1. Introduction

The abandoned Picher mining field, located on the Oklahoma - Kansas border in the central United States, covers approximately 145 km² of land area (Figure 1). The field was extensively mined for lead and zinc ores (primarily galena and sphalerite, respectively) from 1904 through the early 1970s (Brockie et al., 1968; Luza, 1983; Manders & Aber, 2014; Nairn et al., 2009; ODEQ, 2006). Approximately 1.5 million metric tons (m-tons) of lead and 8 million m-tons of zinc were produced from the Picher field during this time (DeHay et al., 2004; Luza, 1983; Playton et al., 1980). The Picher field and adjacent areas, known as the Tri-State Mining District (TSMD), was one of the largest producers of lead and zinc in the world. During peak production, Oklahoma was the leading producer of zinc in the U.S. nearly every year from 1918 to 1945 (Luza, 1983). From 1921 to 1925, the TSMD accounted for 55% of total zinc production in the U.S. (Playton et al., 1980). From 1911 to 1964, the annual average percentage of metal recovery was 2.88% zinc and 0.76% lead, with lower recovery occurring during the later years of mining (McKnight & Fischer, 1970).

One element of interest was germanium. In the 1940s, one mining company, Eagle-Picher, perfected the recovery of high purity germanium from the zinc smelting process, becoming the sole producer of germanium from the 1940s through the early 1950s (Knerr, 1991; O’Connor, 1952).

Ore production began to decline in the mid-1950s due to ore body depletion, and by the late 1960s substantial mining efforts ceased (Luza, 1983; Playton et al., 1980). The Picher field contained approximately 1,500 mine shafts and over 100,000 boreholes by the time mining ceased (McCauley et al., 1983; Luza, 1983; United States Environmental Protection Agency (USEPA), 1994; Luza & Keheley, 2006). Today, at least 200 mine shafts remain open.

After mining cessation, the Picher field workings were abandoned, leaving behind mine tailings that contaminate the land and waters, and extensive subsurface void spaces that are now full of contaminated mine water and prone to collapse (Childress, 1953; Stroup & Stroud, 1967; Brockie et al., 1968; McCauley et al., 1983; Luza, 1983; Oklahoma Water Resources Board (OWRB), 1983; DeHay et al., 2004; Oklahoma Department of Environmental Quality (ODEQ), 2006; United States Army Corps of Engineers (USACE), 2006; Nairn et al., 2009; CH2M, 2010; USEPA, 2020). Due to the contamination, two USEPA Superfund sites include the Picher field. The Oklahoma portion of the Picher field was proposed for the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) National Priorities List (NPL) in 1981 and was listed as the Tar Creek Superfund Site in
1983. The Kansas portion, the Cherokee County Superfund Site, joined the NPL shortly after (Nairn et al., 2009; ODEQ, 2006; USEPA, 1994). Mining has not occurred in the Picher field for over 40 years. However, status as a Superfund site where hundreds of millions of U.S. dollars have been spent on remediation prevent the abandoned area from being forgotten.

Picher field geology was well documented over the lifespan of active mining (Brockie et al., 1968; Fowler, 1942; Fowler & Lyden, 1932; Luza, 1983; McKnight & Fischer, 1970; Reed et al., 1955; Siebenthal, 1925; Snider, 1912). Ore-bearing formations were located in Mississippian aged units, primarily in the Meramec and Osage series, commonly referred to as the Boone formation (Luza, 1983). The Boone formation is approximately 120 meters thick and was originally limestone (Fowler, 1942; Luza, 1983). However, erosion and deformation of the limestone resulted in the deposition of cotton rock, nodular chert, and fossiliferous dolomite, all of which contained ore-bearing inclusions (Figure 2). The distinct differences of the deposited material in the Boone formation allowed geologists to make minute subclassifications of the formations and members. These subdivisions are based on an informal letter classification system and have been widely used since the 1930s in both the literature and to designate working layers on historical mining maps (Brockie et al., 1968; Fowler, 1942; Fowler & Lyden, 1932; Luza, 1983; McKnight & Fischer, 1970).

Mining in the Picher field consisted of random room and pillar mining where most of the ore bearing material was removed, leaving irregularly spaced pillars to support the mine ceiling (Luza, 1983; Westfield & Blessing, 1967). Originally, pillars typically ranged from 6 to 15 meters in diameter and were spaced 9–30 meters apart to prevent roof collapses (Luza, 1983). These pillars contained approximately 12% to 20% of the remaining ore (Westfield & Blessing, 1967). Therefore, as a mine was preparing for closure, pillar robbing to extract the remaining ore was conducted, resulting in unsupported roofs prone to rock falls and collapses (Luza, 1983; Weidman, 1932; Westfield & Blessing, 1967). Invention of the ‘extension jumbo’ (Figure 3), a mobile platform capable of reaching 21 meters high, allowed for additional mining of the ceiling during closure operations, leaving behind mined voids with heights exceeding 36 meters (Brockie et al., 1968; Luza, 1983; Westfield & Blessing, 1967).

Most of the underground workings were surveyed and mapped by lease owners to track progress during production. However, many of the older mines do not have underground mining maps, and the maps that do exist of these older mines are likely sketches rather than surveyed maps (McCauley et al., 1983). The most comprehensive maps are known as the 40-acre (16 ha) maps (Oklahoma Office of the Secretary of Environment (OSE), 2000).

The 40-acre maps are named after the land area of a quarter-quarter section based on the Public Land Survey System (PLSS), still used today in the U.S. The PLSS is a method of describing and subdividing the land, laid out in typically square sections that measure 2.59 km² (640 acres). Each section can be divided into

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Figure 1. Location map of the Picher field underground mine workings and an inset map of the Tri-State Mining District, located in portions of Ottawa County Oklahoma, Cherokee County Kansas, Jasper County Missouri, and Newton County Missouri.
quarters, then subdivided by quarters again, resulting in sixteen equal squares that are 40 acres in size (16 ha), known as quarter-quarter sections. These PLSS grids were used by the lease owners and mining companies to define ownership boundaries because most of the leases were 40 acres in size and based on the quarter-quarter sections.

The 40-acre mining maps still have some shortcomings. These maps were typically hand-drawn, rarely contained a legend of symbols or linework, and often had additional handwritten notes to explain expansions of the workings beyond what was originally drawn. Although many of these historical mining maps have likely been destroyed or lost, numerous groups and individuals have worked to scan and archive the surviving mining maps over the past few decades (USACE, 2006; Keheley, 2020; Missouri Southern State University, 2020; Oklahoma Department of Mines (ODM), 2020). When combined, these archives contain thousands of mining maps in a variety of digital formats.

The objectives of this work were to 1) utilize historical mining map repositories to create a complete map of the Picher field underground workings in a digital format that is readily accessible and can be easily updated as new information becomes available; 2) determine the areal extent and void volume of the mine workings in the Picher field using AutoCAD.

**Figure 2.** Generalized section of geology in the Picher mining field portion of the Tri-state Lead-Zinc Mining District, located in Oklahoma and Kansas, United States (Modified from Brockie et al., 1968; Fowler, 1942; Reed et al. 1955; McKnight & Fischer, 1970; Luza, 1983).
Civil 3D and ArcMap; and 3) address and quantify uncertainties of historical mining maps that were not updated before mining operations were abandoned, thus producing a map that represents the minimum extent of the mine workings. The purpose of this research was to create digitized 2D and 3D renderings of abandoned underground mining voids to help develop a better understanding of environmental liabilities to support future remediation and research activities.

2. Materials and methods

2.1. 2-Dimensional map creation

Approximately four thousand historical mining maps of the Picher field, in a variety of file types, from numerous sources were reviewed (Keheley, 2020; Missouri Southern State University, 2020; ODM, 2020; USACE, 2006). Over 1,400 of these maps were collected and indexed for the creation of the Picher field mining map. This repository was searchable by publication year, mine lease name(s), map creator, and legal description.

A shapefile of the quarter-quarter sections from the PLSS of the area of interest was imported into AutoCAD and ArcMap and served as the primary method to georectify historical mining maps. The map repository was used to identify the newest and/or most detailed historical map of the underground workings for each quarter-quarter section that contained mine workings. The map was then imported into AutoCAD Civil 3D and aligned 2-dimensionally by aligning opposite corners of the quarter-quarter section drawn on the mining map with the corners of the corresponding quarter-quarter section. The line types present on each historical map were identified and associated with the correct geologic bedding layers. Then all the workings were traced using splines with the corresponding AutoCAD layer.

The two-point alignment tool in AutoCAD Civil 3D was often not sufficient to properly align

Figure 3. Roof trimming of underground workings in the Picher mining field using a 70-foot (21 m) extension jumbo. Source: Baxter Springs Heritage Center and Museum, Kansas, United States.
quarter-quarter section borders of the historical mining maps with the corresponding PLSS borders due to slight deformations, such as wrinkles, that were present on the original paper maps. Therefore, linework from each quarter-quarter section was exported as a shapefile from AutoCAD Civil 3D and imported into ArcMap. Using spatial adjustment tools and the rubbersheeting method, mine workings were more accurately aligned in ArcMap. A minimum of fifty alignment points were placed along each border of the quarter-quarter section. Any mine shafts in the section with known coordinates were used as additional alignment points. After completing the alignment, the shapefiles were imported into AutoCAD Civil 3D, where the linework from each quarter-quarter section was combined into a single AutoCAD file. The combined file was used to create the 2D Picher field map and served as the base file to create a 3-dimensional (3D) rendering of the mined voids. In addition, a version of the 2D map was modified to calculate the areal extent of the mine workings as a single layer to make a direct comparison to previous estimates of the areal extent and average height of the mine workings.

2.2. 3-Dimensional rendering for mined volume and area calculations

The linework in the Picher field mining map was divided based on legal section boundaries and saved into separate AutoCAD files to decrease the computational power needed for 3D rendering. The historical mining maps used to create the 2D drawings that contained floor and ceiling elevations of the mined voids were prioritized over other maps in the repository to create the 3D rendering. However, if the map used in the 2D map did not contain elevation data, the map repository was searched to find the best replacement map for a given area that contained elevations. In total, over 400 historical mining maps were used to complete the Picher field mining map and subsequent 3D rendering (Appendix A).

The majority of the elevation data were inserted by typing values from the historical maps into separate point groups for the floor and ceiling of each bedding layer. However, 3D linework was available in select areas on the Oklahoma side of the Picher field that was used in a previous subsidence study conducted by the USACE (USACE, 2006). The accuracy of these 3D lines was verified with the historical mining maps and adjustments were made if necessary.

Next, the elevation data from the point groups or 3D linework were used to create surfaces that represented the floor and ceilings of each bedding layer in each section. Boundaries were added to each surface to create an outer boundary for each bedding layer, then the pillars within the boundary were hidden. The 2D area of each of these surfaces was computed in AutoCAD and recorded in a spreadsheet. The respective floor and ceiling surfaces for each bedding layer were then used to extract a 3D solid between the surfaces, allowing the volume for each piece to be computed by AutoCAD and creating a 3D representation of the underground workings. Figure 4 is an example of the 3D rendering.

The land surface shown in Figure 4 was generated from 0.3-meter contours (1 foot) from a LiDAR flight flown in 2005 and provided by the Oklahoma Department of Environmental Quality. The solids from each bedding layer were merged into a single solid per bedding layer to compute the mean heights of void spaces. A flowchart briefly describing these methods is shown in Figure 5.

2.3. Evaluation of potential inaccuracies within historical mining maps: Domado case study

The historical mining maps selected to create the Picher field map and the 3D rendering were the best available maps. However, it is likely that in many instances, the selected historical mining map pre-dated the closure of a given lease, thus potentially not representing the full extent of the workings at the time of mine closure. The Domado lease was selected for this case study because there were numerous historical maps available spanning a period of 40 years. Four maps with dates ranging from 1927 to 1966 were used to quantify the expansion that occurred over the lifetime of the Domado lease, thus representing the inaccuracies that would result in the Picher field map and subsequent calculations on the Domado lease if the best available map for the lease pre-dated the 1966 map. The 2D and 3D methods previously described were used to calculate the area and volume of the M-bed in the Domado workings for each of the four maps to quantify the expansion that occurred on this lease between each date.

3. Results and discussion

3.1. 2-Dimensional map creation

The final 2D Picher field mining map represents the first comprehensive mining map of the Picher field since mining ceased in the 1970s. The digitization of the historical mining maps used to create the 2D Picher field map was straightforward, with only a few challenges. First, the selection of the correct historical mining map for a given area was often a time-consuming and tedious process. In many instances, multiple maps were similarly dated, but the details (e.g. handwritten notes describing pillar removal,
roof trims, or mine expansion) on each varied. Thus, more than one map would be used to draw a given set of workings, with the most recent details from each used in the AutoCAD drawings to create the most-likely accurate representation of the mine.

Perhaps the greatest challenge was determining the correct bedding layer of a particular set of workings. Most of the historical mining maps did not contain a legend. If legends were present, they were often incomplete, with little to no consistency between line types or symbology between companies or decades. L. Stepp, a former surveyor in the Picher field, gave an example during a personal interview where a solid black line on the Netta East lease indicated the main workings as the M bed level, while the Netta White lease, located to the northwest, the solid black line was representative of the main workings in the G-H bed (Stepp, 2004). Therefore, best approximations of the bedding layers in each area were established based on partial legends written on the maps, surrounding workings with known bedding layers, drill logs, and descriptions of mines from published articles. Despite these challenges, the final product of the Picher field map currently represents the best 2D depiction of the Picher mining field, incorporating information from hundreds of historical mining maps. In addition, providing the map as an easily accessible and editable file type promotes its use in novel and creative manners by technical and non-technical audiences.

3.2. 3-Dimensional rendering for mined volume and area calculations

The area, volume, and subsequent mean void heights were calculated for each of the bedding layers based on 1) the entire Picher field, 2) the Oklahoma portion, and 3) the Kansas portion (Tables 1 and 2). It is important to differentiate between the 2D area of each bedding layer and the areal extent of the mine workings. Many mines had multiple levels of workings that overlapped, resulting in the summed areas of the bedding layers exceeding the areal extent. In fact, comparing the areal extent (1,440 ha) to the summed area of the bedding layers (1,547 ha) suggests that approximately 7.5% of the mine workings had overlapping mined layers (Tables 1 and 3).

The majority of mining in the Picher field occurred in the Oklahoma portion, accounting for nearly 75% of the mined voids by volume and area (Tables 1 and 2). The most frequently mined bed in the Picher field was the M-bed, accounting for 65% of the mined volume. The M-bed was one of the most prevalent and thickest ore-bearing layers in the Picher field.
(Fowler, 1942). On the opposite end, the least commonly mined bedding layers were the E and Chester beds (2% by volume), due to the small intermittent pockets of ore (Brockie et al., 1968). The E and Chester beds were often mined when an ore-bearing pocket was intersected while sinking a mine shaft to a deeper level or if the ore-bearing pocket was present in the ceiling of a previously mined bedding layer, frequently occurring in the GH-bed (Brockie et al., 1968). The intermittent pockets of ore in the E and Chester bed led to sporadic and small workings that were often too small to justify leaving pillars, resulting in the lowest pillar to void ratio (Table 1).

The historical mining maps created an additional challenge when constructing the 3D renderings. Most of the historical mining maps used in the 2D creation contained elevation data for the floor and ceilings of the mined voids. However, some of the older mining maps did not. These mined voids were often smaller mines, located on the outer portions of the Picher field. The mined voids that did not contain elevation data accounted for 1.8% of the overall 2D area. The mined void volume of the workings without elevation data was estimated by multiplying the areas of these workings by the average ceiling height of the corresponding bedding layer.

The creation of the 3D rendering represents the first time that the Picher mining field area and volume were calculated using a computer model. Over the years, there has been a wide range of reported values for the volume of the mined voids and areal extent of the Picher field (Childress, 1953; Luza, 1983; ODEQ, 2006; OWRB, 1983; Stroup & Stroud, 1967; USEPA, 1994). These values are often accompanied by oversimplified assumptions due to technological limitations at the time. In the past, the areal extent of the workings was often a best estimate, with the total volume calculation based on the areal extent and multiplied by a single value to represent the height of the workings across the entire Picher field. It is important to note that some of these estimates were made before mining ceased in the 1970s (Childress, 1953; Stroup & Stroud, 1967) but still exceeded the volume calculated in this paper by over 20% (Table 3). Surprisingly, some of the past estimates were very similar to the values calculated in this study. The volume reported by the Oklahoma Water Resources Board (OWRB) (1983) for the entire Picher field differed by 4.5%, with the percentage of the volume occurring in Oklahoma differing by 0.1% (Table 3). However, the mean void height calculated in this study was at least 75 cm below the estimated void heights used in past publications (Table 3). Two potential causes for the differences in the void heights are 1) the previous publications may have had a cognitive bias towards extreme ceiling heights when determining the estimated void height, resulting in overestimates and 2) previous publications, especially those occurring during the active mining period, may have had a more thorough knowledge of the workings than what is shown on the surviving mining maps that were used in this study, resulting in an underestimated mean void height calculated in this study.

While the 3D rendering is not as easily accessible as the 2D Picher field map due to expensive software and large file sizes, it provides a wealth of knowledge that can be used to improve the work of researchers and reclamationists. The 3D rendering can identify shallow workings or large mine rooms that may exist below ongoing surface remediation. Additionally, it provides the best available visualization of the underground connectivity of the mined voids, which will improve the understanding of the flow paths of the contaminated

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**Figure 5.** Flowchart describing the workflow to convert scanned historical mine maps into 2D and 3D AutoCAD renderings.
water that has filled the mines and now discharges into nearby streams. As new CAD software is developed; future research may be able to convert the 3D objects into a more user-friendly form in order to make the information widely available and accessible by any user.

### 3.3. Domado case study

The need for this case study became apparent while reviewing thousands of mining maps in the repositories. The mining was reportedly active during the 1970s, yet the most recent historical reference map was last updated in 1970, and only 16% of the reference maps were updated in the 1960s (Appendix A). During the final days of mining, Eagle-Picher mining company was the only large company remaining and held the most up-to-date 40-acre maps, along with drill logs, survey notes, and other mining records (OSE, 2000). In 1970, Eagle-Picher moved all records and maps to Reno, Nevada, USA. Since then, Eagle-Picher officials have stated that a flood had heavily damaged or destroyed the majority of the records, with little or no maps remaining (OSE, 2000).

#### Table 1. Area in hectares of mined voids and pillars for each geologic bedding layer in the Picher field portion of the Tri-State Mining District, and the pillar to void ratio of all workings and the percentage of mined void area located on the Oklahoma side of the Picher field.

| Bedding Layer       | Mined Voids (ha) | Pillars (ha) | Pillar:Void | Voids in Oklahoma (%) |
|---------------------|-----------------|--------------|-------------|-----------------------|
|                     | All | Oklahoma | Kansas | All | Oklahoma | Kansas |           |          |
| E and Chester       | 44.1 | 30.8 | 13.3 | 6.51 | 4.91 | 1.60 | 15 | 70 |
| G-H                 | 151.5 | 90.0 | 61.5 | 56.1 | 45.5 | 10.6 | 37 | 59 |
| K                   | 242 | 170 | 72.0 | 78.5 | 60.8 | 17.7 | 32 | 70 |
| M                   | 909 | 718 | 191 | 386.4 | 322 | 64.4 | 43 | 79 |
| Sheet Ground Workings | 201.3 | 123 | 78.3 | 32.49 | 26.6 | 5.89 | 16 | 61 |

#### Table 2. Volume (hectare-m) and mean height (m) of mined voids for each geologic bedding layer in the Picher mining field and the percentage of mined voids by volume located on the Oklahoma side of the Picher field.

| Bedding Layer       | Mined Void Volume (ha-m) | Mean Height of Voids (m) | Voids in Oklahoma (%) |
|---------------------|--------------------------|--------------------------|-----------------------|
|                     | All | Oklahoma | Kansas | All | Oklahoma | Kansas |           |          |
| E and Chester       | 203.8 | 136 | 67.8 | 4.62 | 4.41 | 5.11 | 67 |
| G-H                 | 1,019 | 576 | 443 | 6.73 | 6.40 | 7.20 | 57 |
| K                   | 1,293 | 902 | 391 | 5.37 | 5.30 | 5.43 | 70 |
| M                   | 6,399 | 5,179 | 1,220 | 7.03 | 7.21 | 6.38 | 81 |
| Sheet Ground Workings | 956 | 319 | 637 | 4.75 | 2.59 | 8.14 | 33 |
| Total/Weighted Average: | 9,871 | 7,111 | 2,759 | 6.86 | 7.02 | 6.46 | 72 |

The Domado case study was incorporated to show how these mines evolved over their operational lifetimes and to quantify the extent of the workings that would be unrepresented if the most recent map was not found. The objectives of the Domado case study were to identify potential uncertainties and provide an example by quantifying the expansion of the mine workings at the Domado lease that occurred over a forty-year period.

The volume of voids could not be calculated for the 1927 map because sufficient elevation data were unavailable. However, the areal extent increased by 115% from 1927 to 1946, illustrating the magnitude of uncertainties that can occur when the best available historical map was last updated nearly two decades prior (Table 4, Figure 6). At least one instance with similar circumstances to this date range between these two Domado maps has been identified. The historical reference maps used for the Old Mission and Petersburg leases, located in the southeast section of the Picher field, were published in 1907 and 1912, respectively. However, the Bureau of Mines annual ore production records show the Old Mission mine was still producing ore as late as 1935 (U.S. Department of the Interior: Bureau of Mines, 1936).

#### Table 3. Comparison of published estimates of the areal extent and volume of mined voids of the Picher field underground mine workings.

| Areal Extent (ha) | Estimated Void Height (m) | Mined Volume (ha-m) |
|------------------|--------------------------|---------------------|
| 1953-Childress   | 1,445                    | 8.84                | 12,770              |
| 1967-Stroup & Stroud | 1,457                  | 8.84                | 12,878              |
| 1982-Luza (Only Oklahoma) | 1,028                  | 7.62                | 7,833               |
| 1982-Luza       | 1,316                    | 7.62                | 10,025              |
| 1993-OWRB       | 1,236                    | 7.62                | 9,418               |
| 2021-Shepherd et al. | 1,440                  | 6.86                | 9,870               |

#### Table 4. Expansion of M-bed mine workings on the Domado Lease in the Picher field portion of the Tri-State Mining District over a period of four decades.

| Map Date | Area (ha) | Mean Void Height (m) | Volume (ha-m) |
|----------|-----------|----------------------|---------------|
| 1927     | 3,629     | N/A                  | N/A           |
| 1946     | 7,807     | 11.33                | 88.44         |
| 1953     | 9,163     | 13.88                | 127.2         |
| 1966     | 9,527     | 14.76                | 140.6         |

1Kansas portion estimated to be 28% of total void volume.
A comparison of the later Domado maps highlights the importance of updated elevation data. From 1955 to 1966, the Domado lease does not show any 2D expansion of the outer workings, rather the 2D map showed only pillar removal was occurring (Figure 6). The pillar removal accounted for less than a 4% change in the area, while the volume of mined voids increased by nearly 11% (Table 4). Therefore, the elevation data show that in addition to pillar removal, roof trimming was occurring throughout the mine, which resulted in a mean void height increase of nearly 90 cm. The quantifiable and visual differences determined in this case study emphasize that the Picher field map and 3D rendering should be viewed as the minimum amount of mine workings present in the Picher mining field.

4. Conclusions

The Picher field maps represent the first attempt to compile hundreds of historical mining maps to depict the entire mining field in a modern format, and the first time a 3D computer rendering was used to calculate the mined volume. The areal extent of the Picher field is approximately 1,440 hectares, with a total mined volume of nearly 9,870 ha-meters (Table 3). However, the Domado case study emphasizes that this is likely the minimum extent of the workings present in the Picher field. The availability of a modern format of the Picher field workings allows the map to be easily updated as additional maps are found, and it can be used in new and creative ways by researchers and reclamationists.
Acknowledgments

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Data availability Statement and supplemental online material

The online repositories used to support this work can be found at the following websites:

Missouri Southern State University; Tri-State Mining Map Collection: https://cdm16795.contentdm.oclc.org/digital/collection/tristate.

Oklahoma Department of Mines; Historic Underground Mining Maps: https://mines.ok.gov/historic-underground-mining-maps.

Any additional data will be available from the corresponding author upon request.

Description of Software use

The majority of the map was created using AutoCAD Civil 3D. Images of the maps were imported, 2D aligned to geographic boundaries, then traced to create polylines of the various layers of workings. AutoCAD can only align in 2-dimensions using 2 points and the majority of the time, these mining maps were not perfectly created or scanned, leading to inaccurate boundaries. When the 2D alignment was not sufficient, ArcMap was used to align the map pieces more accurately with field verified locations or geographic boundaries. ArcMap has the ability to stretch the exported polylines using numerous alignment points, as opposed to the two points in AutoCAD. These aligned sections where then imported back into AutoCAD and connected to surrounding workings. This created the 2-dimensional map.

For the volume calculations, floor and ceiling elevations were input into point clouds in AutoCAD. These point clouds were used to create floor and ceiling surfaces for each set of workings. Lastly, a 3D solid was extruded between the surfaces, allowing for the volume to be calculated within AutoCAD.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Geolocation information

This map is located on the border of Oklahoma and Kansas state line in the United States. The town nearest the center of the map is Picher, Oklahoma. The coordinates for the center of the map are: Latitude 36.987062° and Longitude −94.812918°.

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