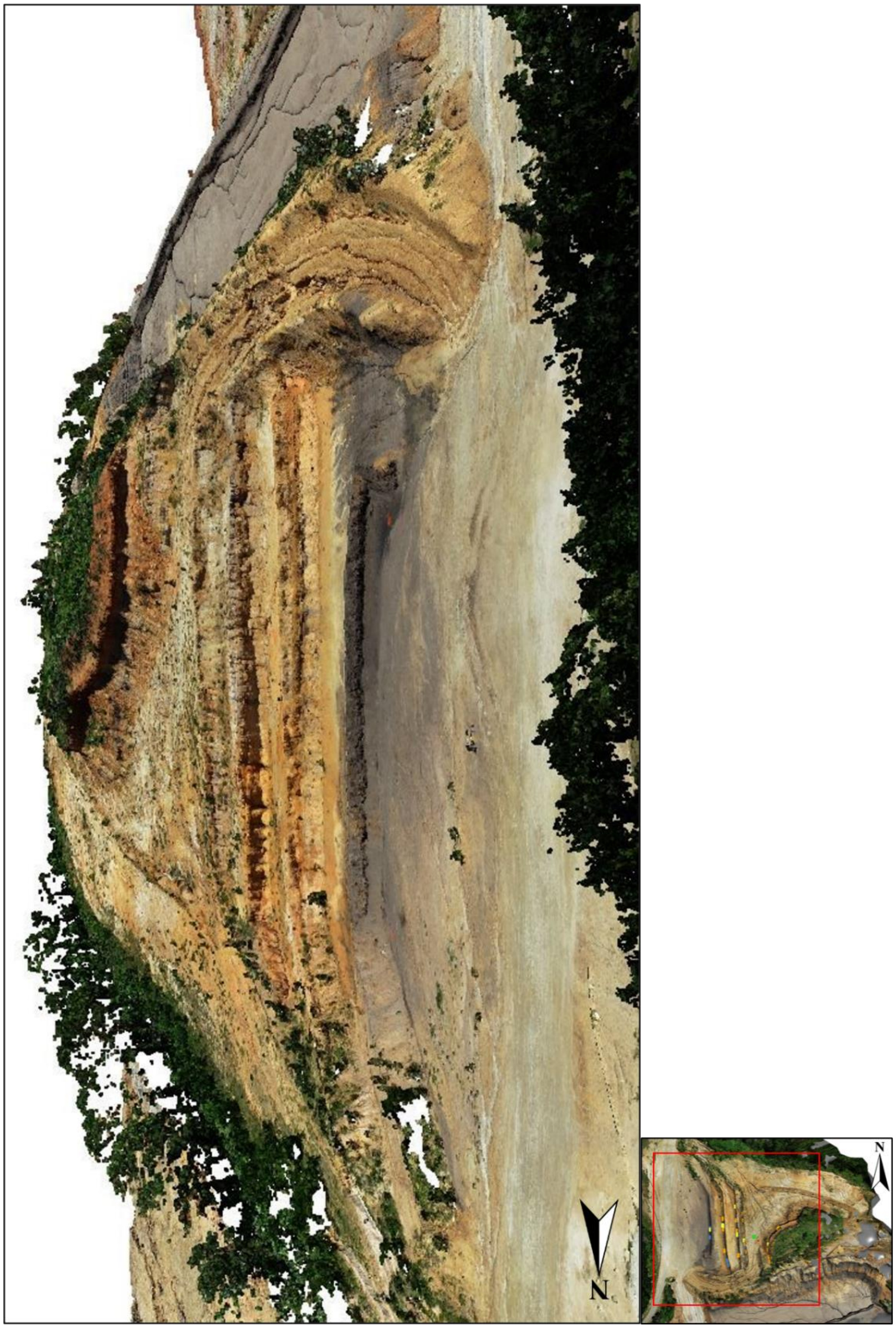


Figure 49: Mesh model made in Agisoft Metashape Professional of the Alabama Mine study area in Saline County, Arkansas.

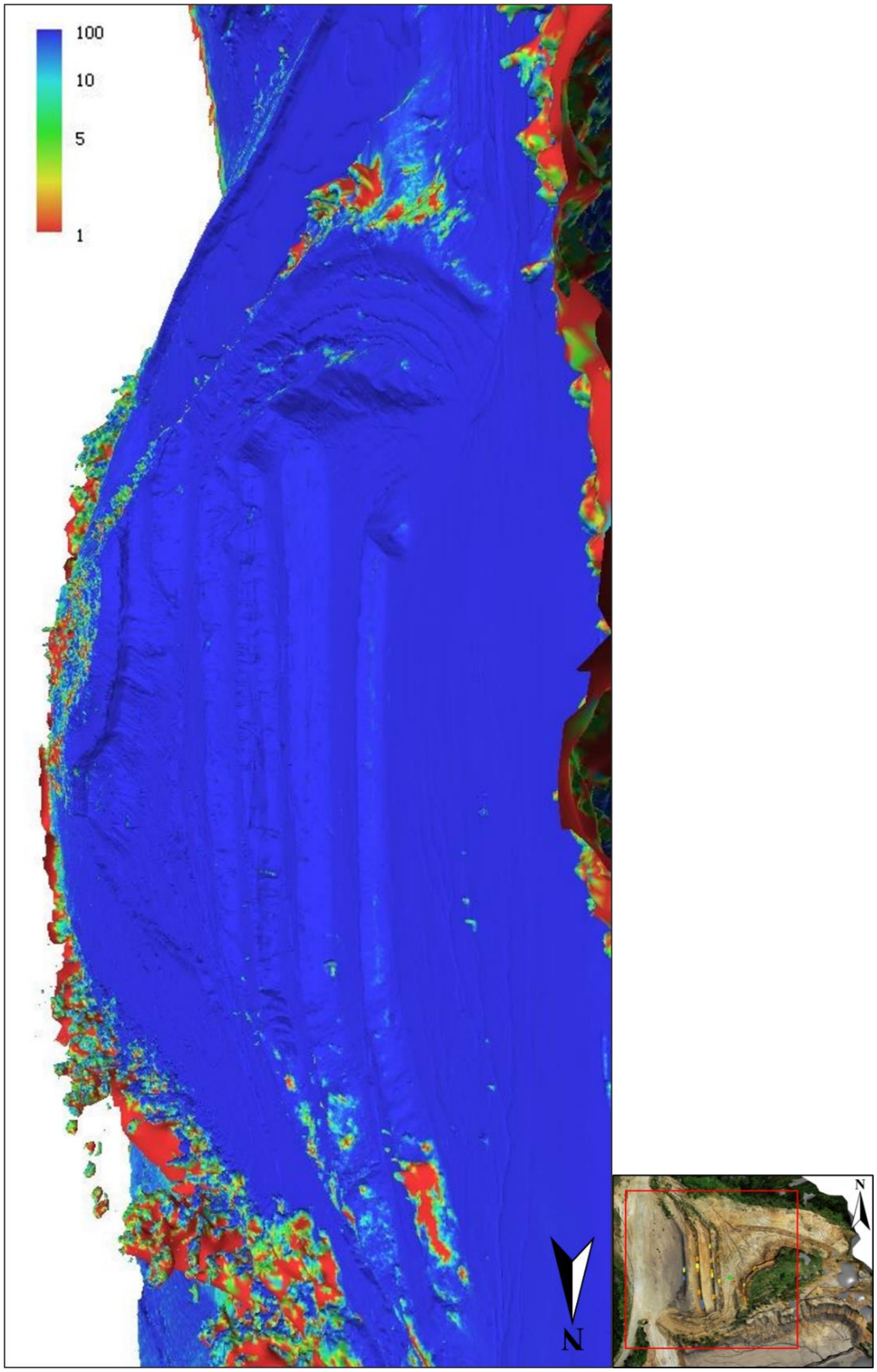


Figure 50: Mesh confidence model of the Alabama Mine study area in Saline County, Arkansas.

Geologic Block Models

The last step of this process was to combine the data points from Trimble® GPS Pathfinder® Office and the 3D model from Agisoft Metashape Professional into a composite geologic model. First, the 3D model was uploaded as a .obj file and its associated imagery as a .tif file. After this the point data was uploaded as a .csv file. The point data was categorized by point ID, Northing coordinates, Easting coordinates, bedding, hazards, and control points. The composite model contained accurate point data along each bench and overlapped the block model with the points (Figure 51). The main difference between this composite model from the ones at South Hallsville No.1 and New Braunfels is the quick succession of bedding changes versus the thick individual beds. Within two feet of this model, the imagery is blurry which made it challenging to identify bedding contacts without the assistance of the point data. Aside from this loss of resolution, the model was rendered and offers spatially accurate data regarding the geology of the highwall, hazards present, and control point data (Figure 52).

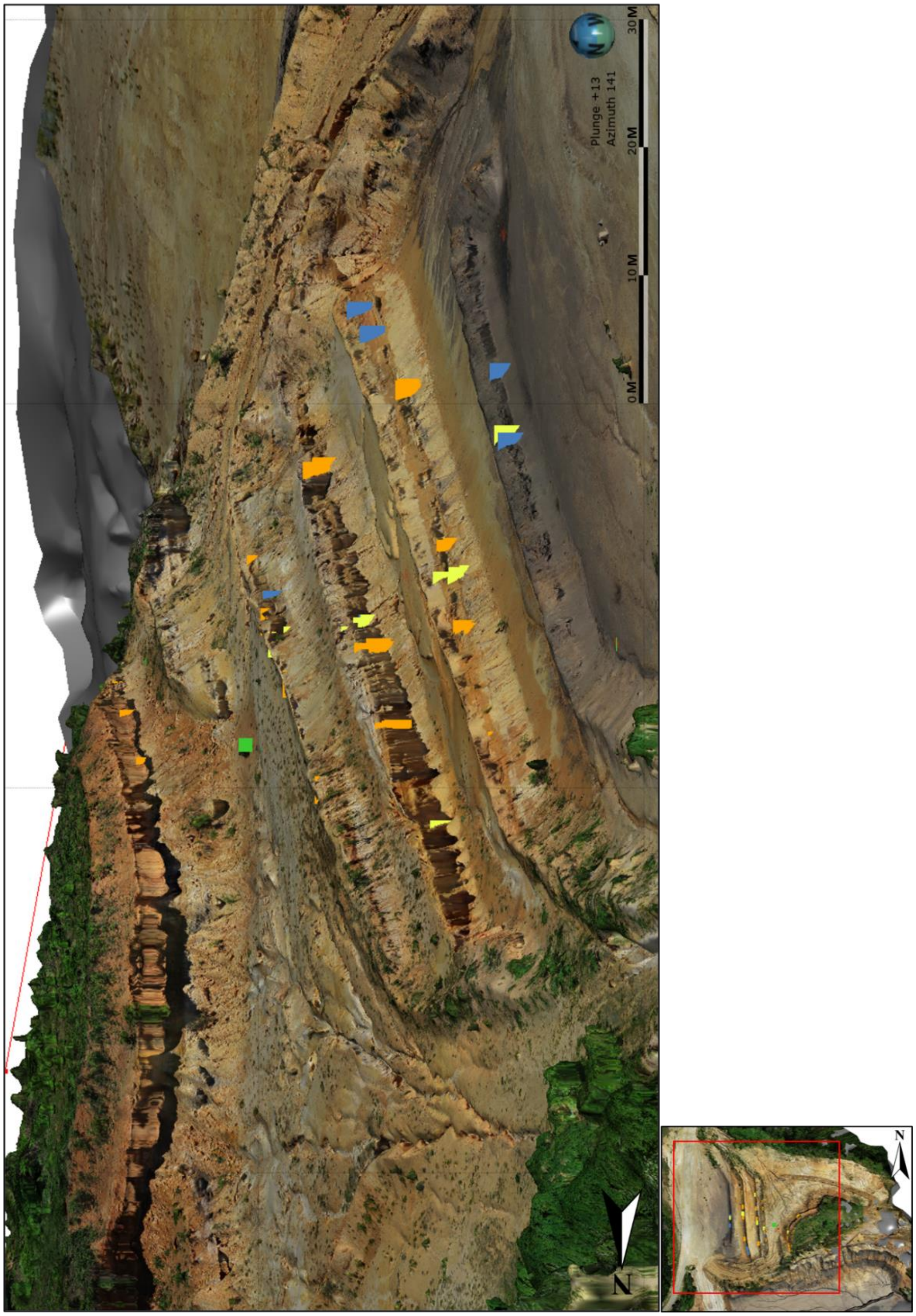


Figure 51: The composite geologic model looking southeast at the Alabama Mine study area.

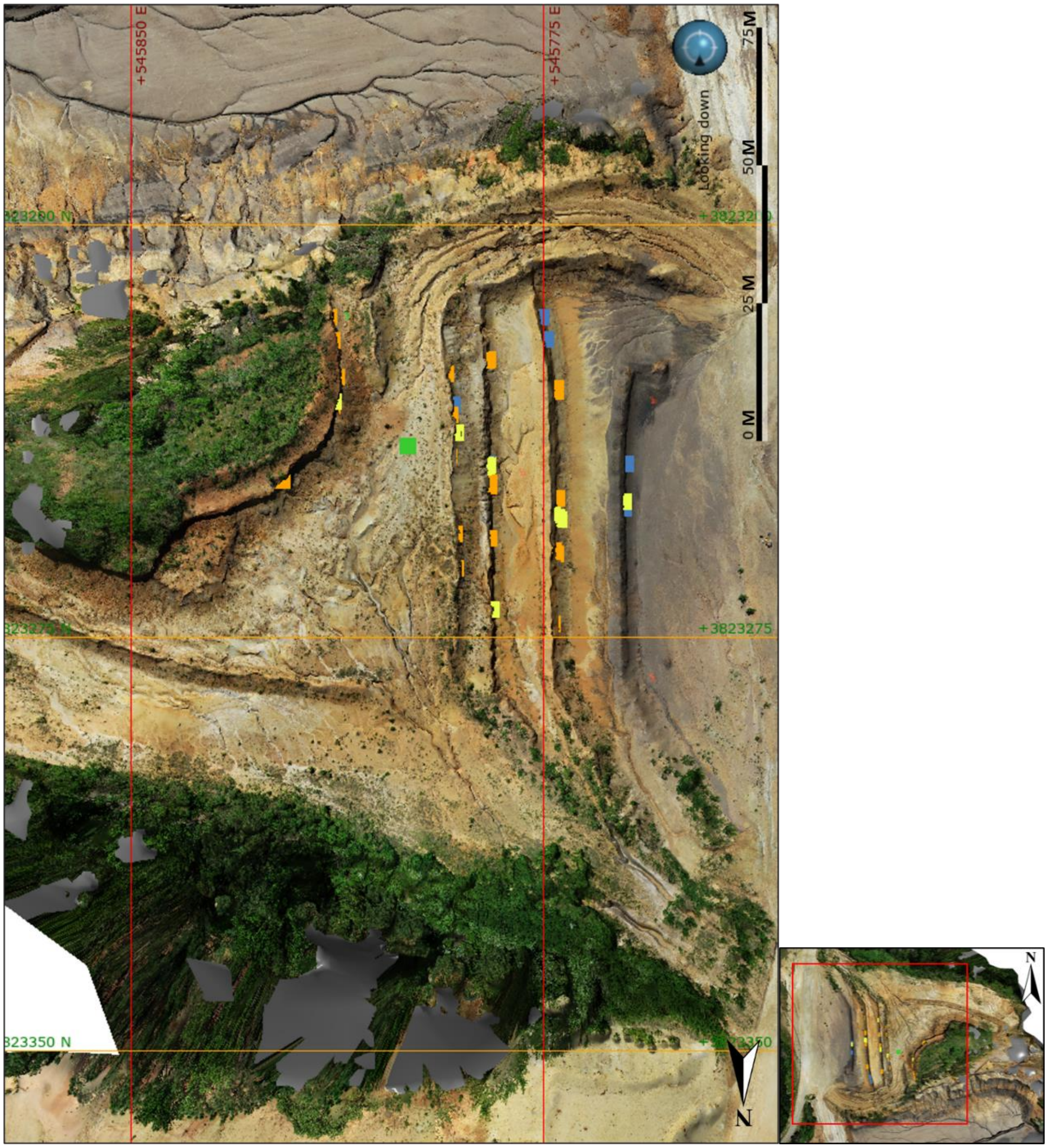


Figure 52: Plan view of the composite geologic model at the Alabama Mine study area.

DISCUSSION

Safety

Safety is of paramount importance in the mining industry. Working in an established open pit quarry, where the surroundings are changing with material, equipment, and people constantly on the move, is challenging, which makes safety so necessary for those working in these environments. Hazards were recognized and mitigated by maintaining safe distances from highwalls, bench ledges, mining equipment, loose rock, and water drainage areas. Caution was exercised while traversing through all outdoor areas, old mine workings contained hazards including loose rock, wildlife (primarily venomous snakes, spiders, and scorpions), and harmful vegetation (primarily cacti and poison ivy). While operating around hazardous environments, the UAS and Trimble™ Geo 7X significantly helped mitigate risks of injury or death.

Sampling

Hand samples were necessary for this methodology so that spatial data could be verified with physical samples. The samples provided a verification of the geologic model and allowed the correlation of the rock units. The safest way to collect rock samples was to pick up rocks from the ground that fit the description of the rock seen on the highwall and to verify with onsite staff that the samples were properly correlated to the in-situ layers. Samples at the Alabama Mine were able to be collected directly from the vertical walls using rock hammers due to the safety of the small size of the faces and large width of the benches. For more accurate samples, mining equipment could be employed to scrape off sections of rock needed for the study, but this was not available at the time. Alternatively, core drilling and/or quality control drilling could be viable alternatives to ground sampling with the caveat that the samples would not be directly correlated to the face. Scrapers from mining equipment could also collect samples directly from the highwall and still be within MSHA regulations.

Applied Technology

Trimble™ Geo 7X

Before being used in the field, the surveying accuracy of the Trimble™ Geo 7X attached to the monopole was tested by surveying the center of a quadrangle on the ground and then surveying another quadrangle 30ft away and five feet up on a wall with the attached laser rangefinder. This process was repeated three times to detect any variations. The surveyed points were processed using Trimble® GPS Pathfinder® Office which corrected the data points to 100% accuracy between zero and five centimeters.

Data dictionaries were very helpful when collecting data because they saved a significant amount of time in the field. Trimble® GPS Pathfinder® Office's data dictionary creator allowed the user to build a system that could contain menus, checklists, buttons, all with specific geologic functions that may be needed. Not all data could be predicted and added to the dictionary before going to the field, so the dictionary acted more as a tool to collect common types of data more rapidly. If the user is repeatedly visiting the same location to collect data, then the dictionary could be a useful and efficient way to conduct the operation.

The number of points taken at each site varied based on the quantity and quality of visible features on the highwall, but these data can be biased based on user objectives and experiences. In practice, if the same highwall was mapped by two different researchers with the same tools and instructions, their results would likely vary. This methodology can be employed in a variety of situations and the data will be skewed towards the interests of the user.

Highwalls were divided into sections in each area based on the height of the highwall and the quantity of collectible data present; the rate at which points were collected was dependent on the complexity of the geology. If features were homogenous and uniform, fewer points needed to be surveyed, whereas complex faces required more data to accurately portray the geology.

Phantom 4 Pro V2.0

A test flight was necessary at every site in order to verify that the flight area was safe and clear of any obstacles. Errors have been made in the past where drones have crashed while flying a programmed mission because the satellite imagery provided by the flight programming application was outdated or the GPS on the app was inaccurate. Safety checks before launching missions can help reduce the risk of damage to personnel or property.

Areas with poor reception inside of the mines caused problems with Pix4Dcapture being able to upload background satellite imagery where the flight path could then be overlayed on the AOI. This issue only occurred on one occasion when there was no satellite reception which resulted in the background satellite imagery failing to be displayed, but the UAS's and control system location remained visible. The solution was to drive out of the pit where the app could receive service and restore the missing information and then plan the flight.

Preprogrammed flights were conducted without the assistance of any outside factors once launched, allowing the pilot in command to monitor the UAS and their surroundings while the UAS gathered photos. Two different Phantom 4 Pro V2.0 UAS's were used during the field work of this research, both were assigned preprogrammed missions and every mission was completed successfully without manual intervention except when landing the UAS, which was done as a safety precaution to make sure that hazards could be avoided.

Leapfrog Geo

Corrected data from Trimble® GPS Pathfinder® Office and a full 3D model from Agisoft Metashape Professional were exported into Leapfrog Geo geologic software and displayed. All three models contained clearly visible geologic features that were enhanced with point data. When zoomed in close to the model, the smallest discernable features are roughly three feet in diameter protruding from the highwalls. Features smaller than that were sometimes visible and other times blended into the model and were not easily identified. With a flight closer to the study area and more overlapping imagery in the future, these smaller features could be rendered more accurately. As with all things data related, more data comes at the cost of longer hours of field work, larger files, and longer processing times, but with the benefit of having a more visually appealing model.

Modeling Clastic vs Carbonate Faces

The time it took to process all of the imagery from each site depended on three things: the number of images collected, the quality of the modeled images, and the processing power of the computer. After the modeling process was completed and a textured mesh was produced, the quality of the lithology was more apparent when comparing the results between the New Braunfels mine (carbonates) and the South Hallsville No.1 Mine (clastics). The highwall faces at both study areas displayed bedding changes, hydrogeologic features, safety hazards, and other smaller details. The main difference between the two lithologies was that the carbonate faces appear homogenous with little visible evidence of bedding changes, which is where the Trimble™ Geo 7X assisted in identifying these poorly visualized features. The clastic highwalls at the Alabama Mine and the South Hallsville No.1 Mine were much clearer in the models as they are separated by different colored bedding units. The clastic sites had more unique colors and physical features that Agisoft Metashape Professional could identify in separate photos and then connect with a tie point. The more tie points in a model, the better the model is constructed and detailed.

The most important takeaways from this research are that safety that can be improved while conducting geological research with state-of-the-art technology. This process drastically reduces the need to approach hazardous areas for research and promotes a spatially accurate method of collecting geologic field data. From this collection of information, these models can be stored, shared, and updated; important features for constantly changing data in a mine setting.

LIMITATIONS OF STUDY

This methodology is the most widely employed process for using photogrammetry and point data for the purpose of geologic face mapping. Future research using this methodology should take the following limitations into consideration:

- The continuous advancement of geospatial tools, UAS technologies, and software. The Phantom 4 series is no longer considered the industry standard UAS on the market, with newer and better series available and commonly used for these purposes. The Trimble™ Geo 7X is a reliable survey tool that can achieve survey grade accuracy but has been surpassed by newer geospatial tools. The equipment used to conduct this research is not obsolete or inaccurate, but technology changes rapidly, with newer and more accurate tools becoming more widely available.
- The satellite reception availability varies significantly in open pit quarries. This can affect the user's ability to prepare the UAS flight. Reception could be improved by conducting the flight from a vantage point, overlooking the AOI where the UAS receives adequate coverage. The Trimble™ Geo 7X did not encounter problems with satellite reception during this research.
- Post processing reduced the spatial error for each point, but on multiple occasions could not resolve the data to reach centimeter (survey grade) accuracy. In order to achieve centimeter accuracy, the Trimble™ Geo 7X must have substantial satellite reception with an estimated field accuracy between 30in and 1in to improve accuracy to centimeter-grade in post processing. Reduced reception within each

study area is the most likely cause for this reduction in accuracy, but it does not mean that the collected data should be discarded if not survey grade.

- There were issues finding working base stations near the data collection area. Some instances required multiple checks to locate a working station that provided acceptable results. For this research, an acceptable corrected dataset would yield at least 50% of the data in the 0-15cm range.
- Weather related challenges can affect the quality of photogrammetric models, such as attempting to collect data during sunny conditions rather than overcast weather. This was challenging to accomplish due to the predetermined dates and times that the researchers were allowed access to the mines. Another issue was the travel distance to each location and once on site, adjusting to the weather conditions. When possible, future work could (and should) plan to collect imagery on days with ideal weather conditions.

CONCLUSIONS

The purpose of this research was to develop methodology for a safer, nonintrusive way for geologists to conduct face mapping work. By using an unmanned aerial system to collect imagery of the study areas in conjunction with a GPS device with a laser rangefinder to gather survey grade point data, users can collect valuable geological information while maintaining a safe distance from potentially hazardous areas. This research was conducted in three active surface quarries, mining three different ores, using three different benching techniques. The data collected and modeled was shared and edited to better define the surface geology of each study area. This method provides a safe alternative to traditional face mapping techniques. Three interactive models were successfully constructed and provided meaningful data to mine operators and engineers for volumetric and extraction purposes, while maintaining the safety of employees.

RECOMMENDATIONS FOR FUTURE STUDIES

This research provided an effective method for geological face mapping using modern technology to improve accuracy and safety. This research specifically used hardware and software from brands that were already industry standards in order to provide the most widespread usage for this process.

It is recommended that different cameras and sensors are tested on rock faces using this methodology because there can be other ways to delineate bedding changes and other geologic attributes. Changes in color, porosity, vegetation species, and other attributes can be identified using different types of equipment. Multispectral cameras can be tested to see how different lithologies can be characterized using different wavelengths; LiDAR could be used to assess point density on different types of rocks.

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APPENDIX ONE – UNIFORM DATA PROCESSING

Each mine was unique in its own regards to this methodology, but the way in which the aerial imagery and point data was processed was done the same way in order to validate the effectiveness and efficiency of the process. Below are the steps that were used to post-process and export the GPS point data in Trimble® GPS Pathfinder® Office as well as how to create a 3D model from GCPs and aerial imagery in Agisoft Metashape Professional:

The workflow of how data was collected on the Trimble™ Geo 7X is explained below:

1. Turn on the Trimble™ Geo 7X by pressing the green button once at the bottom of the device.
2. Once the home screen is visible, use the pen to press the center icon.
3. Calibrate the device. Press the Windows logo in the bottom left corner, next press the "Compass" icon, then press the tool icon in the bottom left corner, press "Calibrate", press "Fast Calibration" and follow the directions on the screen.

Once the calibration is complete, press the "X" icon in the bottom left corner and this will return you to the "Status" page.

4. Calibration should occur once a day, every day that you return to the work area.
5. In the top left corner press the arrow on the "Status" menu and press "Data".

5. The “Create New Data File” screen will appear. Change the file name to your project’s title. If the keyboard does not appear, press the keyboard icon at the bottom center of the screen.

6. Scroll to the “Dictionary Name” and select the data dictionary for this project.

7. Press the “Create” icon at the bottom of the screen.

8. “Height” is what your survey pole height is set to (set the height to a comfortable position for you), this measurement is displayed at the center of the pole.

“Type” is “Geo 7X Internal”. “Measure To” is “Bottom of monopole bracket V2”. Press “Ok” icon when done.

9. Press the icon of the feature that you want to map.

10. A variety of options to input data will appear (listed below). Fill them with information regarding the feature being mapped.

    a. Dropdown menus
    b. Numbers
    c. Text
    d. Date
    e. Time
    f. Pictures

11. Before logging points, make sure that you are connected to 5+ satellites and have 25-to-15-inch accuracy.

12. When ready to log your position, center the bubble level on the pole. Press the “Log” icon at the bottom right. Remain still with the bubble centered. The Geo 7x will record up to 10 positions. This can be seen in the top right corner of the screen.

13. Repeat steps 9-12 on each feature that requires surveying.

14. Once the surveying is complete and you are done, press the “Close” icon in the bottom right corner. A tab will appear with the question “Close this file. Are you sure?” press yes.

15. To return to the home screen, press the top left dropdown menu, press “EXIT”.

16. To shut down the Geo 7x, press the “Power” icon in the bottom right, then press “Shutdown”.

Steps to survey offset wall points:

1. Access the rangefinder by pressing the center button once.
2. Aim the crosshairs at the feature of interest. Press the center button once to record that point. Press the check mark in the bottom right corner.
3. The screen will return to the “Choose Feature” window.
4. Repeat the data input, logging, and rangefinder process on each feature that requires surveying.

APPENDIX TWO – AGISOFT METASHAPE PROFESSIONAL MODEL DEVELOPMENT

The images from the UAS flight were first cut from the Phantom 4's SD card and uploaded to a computer. From there, the images were uploaded to Agisoft Metashape Professional software. The workflow for creating a georeferenced 3D model from aerial imagery and then exporting that model to Leapfrog Geo software is explained below:

1. Open Agisoft Metashape Professional.
2. Select the "Workflow" tab, click **Add Folder**.
    a. Select the folder with the drone images that you want to process.
3. An "Add Photos" window will appear, select "Single cameras", click **OK**.
4. Select the "Workflow" tab, click **Align Photos**, select the following specifications as below then click **OK**:
    a. It will then process the data.
    b. A message may appear that some photos failed to align, if so, right click on all of the images without a checkmark on the bottom of the screen, right click one image and click **Reset Camera Alignment** and click **OK**. Redo the photo alignment process on the misaligned photos.
5. Next, select one of the images in the "Cameras" tab on the left, click **Ctrl+a** to select all images, then uncheck one box. This will uncheck all of them.

6. Select “Workflow”, click **Build Mesh** and select the following specifications as below then click **OK**:
    a. It will then process the data.

Reference the Trimble® GPS Pathfinder® Office process for processing and converting control points into a .txt file in order to apply the control points before continuing.

7. Next, import the control point data. Under the “Reference” section on the left, click **Import Reference**.
8. Select the folder containing the .txt file with the control point data (ID, Latitude, Longitude, Height Above Ellipsoid).
9. The “Import CSV” screen will appear with the data from the .txt file. Select the following specifications as below then click **OK**:
10. A message will say “Can’t find match for “”, entry. Create new marker? Click **Yes to All**.
11. Double click on an image at the bottom of the screen to enlarge the image and find a ground control point (GCP) in it (if one is present). Right click on the GCP, click **Place Marker** and select which GCP it is.
    a. A flag will appear, click and center it in the middle of the GCP.
    b. A green flag means that you have confirmed that GCP’s location.
12. Repeat this process with each image, once you have confirmed the same GCP a few times, it will predict where that GCP is in future images, those images will have a white flag in the corner.

a. As you confirm GCP’s, periodically update the images by clicking **Update Transformation** under the “Reference” tab.

13. After all GCP’s have been confirmed and updated, click **Optimize Cameras** under the “Reference” tab.

    a. A screen will pop up. Select the following specifications as below then click **OK**:

14. A warning message stating that “Models, dense clouds, and depth maps will be removed. Continue?”. Click **Yes**.

15. Once completed, continue creating new models to your specifications in the “Workflow” tab.

Once the steps above were completed it was then necessary to convert the model from lat/long coordinates to Universal Transverse Mercator prior to transferring the model to Leapfrog Geo. The steps below explain how to do this:

1. Open Agisoft Metashape Professional.
2. Open the model you want to change.
3. Go to “Reference” tab (Left side).
4. Click **Convert**.
5. Click the **Coordinate System** dropdown menu.
6. Scroll to the bottom, click the dropdown menu **Projected Coordinate Systems**.
7. Click the dropdown menu **World Geodetic System 1984 ensemble**.

8. Locate and click **WGS 84/UTM Zone (your zone number)** (Link for world zones: https://www.arcgis.com/apps/View/index.html?appid=7fa64a25efd0420896c3336dc2238475)

9. Click **OK**.

This will change the model from Latitude and Longitude to Northing and Easting.

Next, the model is ready to be exported and uploaded to Leapfrog Geo for the final model. Follow the steps below to complete this:

1. Follow the steps to georeference and build a 3D model from the drone imagery.
2. Under the "Workflow" tab, build a Dense Cloud, a Mesh, and an Orthomosaic.
3. Navigate to the File > Export > Export Model
    a. This will export your block model into Leapfrog Geo.
4. Name the file and select Save as Type: **Wavefront OBJ (.obj)** and save it to a folder.
5. Make sure that the "Coordinate System" is **WGS 84/UTM zone#** then select the following specifications as below then click **OK**:
    a. The data will then be processed.
6. Navigate to the File > Export > Export Orthomosaic

a. This will export your drone images that will cover the block model.

7. Name the file and select Save as Type: **TIFF/GeoTIFF (*.tif)** and save it to a folder.

8. Make sure that the "Coordinate System" is **WGS 84/UTM zone#** then select the following specifications as below.

   a. Click **Max. dimension (pix):** and set it to 30000.

   b. Click **OK**:

▲

   c. The data will then be processed.

9. Open Leapfrog Geo.

   a. No extensions are needed.

   b. Click **Get Started** and follow the steps to open Leapfrog Geo.

10. Under the "Projects" tab click **New** or **Open**.

   a. Name your project and select a location to store the file.

11. Click **OK**.

12. Under the "Project Tree" right click **Meshes**.

13. Click **Import Mesh**.

14. Select the .obj file exported from Agisoft Metashape Professional. Click **Open**.

15. A "Cleanup Mesh" window will appear, select the following specifications as below then click **OK**:

16. The model will then be processed and once complete appear under the "Project Tree" within the "Meshes" tab.

17. Right click on the model that was just processed under the "Meshes" tab. Click **Drape Image**, then click **Import Image**.

18. Select the *.tif file exported from Agisoft Metashape Professional. Click **Open**.

19. The image will then be processed and once complete appear under the model name.

20. Click and drag the model to the scene window. The data will be displayed with the block model and image draped over.

APPENDIX THREE – POST PROCESSING DATA

Trimble® GPS Pathfinder® Office Geologic Point Data

The data collected using the Trimble™ Geo 7X was uploaded from the unit to a computer with Trimble® GPS Pathfinder® Office software. This processing software allowed the researchers to refine and export the data for other use.

The steps to process the raw data into accurate and useful geologic information is explained below:

1. Open up "Trimble® GPS Pathfinder® Office."
2. Select or create a project folder for the data to save to.
3. Stick in the SD Card or connect the Geo 7x cable to the computer.
4. Navigate at the top Utilities > Data Transfer.
5. Wait for the SD card/Geo 7x to show connected.
6. Leave it on the "Receive Tab."
7. Click on **Add…** and click **data file.**
    a. Highlight the files you want to pull off the SD card/Geo 7x.
    b. Click **OK.**
8. Click **Transfer All…**
9. You should see a success message once complete.
10. Navigate to the File > Open.
    a. Select the files you want to process/export (the file type is .SSF).
11. Navigate at the top Utilities > Differential Correction.

12. You will see your file listed and the start and stop times for the individual file listed.

13. Click **Next.**

14. The default settings of “Automatic Carrier and Code Processing” and “Use a single base provider” will be adequate settings in most scenarios. If you are in an area where base stations are not nearby, multiple base providers may be a better option. The recommended ranges are a single base station within 80km, or 3 or more within 200km.

15. Click **Next.**

The default settings shown below will be adequate in most scenarios.

17. Click **Next.**

18. You will select your base station at this screen. In the “Base Data” section, toggle “Base Provider Search” and click **Select…**

19. Choose the working base station closest to your collected data location.

20. For the “Reference Position” section, we will want to click the second option that states **Use position from base station list** and ensure it has a matching base as what we chose in step 19.

21. Click **Next.**

22. Default settings to output to the project folder and create a unique filename are recommended, but you can choose the options to suit your needs.

23. Click **Start.**

24. The correction wizard should download the required base files from the station you selected. Please note that base stations upload their files at different time intervals, and there can be a delay in access to the files. If the file fails to download, the most common issue is it has yet to have been uploaded, and you should try again later or try a different base station. Click **Back** to select a new base station.

25. You will want to verify "Distance from base provider:" is close to 1 meter. This will ensure you are getting the proper transformation to WGS 1984. You will also want to verify you have 100% total coverage as seen on the screen.

26. Click **Confirm** to initiate the correction.

27. The correction process should initiate. Once it is complete, you will see a "Differential Correction Summary" displaying the estimated accuracies your file achieved with the correction.

28. Once you are satisfied with the results, click **Close**.

29. You should now be able to select File>Open to open your new .COR file within the project folder.

Process to export point data

30. Navigate at the top Utilities > Export.

31. For the "Choose an Export Setup" click **New Configurable ASCII.**

32. Click **New…**

33. For "Data" section, under "Type of Data To Export" click **Features – Positions and Attributes.**

a. Export All Features

34. For “Output”, under “Output Files” click **Combine all input files and output to an Auto-generated subfolder**.

35. For “Attributes”, under “Export Menu Attribute As”, click **Attribute Value**. Under “Generated Attributes”, select the types of data that you need in your final output. This will be displayed as text or numbers in the final output.

36. For “Units”, click **Use Current Display Units**. These will be meters, square meters, and meters per second.

37. For “Position Filter”, under “Position Filter Criteria” click **Filter by GNSS Position Info**.

38. For “Coordinate System”, click **Use Export Coordinate System**. For “System” click **UTM**, for “Zone” select the zone where the data was collected. (The link below will take you to the world UTM zones). For “Datum” click **WGS 1984**. For “Altitude Measured From” click **Height Above Ellipsoid**.

https://www.arcgis.com/apps/View/index.html?appid=7fa64a25efd0420896c3336dc2238475

39. For “Configurable ASCII”, under “File Options” click **One Set of Files Per Feature Type**. Under “Template List” click **New…**The “Template Name” should relate to the project. Click **OK**.

40. For “Output File Extension”, type “csv” (Microsoft Excel Comma Separated Values File). Under “Macro Palette”, click on the features that you want in your final Excel output. Make sure to include **Feature Name, Northing, Easting, and HAE** (Height Above Ellipsoid). Click **OK**.

41. A warning will appear, click **OK**. Click **OK** again. In the top right corner of the Export window, click **OK**. You should receive a success message once complete.

42. The data will then be processed and placed in a folder within the Export folder.

43. Navigate on your PC to Documents > GNSS Projects > Default > Export. The project folder is located with the Export folder. The data will be in a .csv file.

Once the steps above were completed and the data has been exported into a comma-separated values file, the data is ready to be uploaded into Leapfrog Geo and added to the model. The steps to do this are below:

1. Open “Leapfrog Geo.”
    a. No extensions are needed.
    b. Click **Get Started** and follow the steps to open Leapfrog Geo.
2. Under the “Projects” tab click **New** or **Open**.
    a. Name your project and select a location to store the file.
3. Click **OK**.

4. Under the "Project Tree" right click **Points**.

5. Click **Import Points**.

6. Select the .csv file with the Geo 7x data that you want to model.

    a. A window should appear with the data separated.

7. Click on the **Not Imported** dropdown menus of the columns that you want to import and select the parameters of those columns.

    a. Include the following columns: Northing, Easting, Elevation, top and bottom lithology, and notes.

    b. For example, for the top lithology column, click the **Not Imported** dropdown menu, click **Custom Name…**, for "Column Name" type "Top Contact" and for the "Data Type" click **Lithology**. Click **OK**.

8. The final data set should look similar to this:

9. Click **Finish**.

10. The data will then be processed. The progress can be tracked in this blue section. It will contain no number when completed.

11. The data should now be visible under the "Project Tree" in the "Points" tab.

12. Click and drag the data to the scene window. The data will be displayed.

VITA

After graduating from Cypress Woods High School in Cypress, Texas in the Spring of 2017, Luke Whitenburg attended Stephen F. Austin State University in Nacogdoches, Texas that Fall. He graduated with a Bachelor of Science in Geology in December 2021. Luke enrolled in the Graduate School of Stephen F. Austin State University in 2022 to pursue his Master of Science in Geology, while in school he worked as an assistant geologist for Russell Drilling Company and later completed a geology co-op and internship with Lhoist North America. Luke earned his Master of Science in Geology in May 2024.

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