Abandoned Mined Lands Perspective

Accuracy and Precision of Mine Maps and Map Geo-rectification

By: Robert D. Gibson
Illinois Department of Natural Resources
Office of Mines and Minerals
Abandoned Mine Lands Division

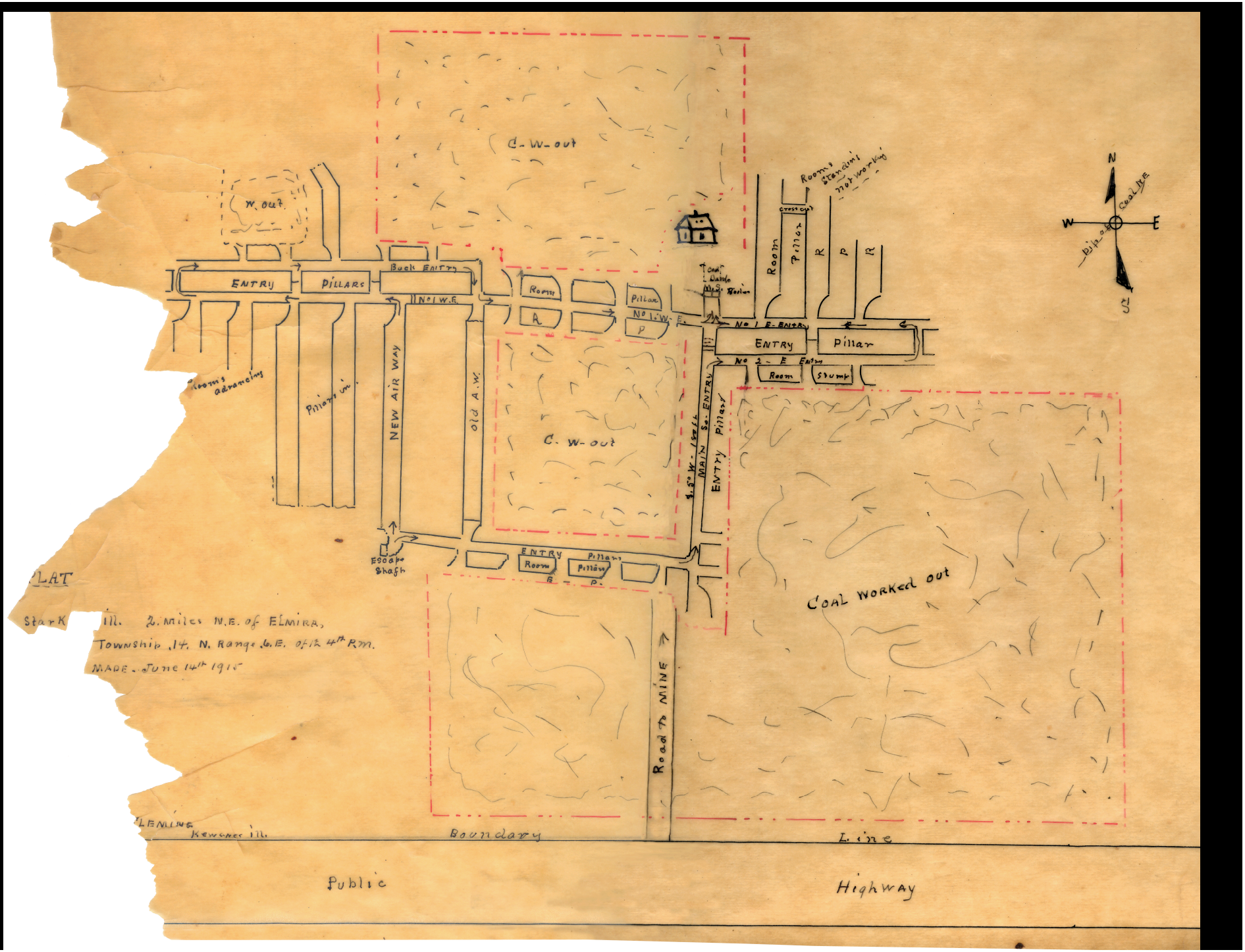
Abandoned Mined Lands Perspective

Common Perception Is That Old Abandoned Mine Maps Are Not Very Precise Or Accurate

Illinois Experience With Old Abandoned Mine Maps Suggest Otherwise

Mine Map Considerations

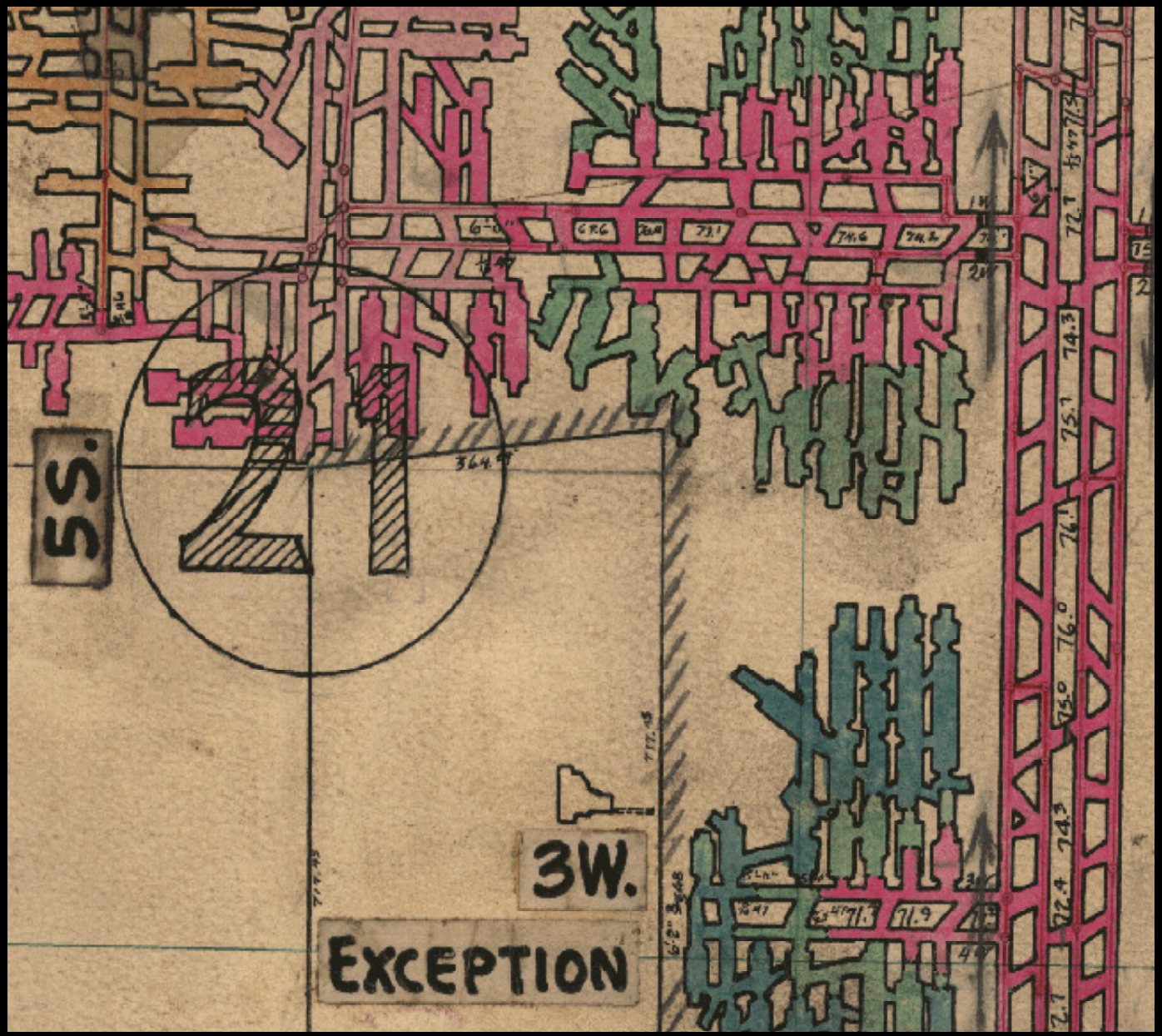
- Is the map intended as a pictorial rendering or as a representation of mining conditions ?


C. W. out
W. out
ENTRY
PILLARS
Back ENTRY
No 1 W.E.
Rooms
A
Pillar
P
No 1 W. E.
Rooms standing not working
Room
Pillar
R
P
R
Cross cut
Coal Visible
Dip of Seam
N
W
E
No 1 E. ENTRY
ENTRY
Pillar
No 2 E Entry
Room
Stump
Rooms abandoning
Pillars in
NEW AIR WAY
old A.W.
C. W. out
4.5° W. 1575
MAIN So. ENTRY
Entry Pillars
Escape Shaft
ENTRY
Room
Pillars
R
P
Road to MINE
COAL WORKED out
PLAT
Stark Ill. 2 Miles N.E. of ELMIRA,
Township 14. N. Range 6. E. of 2 4th P.M.
MADE - June 14th 1915
LENLINE
Kewanee Ill.
Boundary
Line
Public
Highway

Mine Map Considerations

- Is the map intended as a pictorial rendering or as a representation of mining conditions ?
- How close does the map intend to portray actual pillar geometry ?

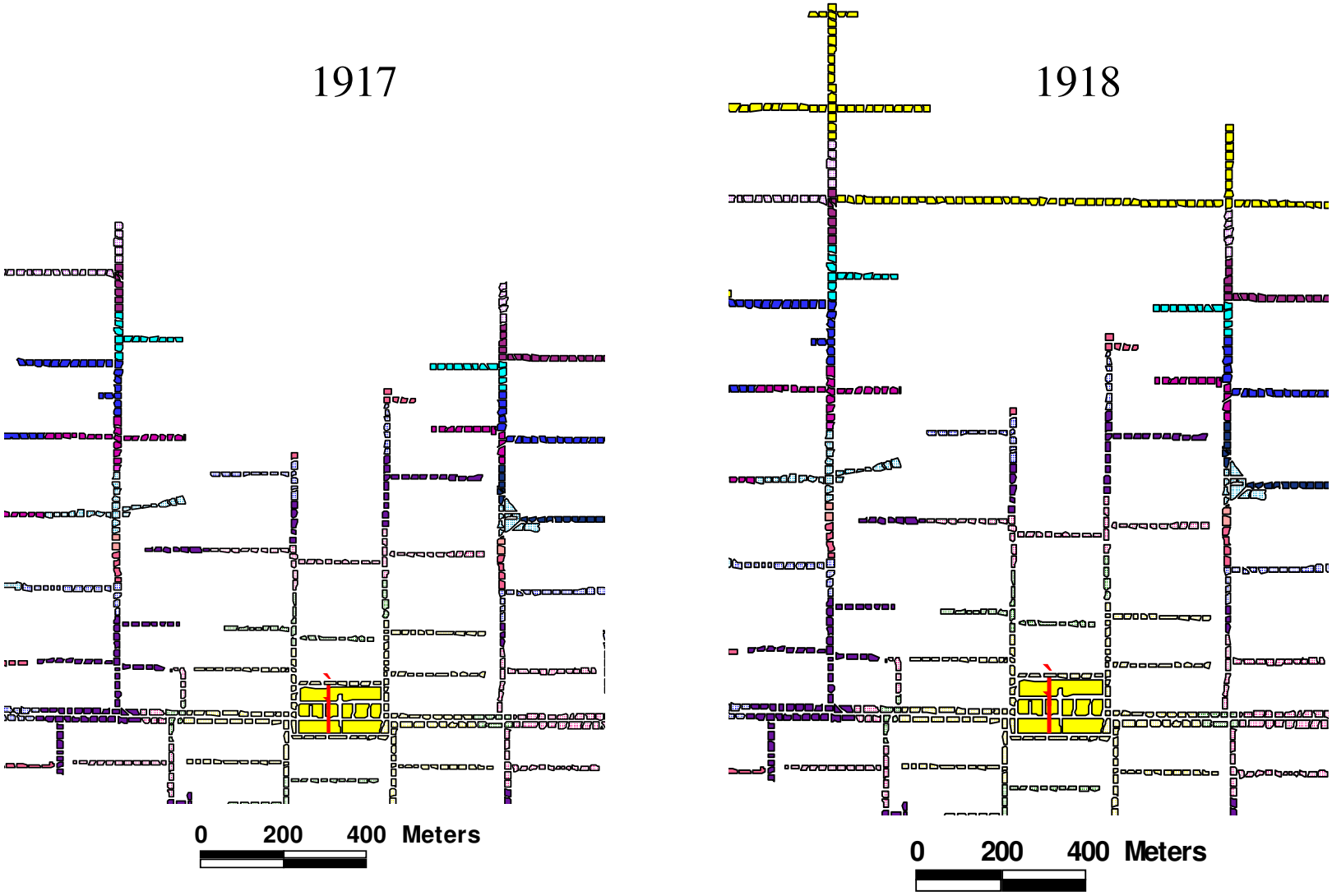
Exactness of Pillar Geometry Renderings Example



Mine Map Considerations

- Is the map intended as a pictorial rendering or as a precise representation of mining conditions ?
- How close does the map intend to portray pillar geometry ?
- Exactness of overall mine geometry ?

Example of Mine Geometry Exactness



Mine Map Considerations

- Is the map intended as a pictorial rendering or as a precise representation of mining conditions ?
- How close does the map intend to portray pillar geometry ?
- Exactness of overall mine geometry ?
- Does the map include sufficient surface features for geo-rectification ?

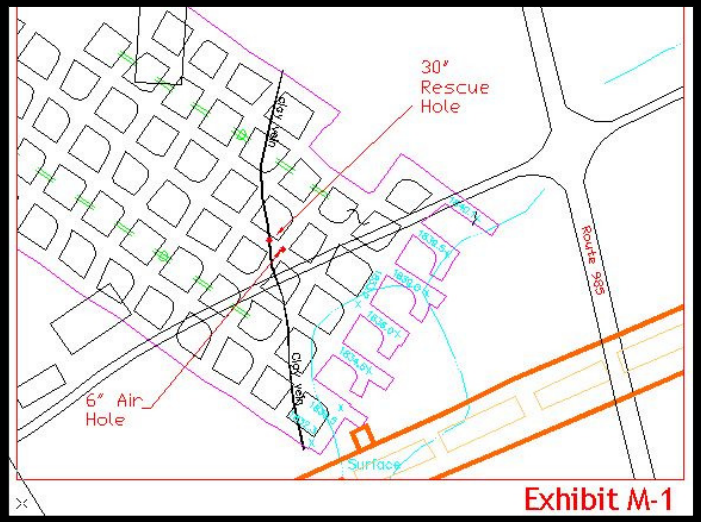

Spruce
Joseph Hartman
Stone
Main Street
Bait
187.25
Mrs Emma Dee (Leased)
75 South Methodist Church
Sunset Avenue
Louis Nevero
1st Alley
Collinsville Ave.
Pump House
Austin Avenue
Office
Depot
C.R.R.

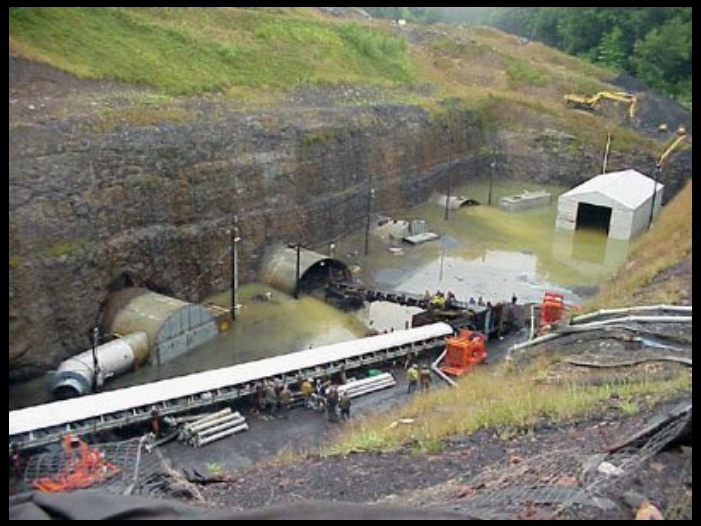
Mine Map Considerations

- Is the map intended as a pictorial rendering or as a precise representation of mining conditions ?
- How close does the map intend to portray pillar geometry ?
- Is the map scaled appropriately for intended use ?
- Does the map include sufficient surface features ?
- Is the map complete ?

QueCreek

From: US Department of Labor – QueCreek Mine Rescue





Not All Mine Maps Are Created Equal
However, the norm is that …

- Good faith effort was made by coal companies in mapping their workings as accurately as possible.

Room Map Circa 1940

Coal highlighted for cartographic purposes

Mine Map
Circa 1948

Room Map and Mine Map Comparison

Room Map Trace

Mine Map Trace

Not All Mine Maps Are Created Equal
However, the norm is that …

- Good faith effort was made by coal companies in mapping their workings as accurately as possible.

- The same good faith effort is being made by various governmental programs in geo-rectifying the mine maps.

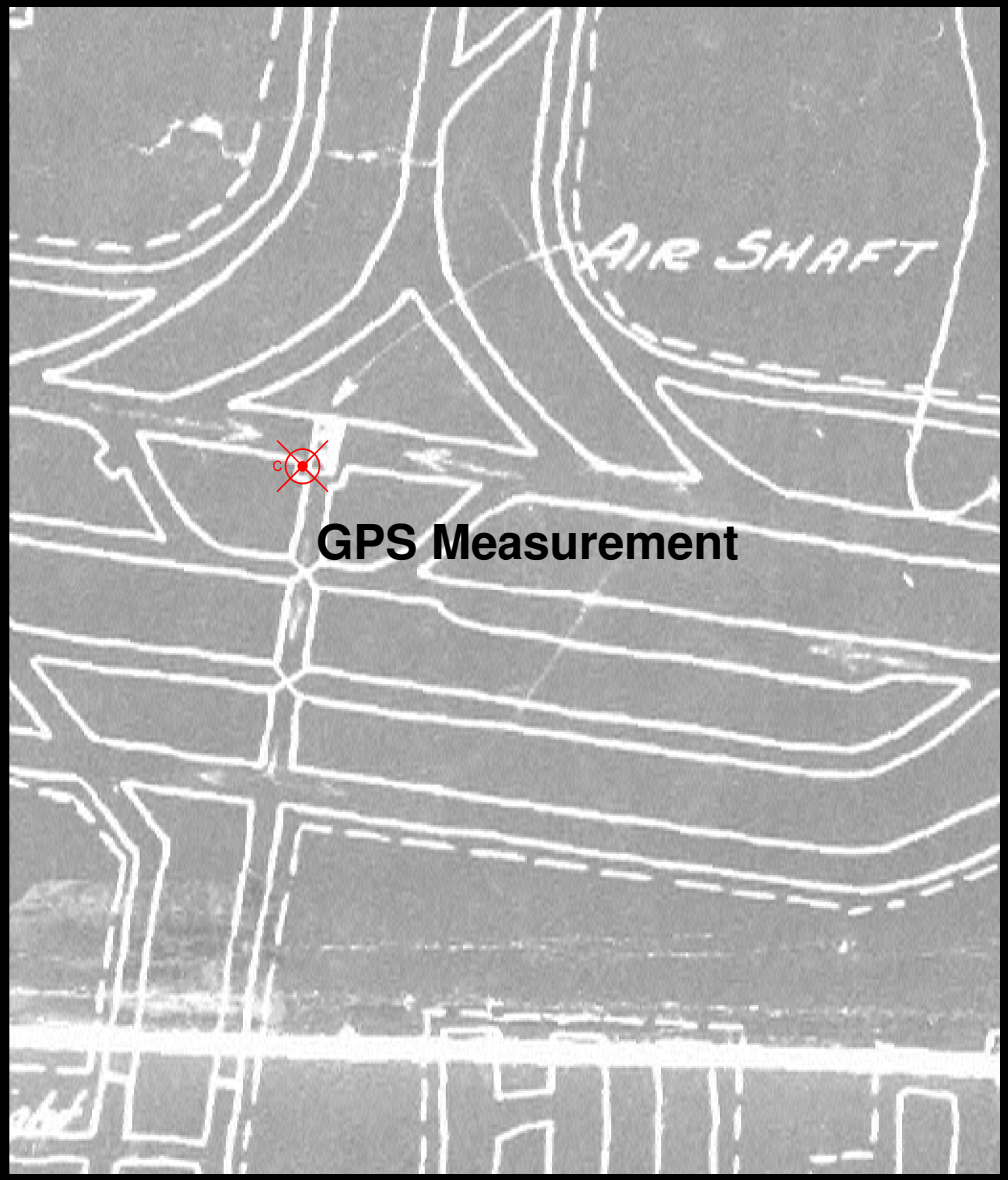
How Can We Confirm The Accuracy And Precision Of The Mine Map And Geo-Rectification Process ?

- Map Inspection
  - Exactness of pillar geometry renderings
  - Exactness of overall mine geometry

How Can We Confirm The Accuracy And Precision Of The Mine Map And Geo-Rectification Process ?

- Map Inspection
- GPS measurement of surface features shown on the mine map.

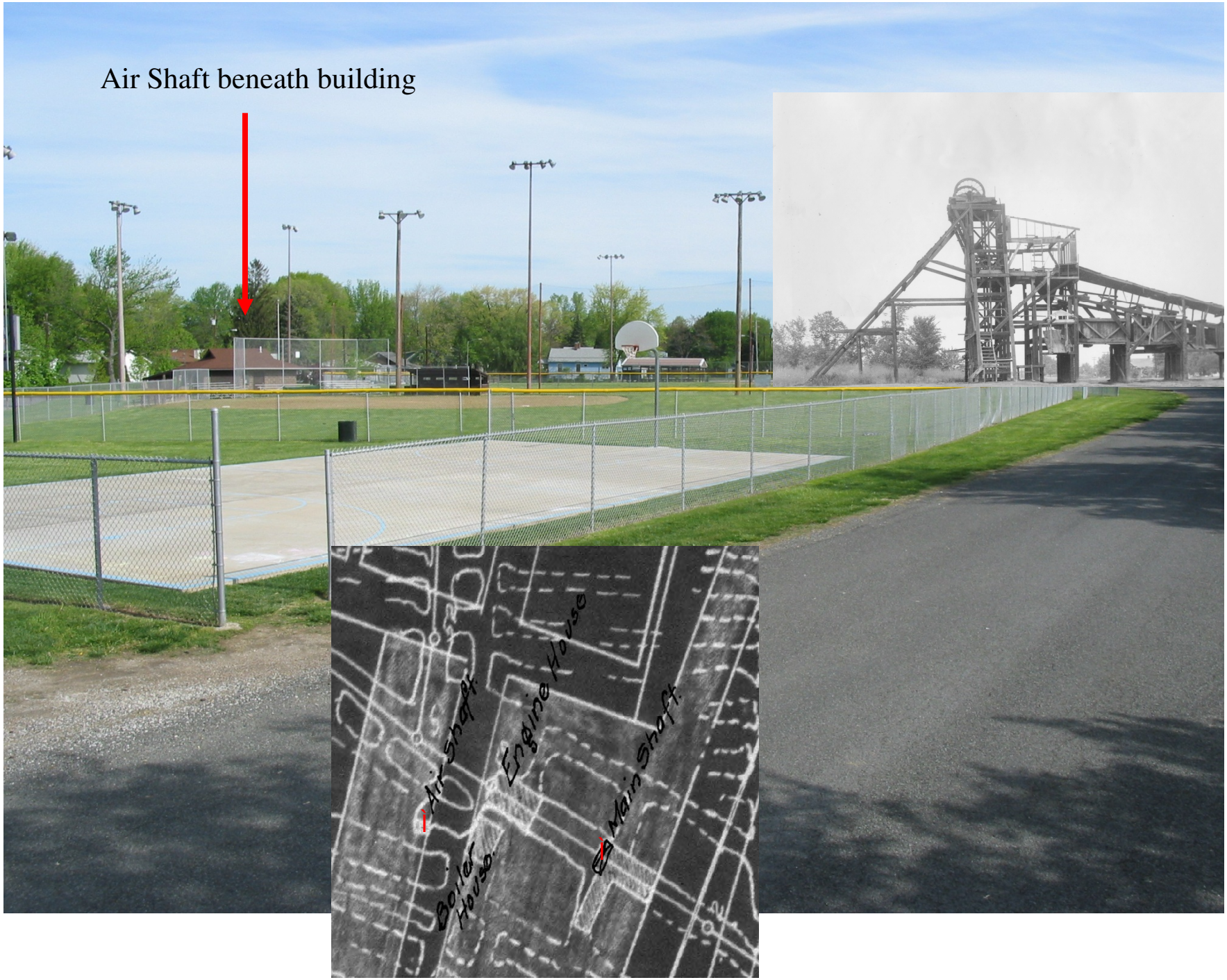
GPS Location of Shaft On Geo-Rectified Mine Map



Donk Brothers Coal & Coke Thermal Mine c. 1940s

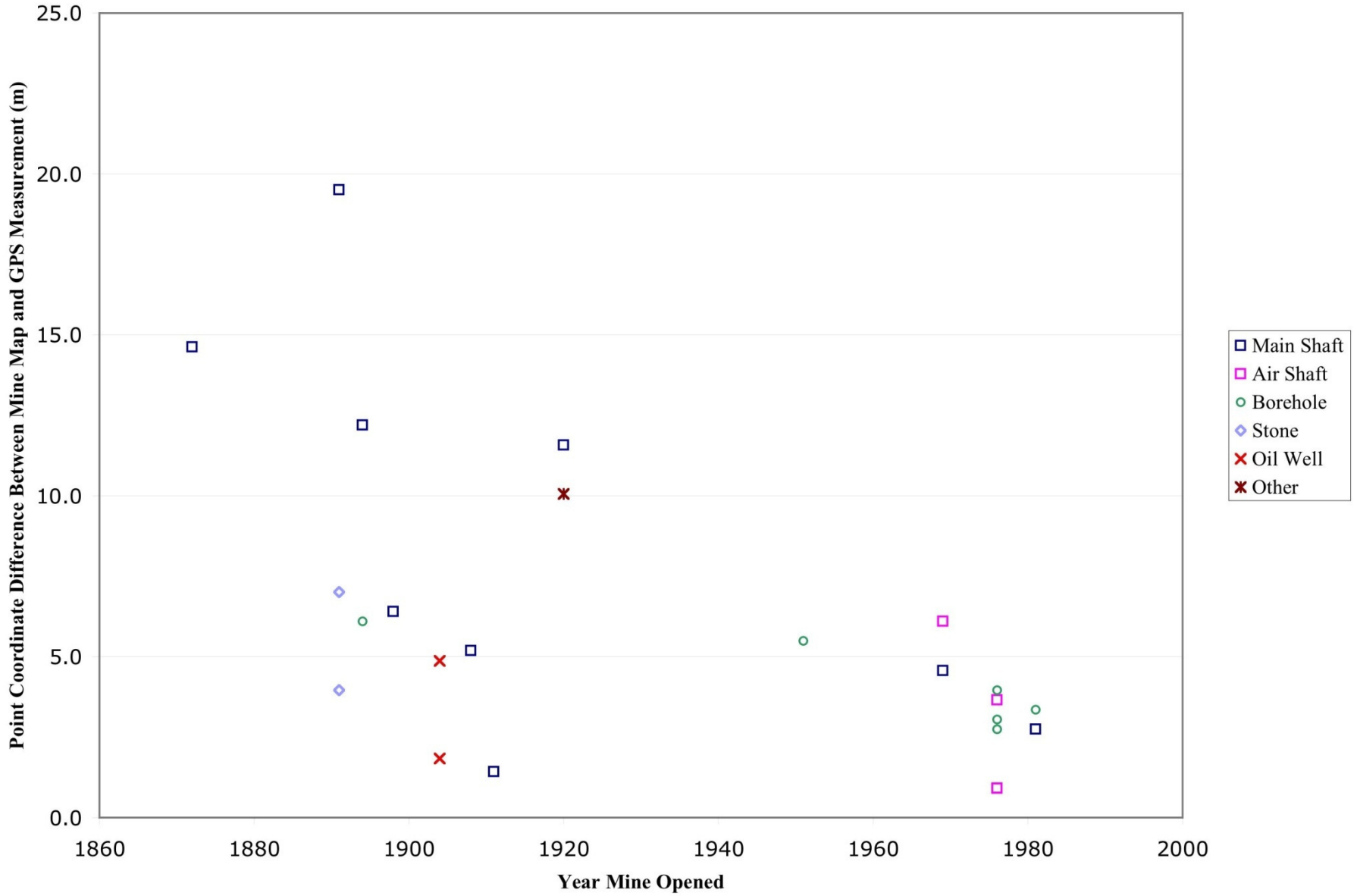
Courtesy of Madison County Historical Society

AML Project : Shaft Fill and Concrete Cap – 2002 Photo


Air Shaft beneath building
Air Shaft
Engine House
Main Shaft
Boiler House


GPS on Stone
GPS of Stone
0 10 20 30 40 50 Feet

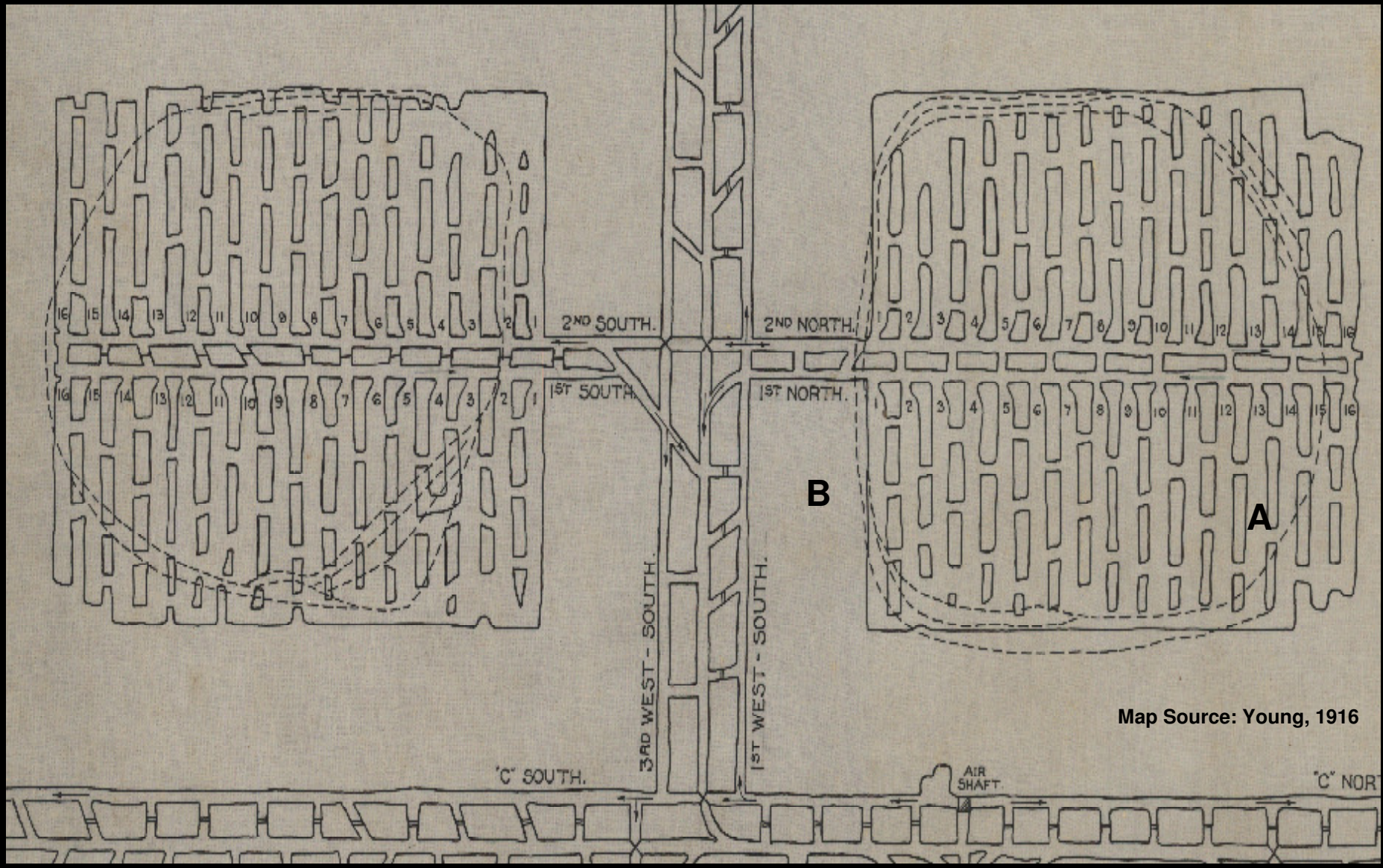
Plot of X-Y Coordinate Differences Between GPS Measurement and Point Location Shown on Geo-rectified Mine Map.



How Can We Confirm The Accuracy And Precision Of The Mine Map And Geo-Rectification Process ?

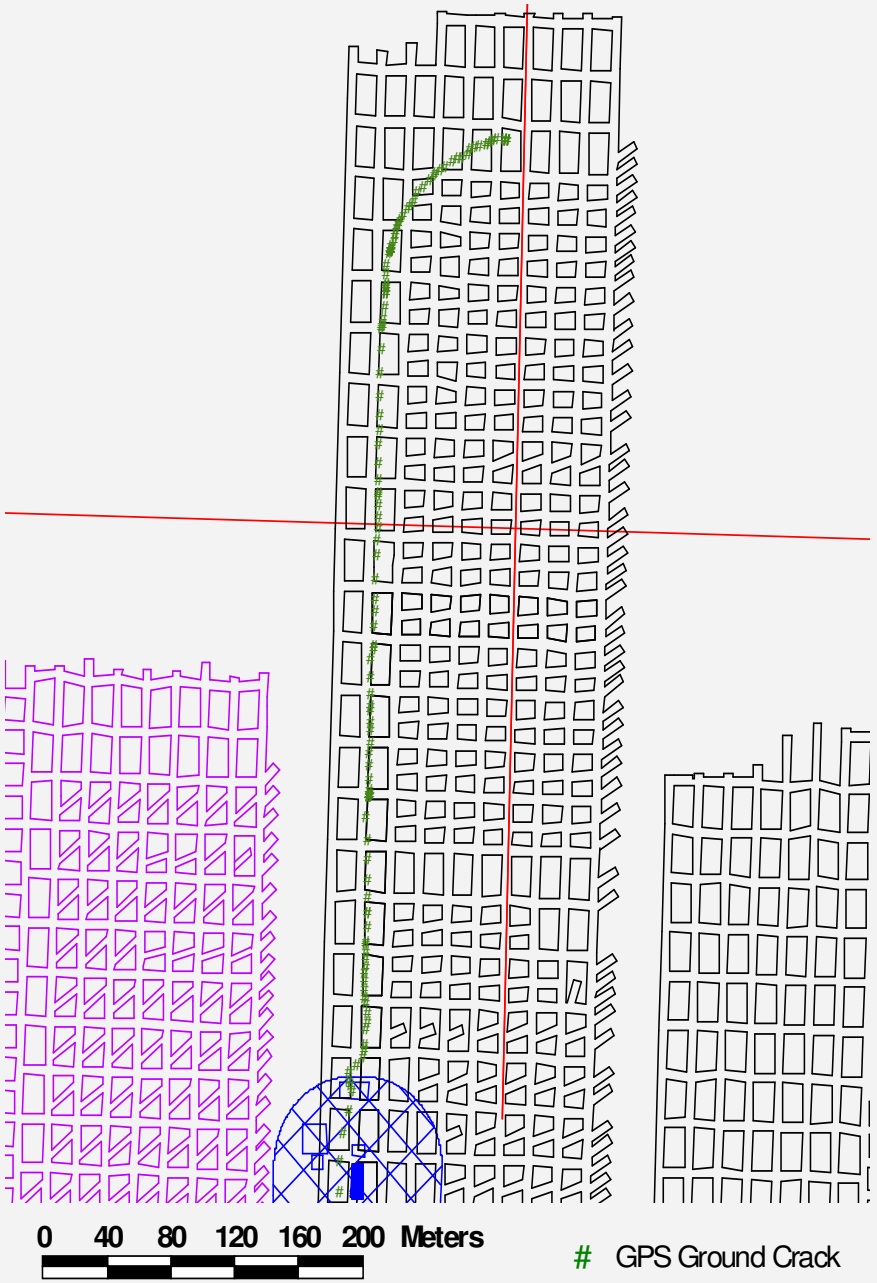
- Map Inspection
- GPS measurement of surface features shown on the mine map.
- Subsidence as an indicator

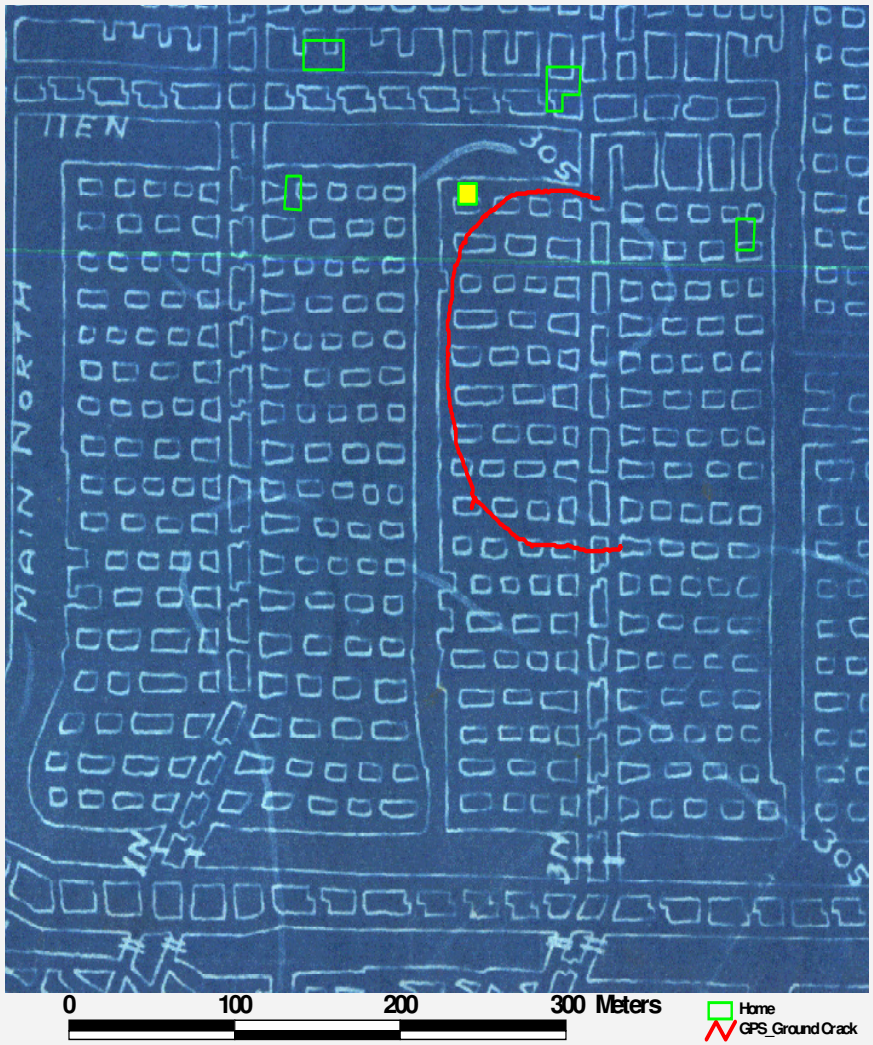
Fundamental Relationship of Subsidence To Mining



In 1916, Young found that: 1) subsidence forms directly over mine failure and
2) ground cracks form within panel at ribside

GPS Measurement of Subsidence Related Ground Cracks On Geo-Rectified Mine Map.





Subsidence Characteristics in Relation to Underground Mining

Young, 1916:

- Subsidence forms directly above the mine failure .
- Subsidence related ground cracks form within a panel at ribside.

Herbert and Rutledge, 1927:

- Subsidence related ground movements can be measured and expressed quantitatively.

Subsidence Characteristics in Relation to Underground Mining

Young, 1916:

- Subsidence forms directly above the mine failure .
- Subsidence related ground cracks form within a panel at ribside.

Herbert and Rutledge, 1927:

- Subsidence related ground movements can be measured quantitatively.
- Ground settlement increases in magnitude through time until subsidence is complete.

Subsidence Characteristics in Relation to Underground Mining

Young, 1916:

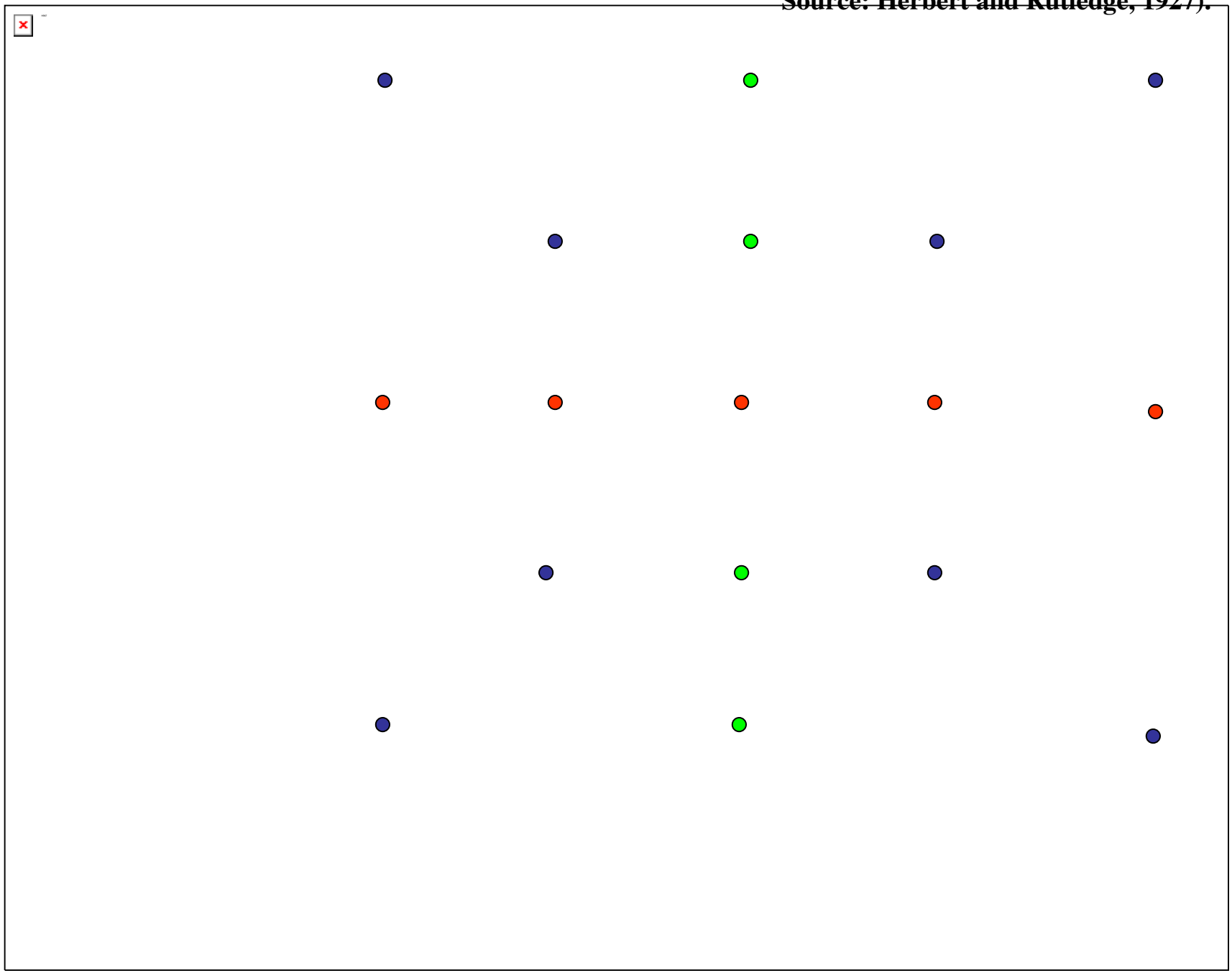
- Subsidence forms directly above the mine failure .
- Subsidence related ground cracks form within a panel at ribside.

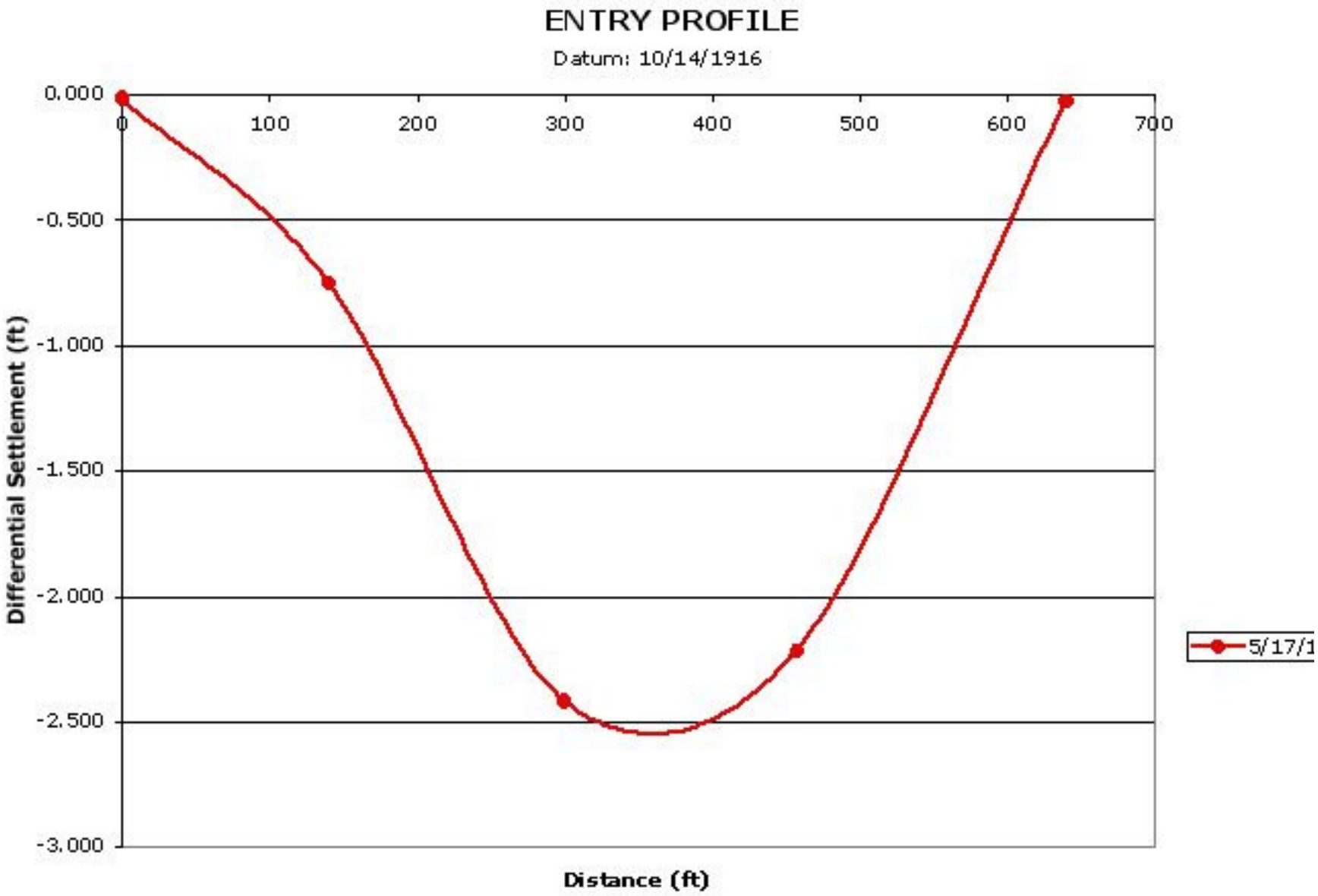
Herbert and Rutledge, 1927:

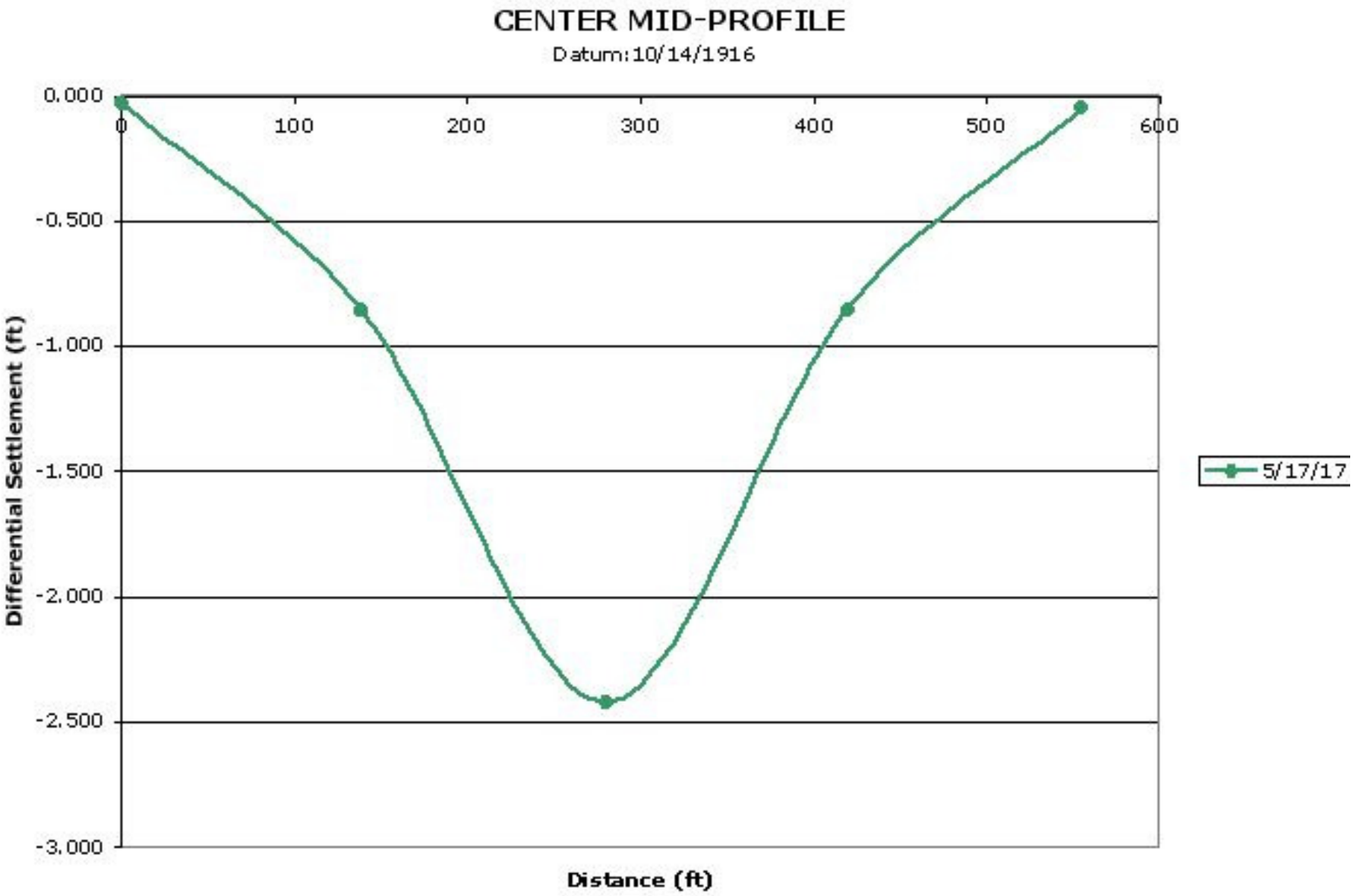
- Subsidence related ground movements can be measured quantitatively.
- Ground settlement increases in magnitude through time until subsidence is complete.
- Maximum settlement occurs over the panel and decreases in magnitude until there is zero settlement at or near ribside.

Location of Survey Monuments and Ground Cracks Relative To Mine Workings.

Source: Herbert and Rutledge, 1927).



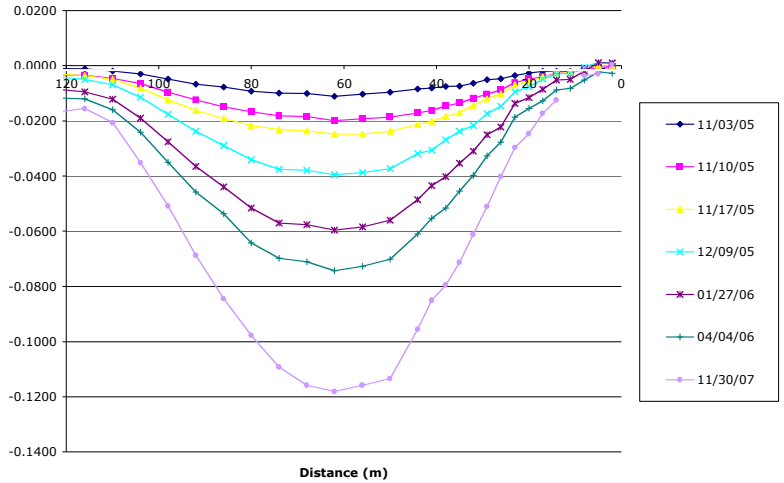

ENTRY PROFILE
Datum: 10/14/1916
0.000
-0.500
-1.000
-1.500
-2.000
-2.500
-3.000
0
100
200
300
400
500
600
700
Differential Settlement (ft)
Distance (ft)
5/17/1


CENTER MID-PROFILE
Datum:10/14/1916
0.000
-0.500
-1.000
-1.500
-2.000
-2.500
-3.000
0
100
200
300
400
500
600
Differential Settlement (ft)
Distance (ft)
5/17/17

Subsidence Information Sources

- Direct field measurement of active subsidence.
  - GPS ground cracks
  - Establish Survey Profiles

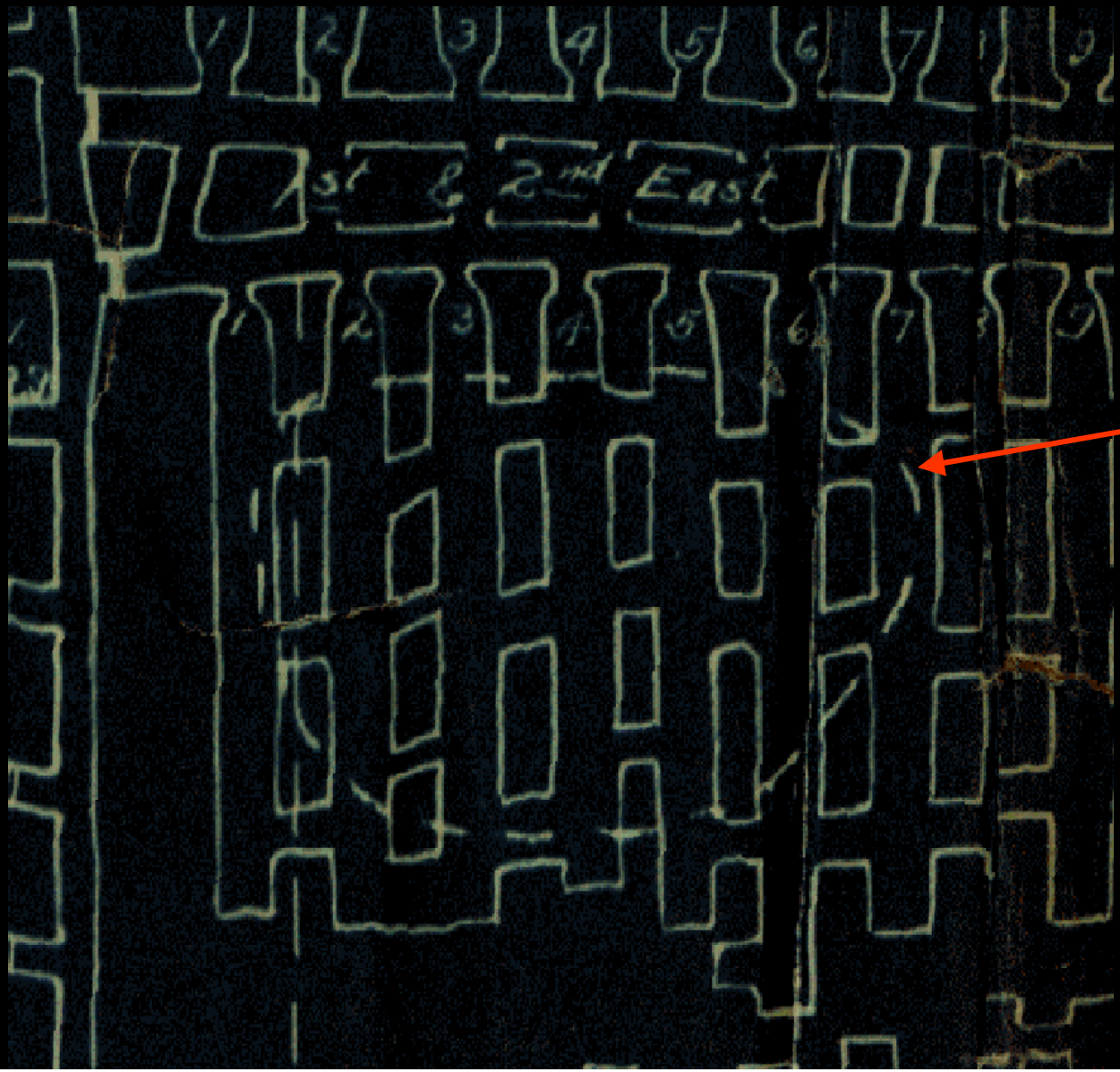
DN Profile (Datum 10/27/2005)



Subsidence Information Sources

- Direct field measurement of active subsidence.
  - GPS ground cracks
  - Establish Survey Profiles
- Historical Records and Subsidence Studies.

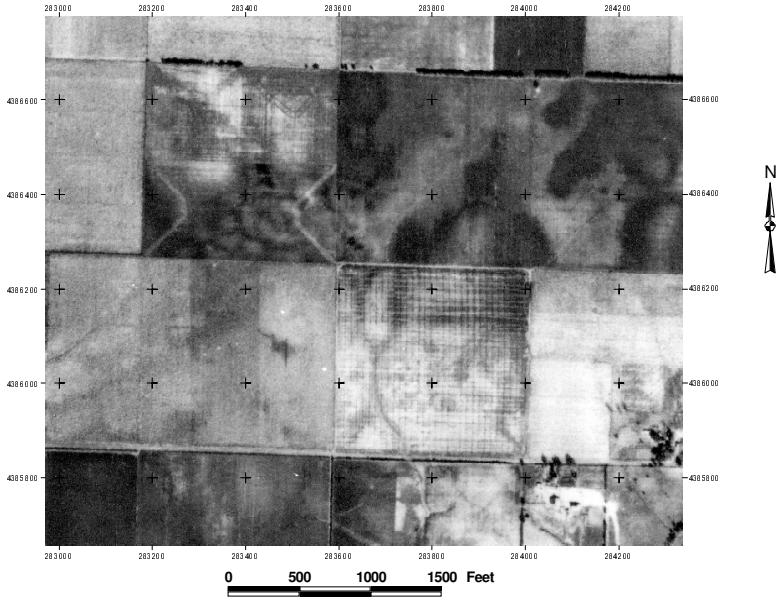
Example Of Subsidence Identified On Mine Map



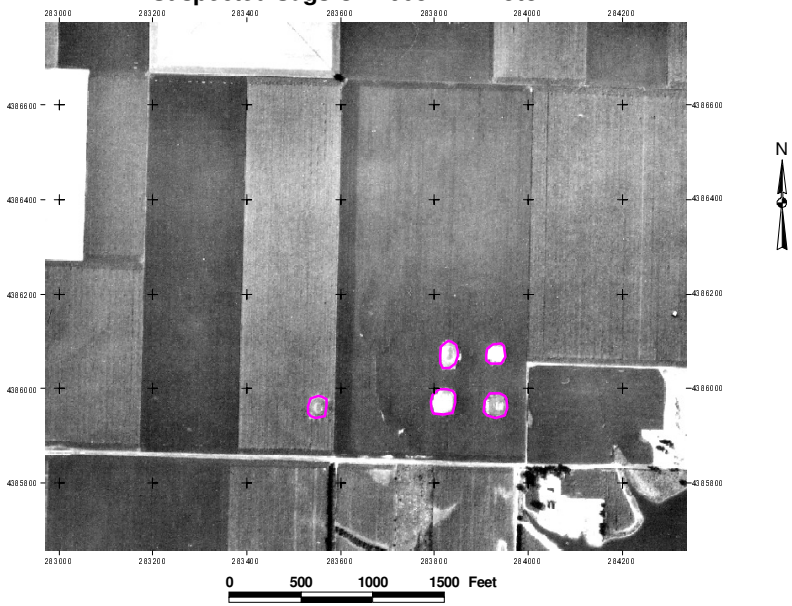
Subsidence Information Sources

- Direct field measurement of active subsidence.
  - GPS ground cracks
  - Establish Survey Profiles
- Historical Records and Subsidence Studies.
- Aerial Photography.

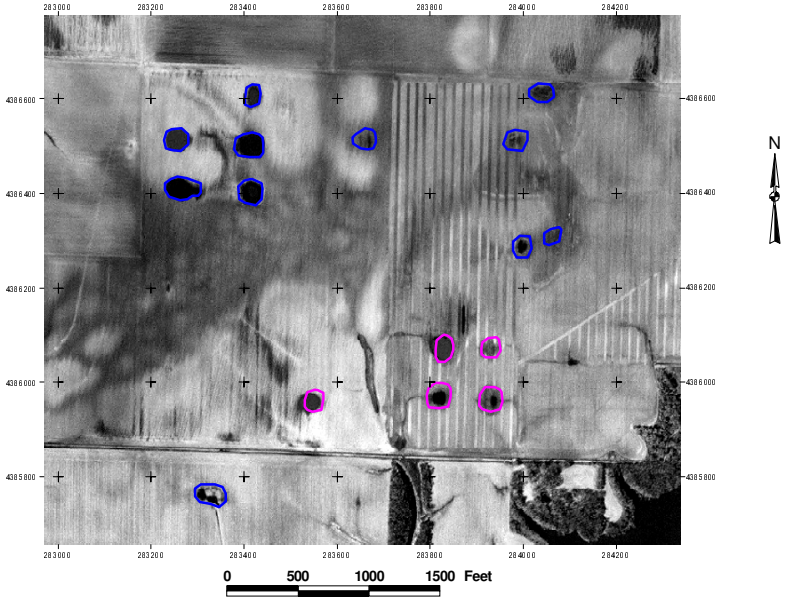
1938 Airphoto Pre-mining



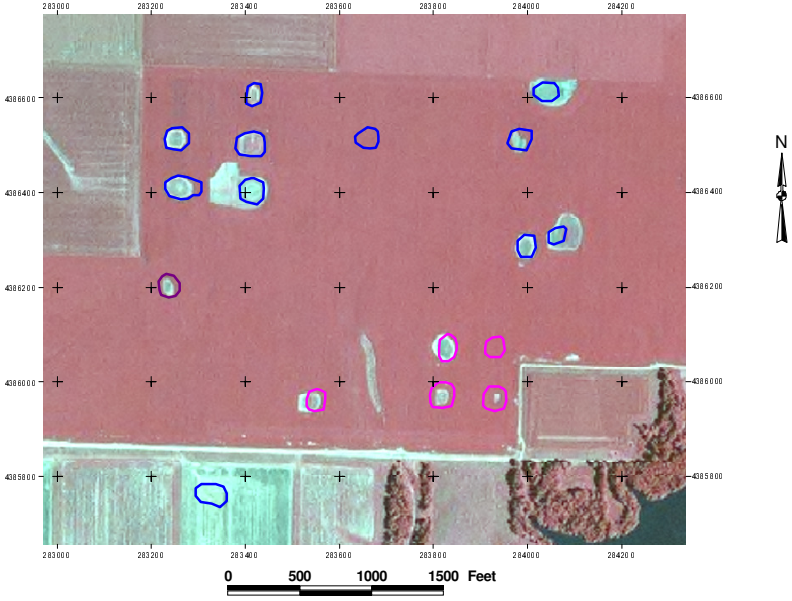
Suspected Sags On 1968 Air Photo



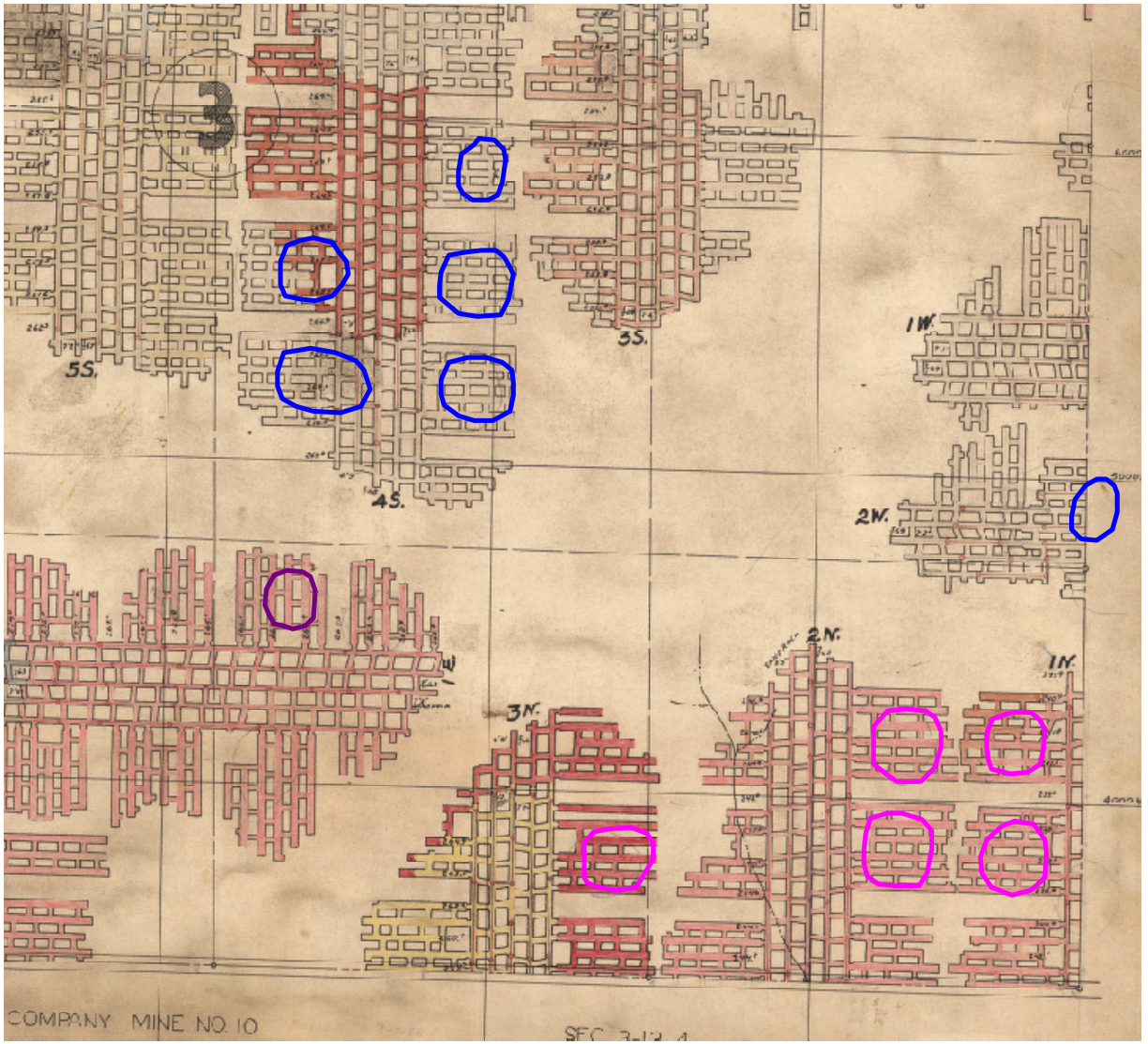
Suspected Sags 1968 Air Photo (Pink) 1998_1999 Air Photo (Blue)



Suspected Sags 1968 Air Photo (Pink) 1998_1999 Air Photo (Blue) 2004 IR (Purple)



Sag Subsidence Identified From Aerial Photography



N
W E
S

1968 _Suspected Sag
1998_ Suspected Sag
2004_Suspected Sag

0 500 1000 1500 2000 Feet

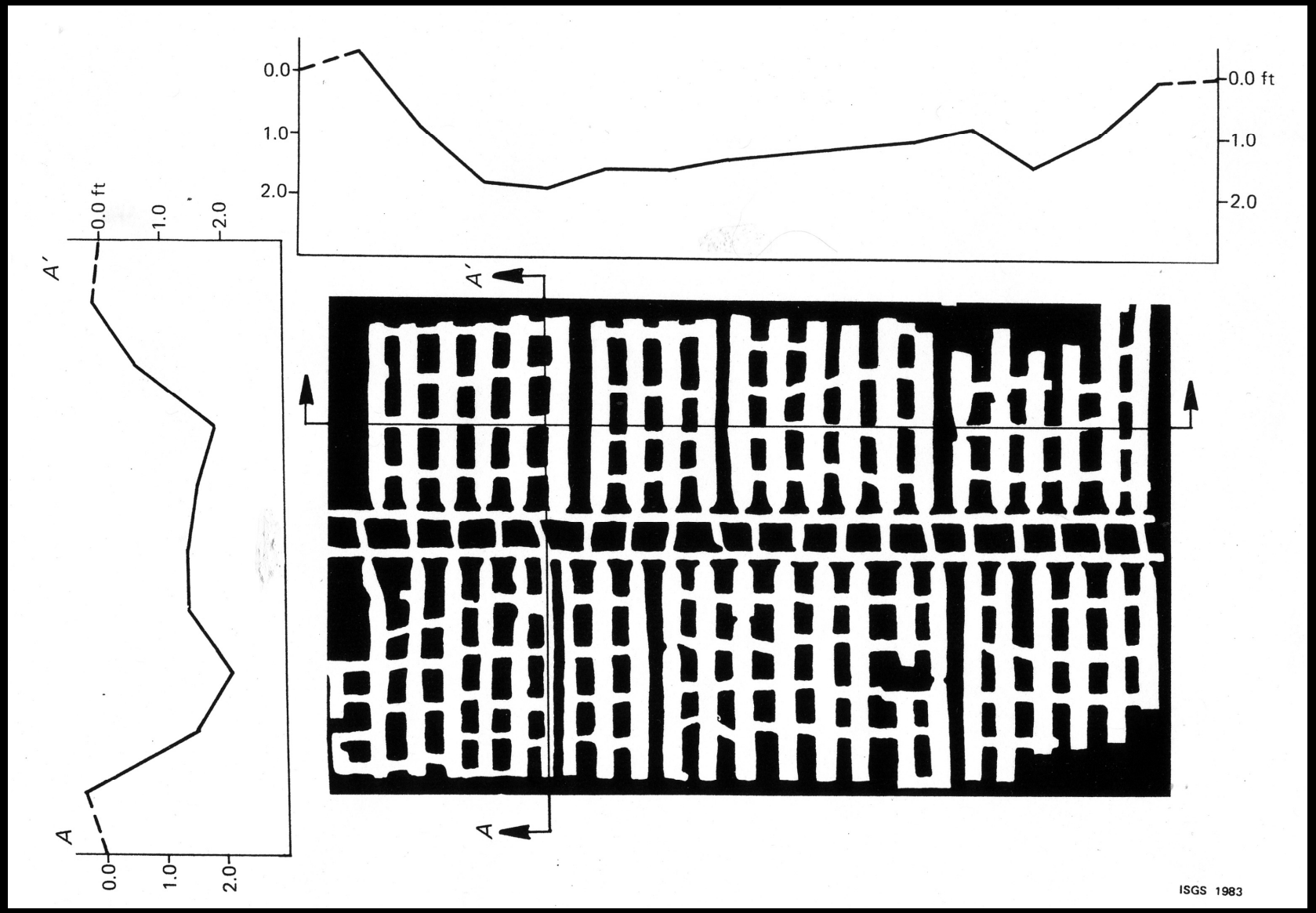
GPS Measurement, Mine Map and Aerial Photography Supermimposed

Sag located 4.5 miles from shaft

N
W E
S

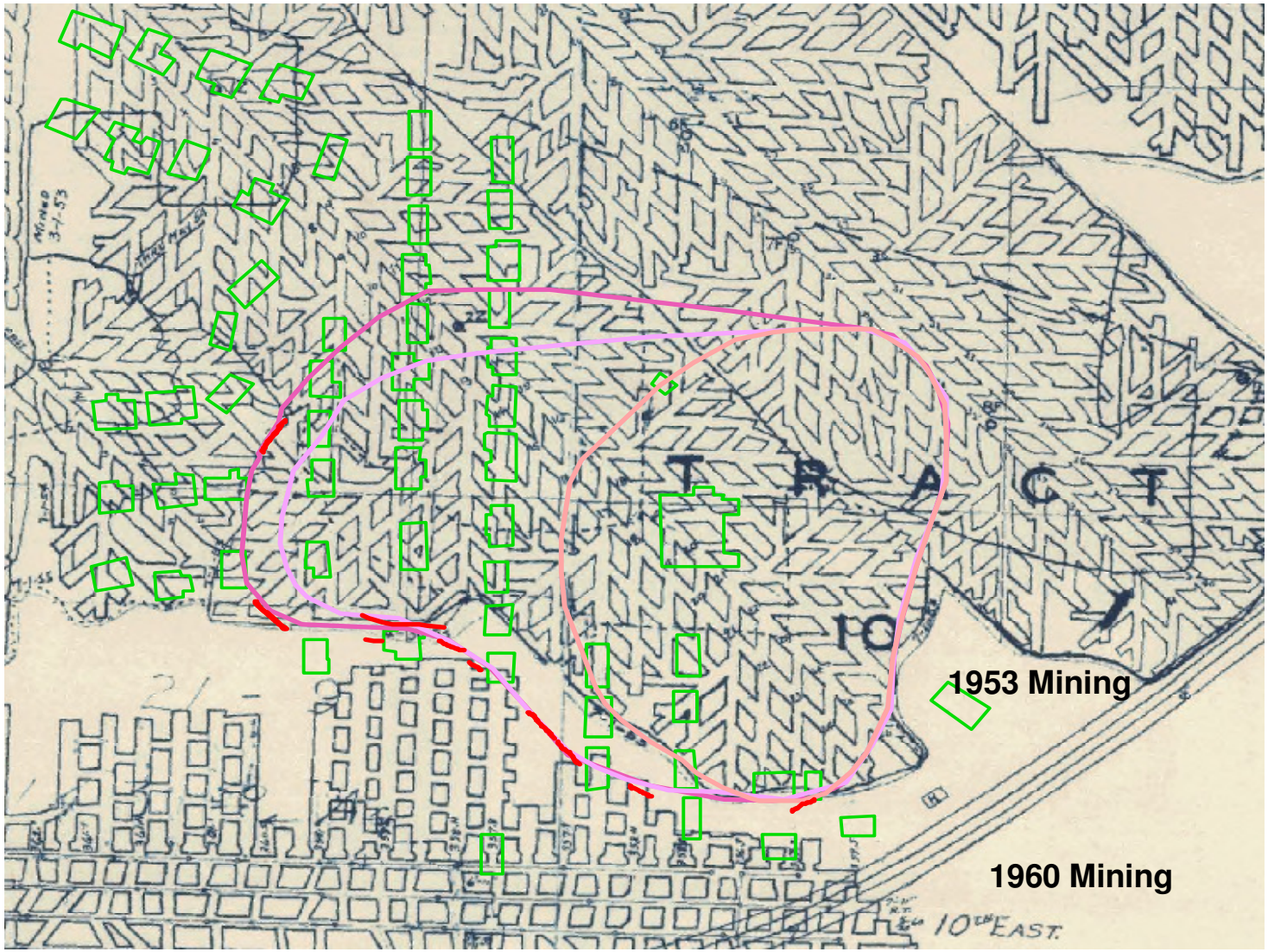
Sags Noted On Mine Map
1934 Quade Sag_GPS
1901 Entry Pillars
1902 Entry Pillars
1903 Entry Pillars
1904 Entry Pillars
1905 Entry Pillars
1906 Entry Pillars
1907 Entry Pillars
1908 Entry Pillars
1909 Entry Pillars
1910 Entry Pillars
1911 Entry Pillars
1912 Entry Pillars
1913 Entry Pillars
1914 Entry Pillars
1915 Entry Pillars
1916 Entry Pillars
1917 Entry Pillars
1918 Entry Pillars
1919 Entry Pillars
1920 Entry Pillars
1921 Entry Pillars
Barrier Pillars
Reserved Coal
Shaft Locations
Shaft Pillars

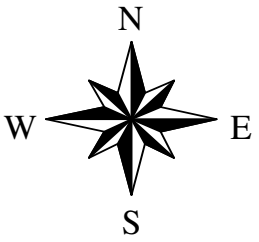
0 200 400 600 800 1000 Meters


0.0
1.0
2.0
0.0 ft
1.0
2.0
A'
0.0 ft
1.0
2.0
A'
A
A
0.0
1.0
2.0
ISGS 1983

Examples of Mapping Discrepancy

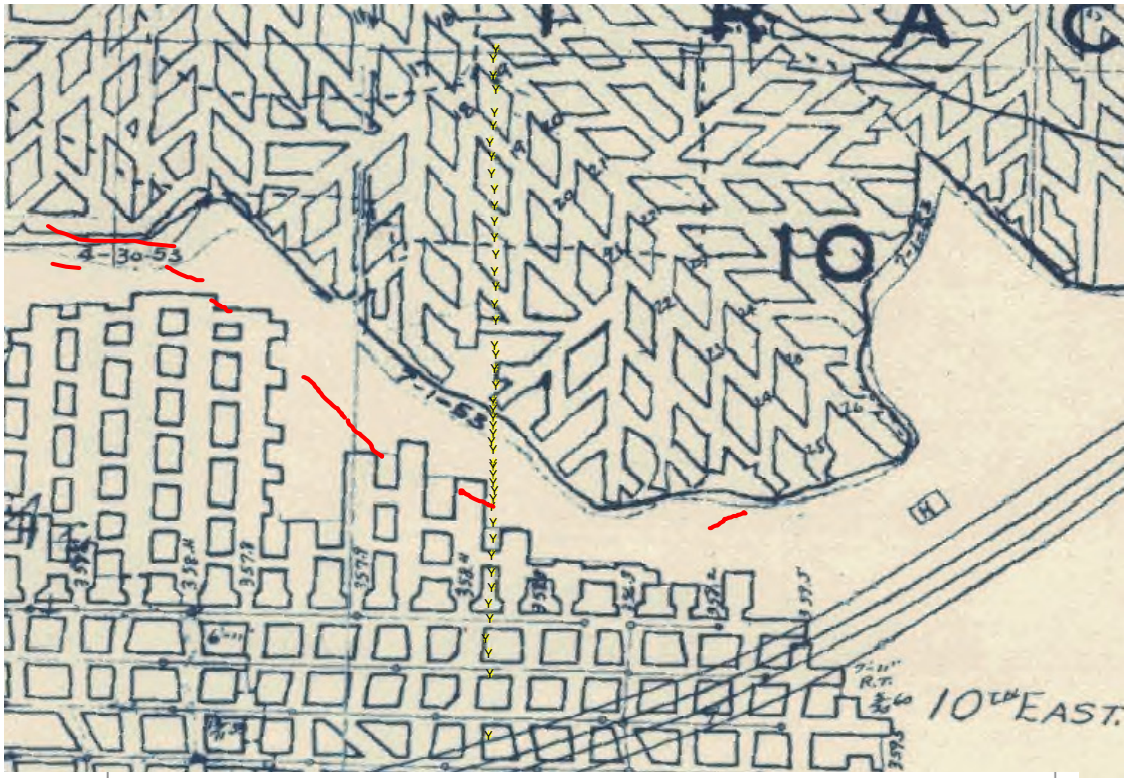
Mine Map Accuracy AML Concern

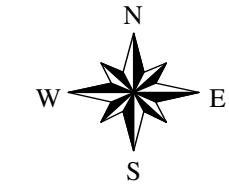




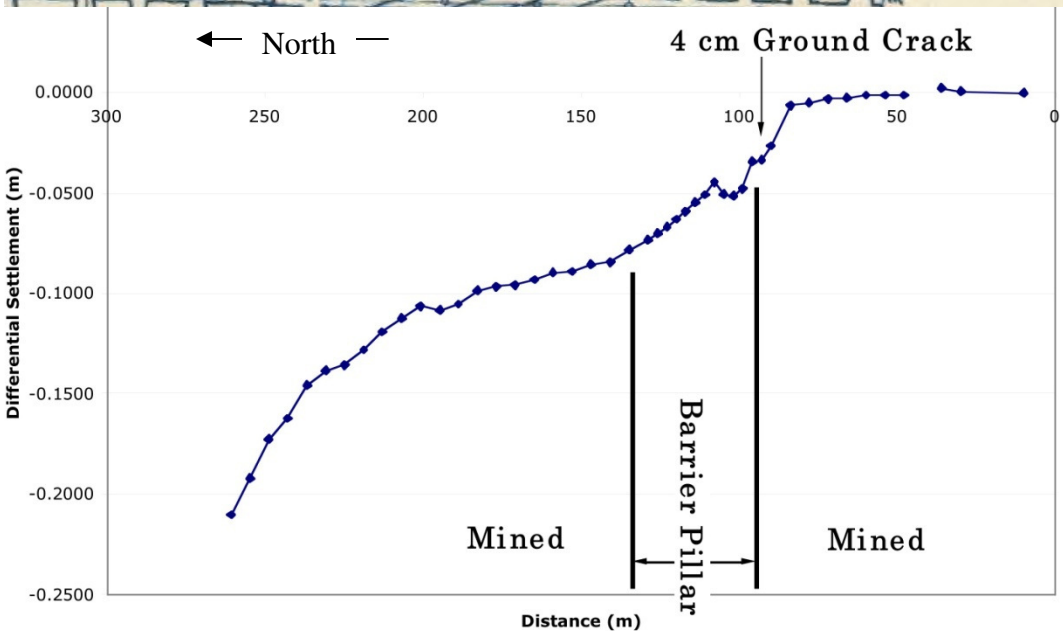
Ground Cracks 1_2008
Sag Bounds 7_16_2007
Sag bounds 8_21_2007
Sag Bounds 9_18_2007
Home

0 60 120 180 240 300 Meters



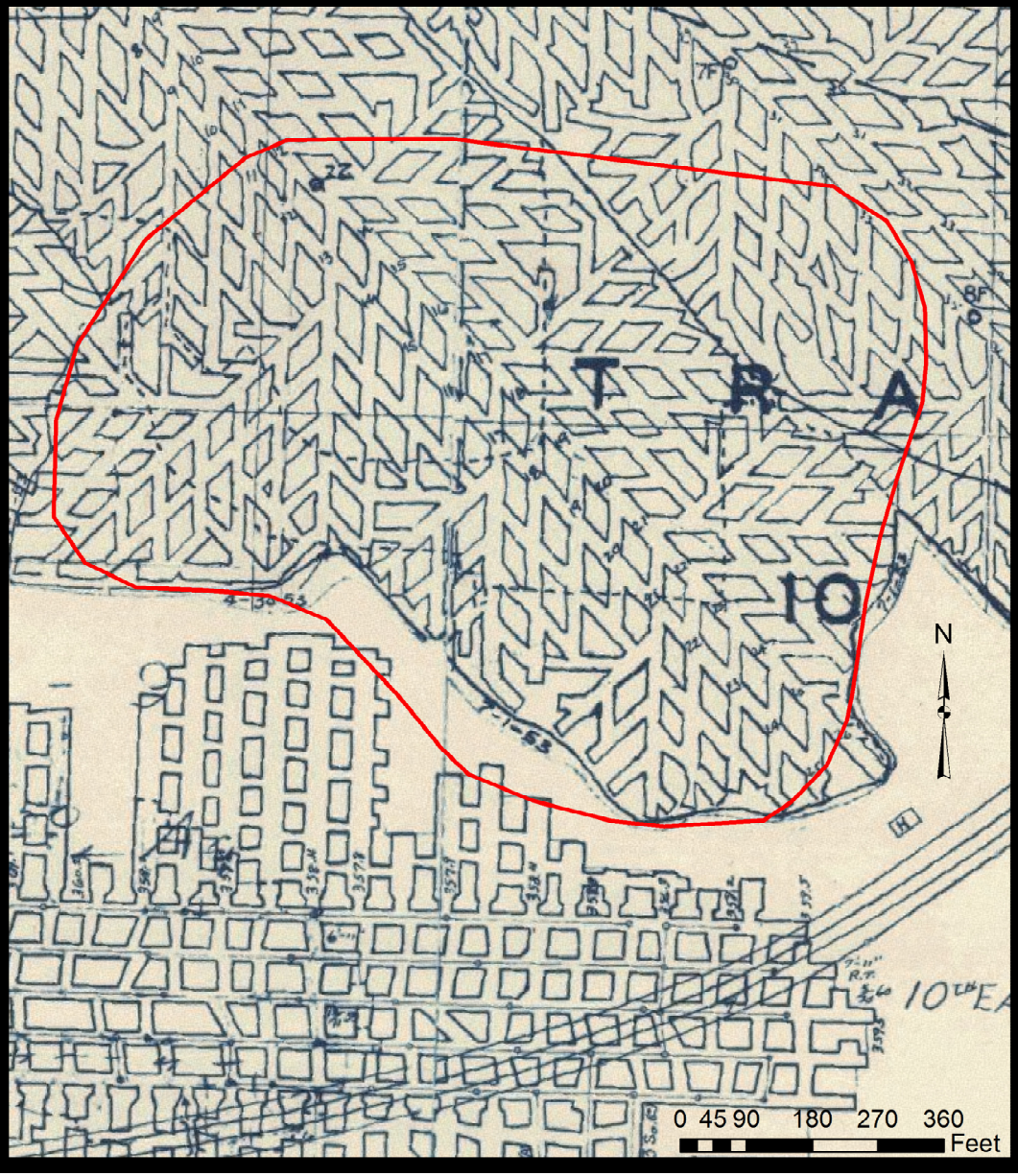


Ground Cracks 1_2008
Survey Pts 8_21_2007



Mine Map Accuracy Mine Development Concern

2008 Sag Boundary Indicates +/- 50 foot Map Error



1953 Mining

1960 Mining

Mine Map Accuracy Circa 1930

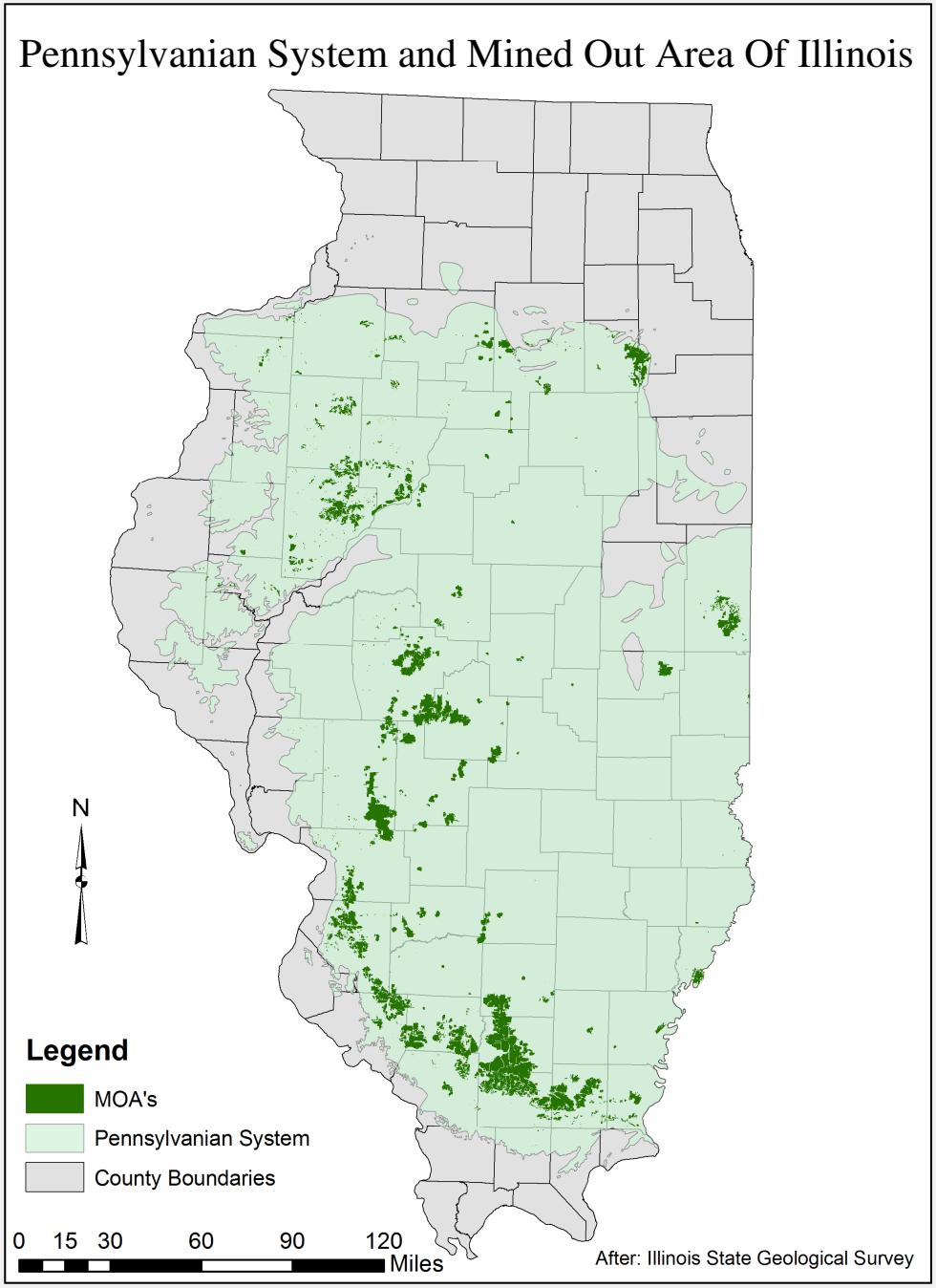
I-72 Bridge Project

Boreholes Drilled = 104
Coal = 5
Mine Voids = 99
Success Rate = 95%

Date of Mining Shown:
Mar. 31, 1927 – Mar. 20, 1932

“Discuss the identification of potential subsidence probabilities related to underground mining”

Personal Communication Greg Conrad, 1.23.2012


Pennsylvanian System and Mined Out Area Of Illinois
N
Legend
MOA's
Pennsylvanian System
County Boundaries
0 15 30 60 90 120
Miles
After: Illinois State Geological Survey

Herrin Coal Depth

The digital files and maps used for this study were compiled from data obtained from a variety of public and private sources and have varying degrees of completeness and accuracy. They present reasonable interpretations of the geology of the area and are based on available data. However, the interpretations are based on data that may vary with respect to accuracy of geographic location, the type and quantity of data available at each location, and the reliability of the data sources. Consequently, the accuracy of features shown in these files varies from place to place.

ISGS
Illinois State Geological Survey

DRAFT

Legend

Herrin Depth

Depth in Feet

- < 200 ft
- 200 to 300 ft
- 300 to 400 ft
- 400 to 500 ft
- 500 to 600 ft
- 600 to 700 ft
- 700 to 800 ft
- 800 to 900 ft
- 900 to 1000 ft
- 1000 to 1100 ft
- 1100 to 1200 ft
- 1200 to 1300 ft

This map is made available at this time in DRAFT form only. It has not yet been reviewed to the normal standards of the Illinois State Geological Survey (ISGS) review process. It is made available in this manner as an 'open file' in order to deliver a product to our customers as fast as possible and to meet a particular need that we have encountered in public requests for this information

http://www.isgs.uiuc.edu

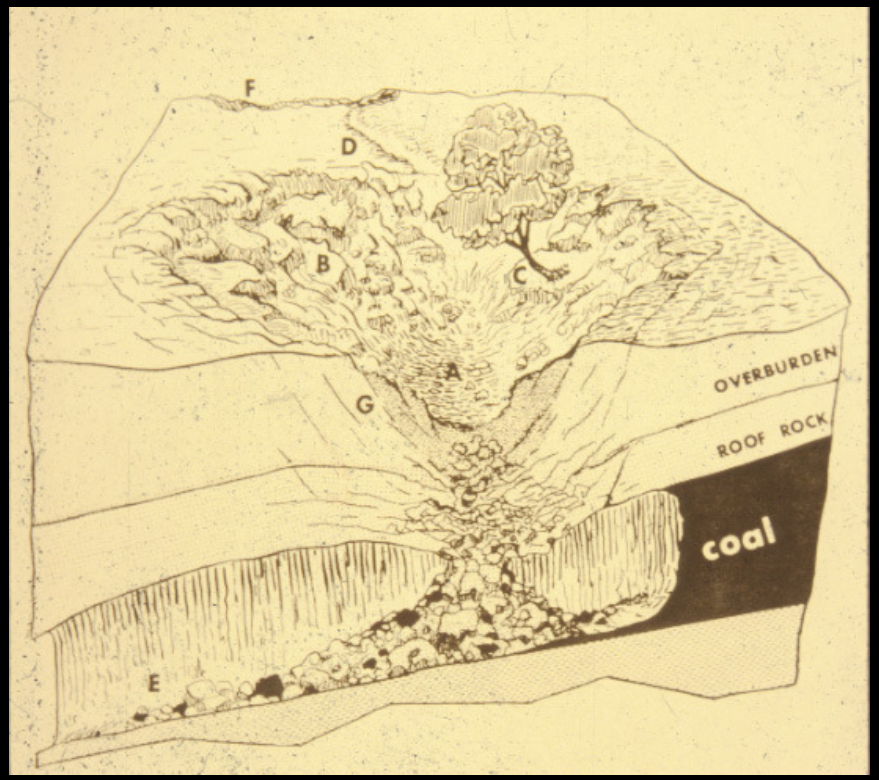
http://www.isgs.uiuc.edu/isgshome/coal.htm

0 20 40
Miles

N

1:2,350,000

Pit Subsidence In Illinois



'Where shallow mining is carried on, falls of mine roof are frequently followed by surface subsidence causing pit holes or caves." - Lewis Young, 1916. p35.

Aerial photograph of numerous pit subsidence events (speckled soil pattern) near Kangley.

From: Willman and Payne
ISGS Bulletin 66, 1942

"The upward limit of a roof fall has seldom been observed to be more than 1 to 1.5 times the span of the room or intersection …

- Stephen Hunt, 1980

The caving process stops when it encounters roof material sufficiently strong to bridge the opening or the volume of broken materials, due to bulking, fills the remaining void.

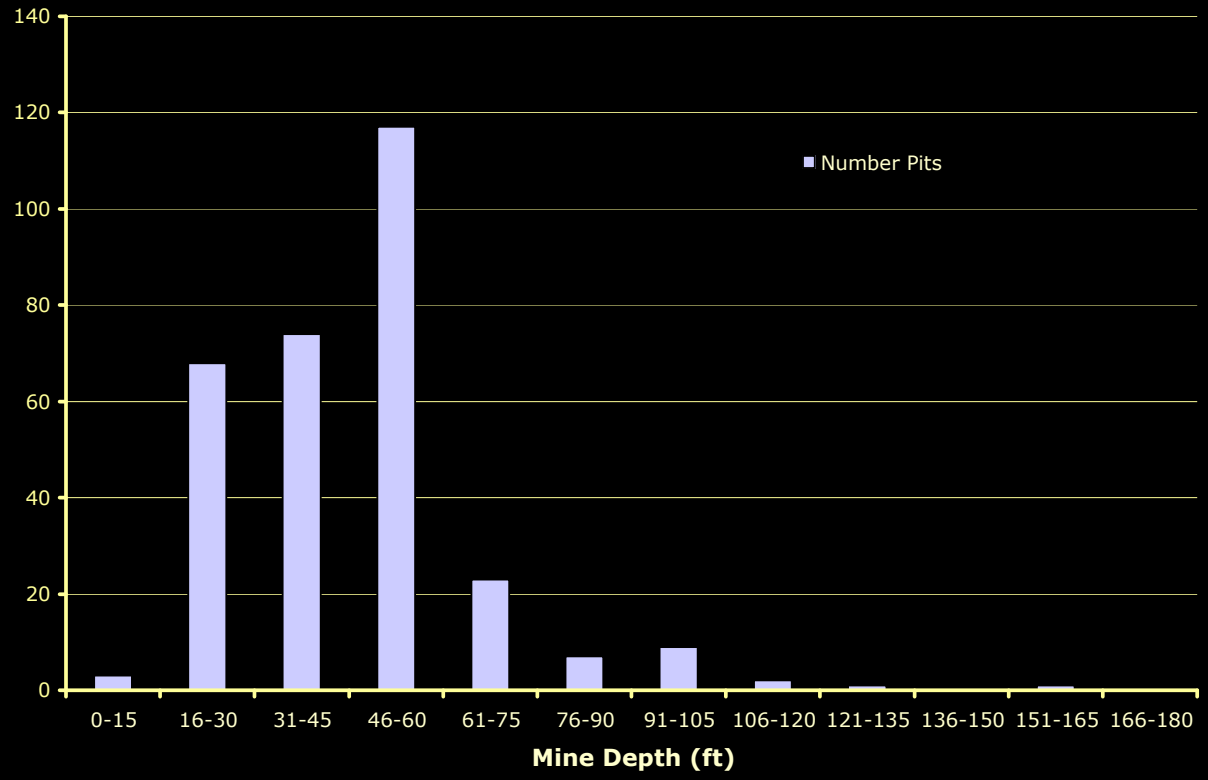
Room and Pillar Mining Characteristics In Illinois		
Mining Method	**Room Width (ft)**	**Expected Roof Caving Height (ft)**
Modified	**15-40**	**15-60**
Panel	**15-30**	**15-45**
Blind	**15-25**	**15-38**

Sources: compiled from Andros, S.O. 1914, ISGS and Stephen Hunt, Doctoral Thesis 1980

- In general, older mines are characterized by having wide rooms with narrow, irregularly shaped pillars.

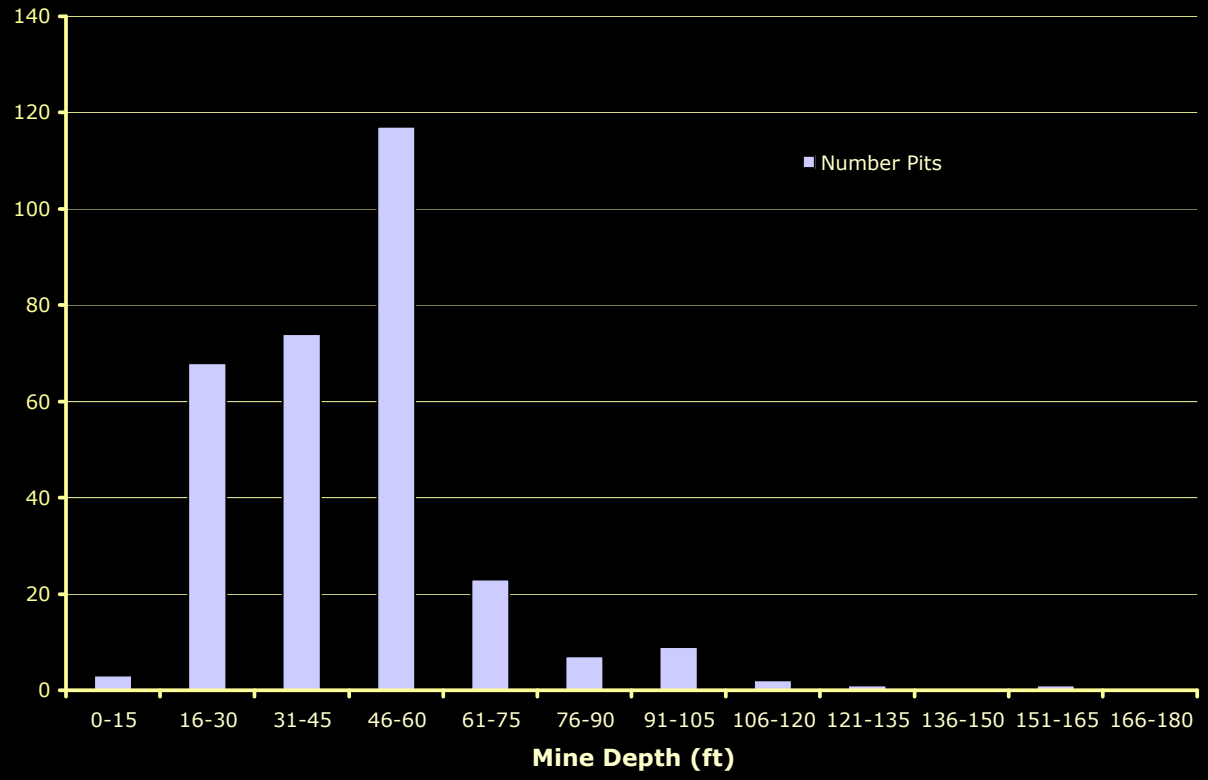
- If caving were the only factor in pit development, one would expect pit subsidence to be limited to mines operating at depths less than 60 feet.

Pit Frequency at Increasing Mine Depth Intervals



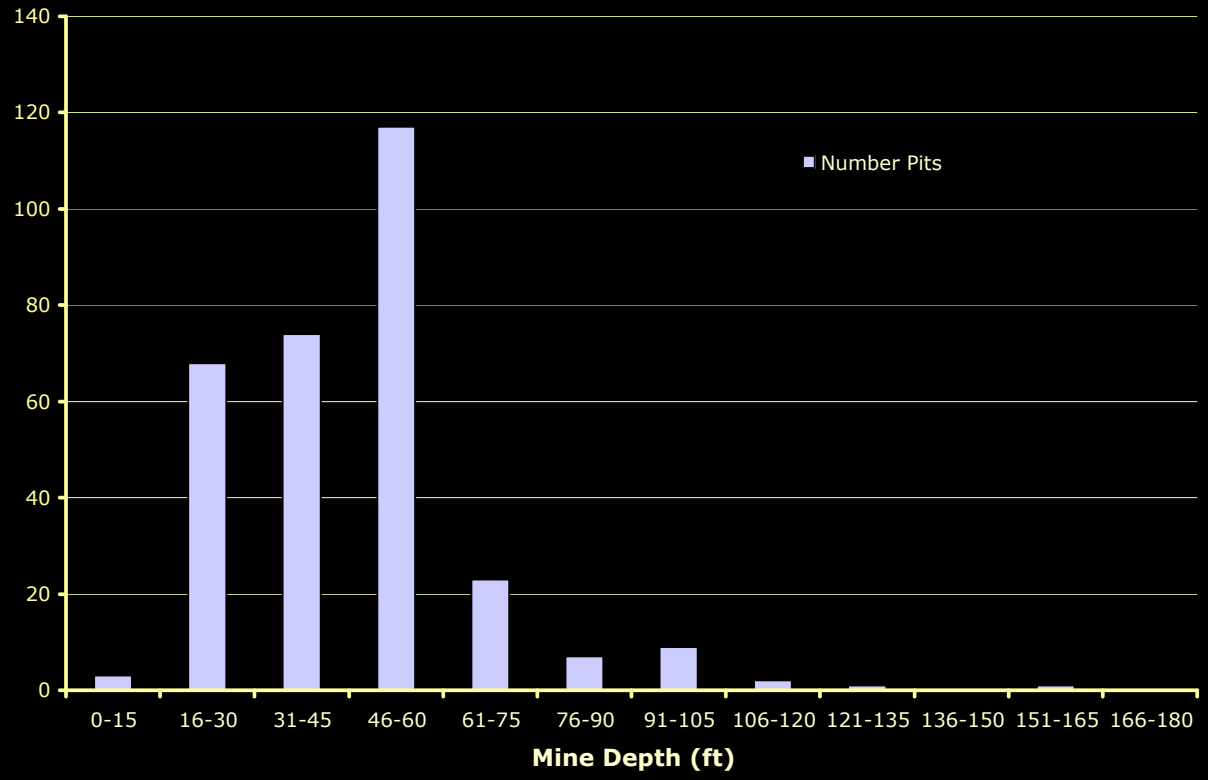
The above graph plots the frequency of pit subsidence in Illinois with respect to mine depth. The data is from AML Emergency Program files and is limited to pits forming over abandoned room and pillar mines.

Pit Frequency at Increasing Mine Depth Intervals



Eighty- five percent of the 306 pit subsidence events investigated developed over abandoned room and pillar mines that operated at depths less than 60 feet below ground surface.

Pit Frequency at Increasing Mine Depth Intervals



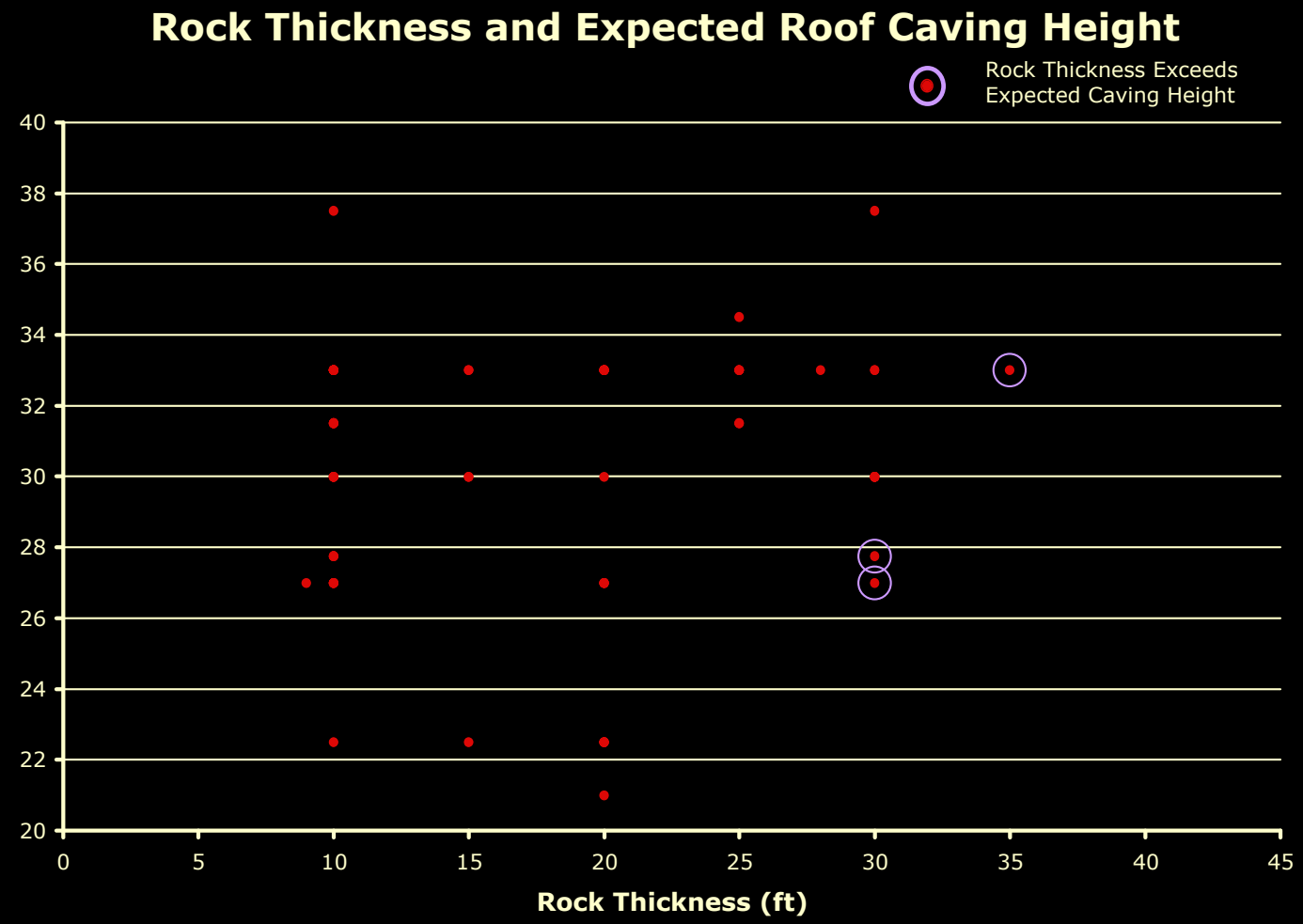
The skewing of the data towards mine depths 60 feet or less, suggests that caving height is an important factor in pit development but does not fully explain pit formation. Other factors must influence pit development in order to explain the 44 pits that formed over deeper mines.

What other factors influence pit development?

Rock Thickness and Rock Type

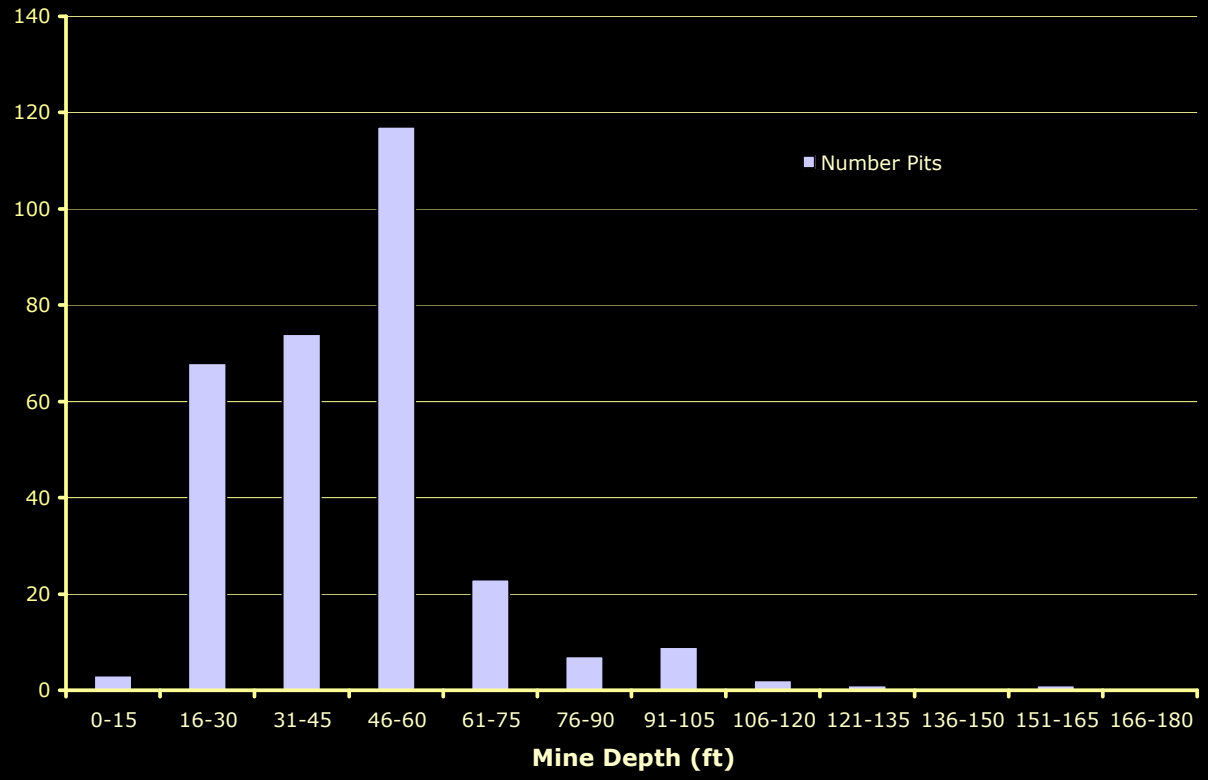
‘ If the rock cover is not thick and the surficial beds are heavy and loose, the mine openings may be filled by a rush of surficial material, so that the pit hole may have a much greater volume than the single mine chamber in which the break occurred.’

- Lewis Young, 1917 p35



The AML data, although few, suggests pit development is limited by rock thickness. Specifically, where rock thickness exceeds the calculated caving height pits are not likely to form.

Pit Frequency at Increasing Mine Depth Intervals



- In 1982, Bauer and Hunt suggest that pits are limited to mine depths less than 165 feet.

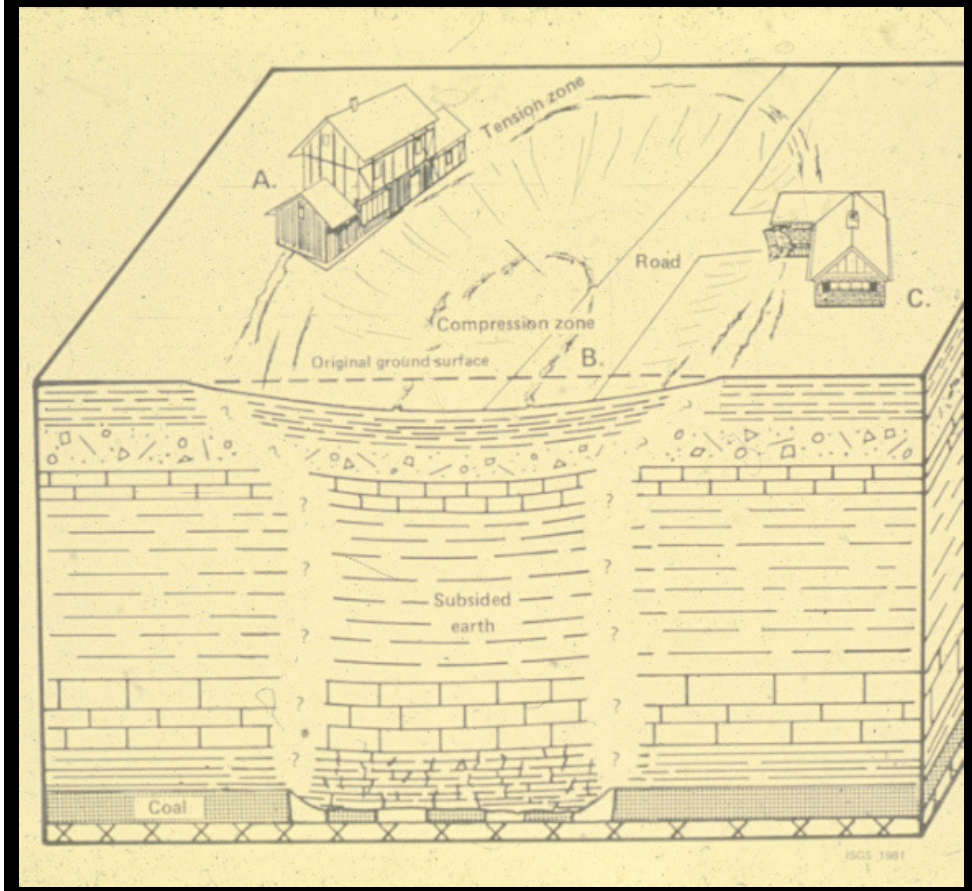
- AML Emergency Program data (1984-2004). Eighty- five percent of the 306 pit subsidence events developed over mines that operated at depths less than 60 feet below ground surface.

Introduction to the mechanics of

Sag Subsidence

Sag Type Subsidence

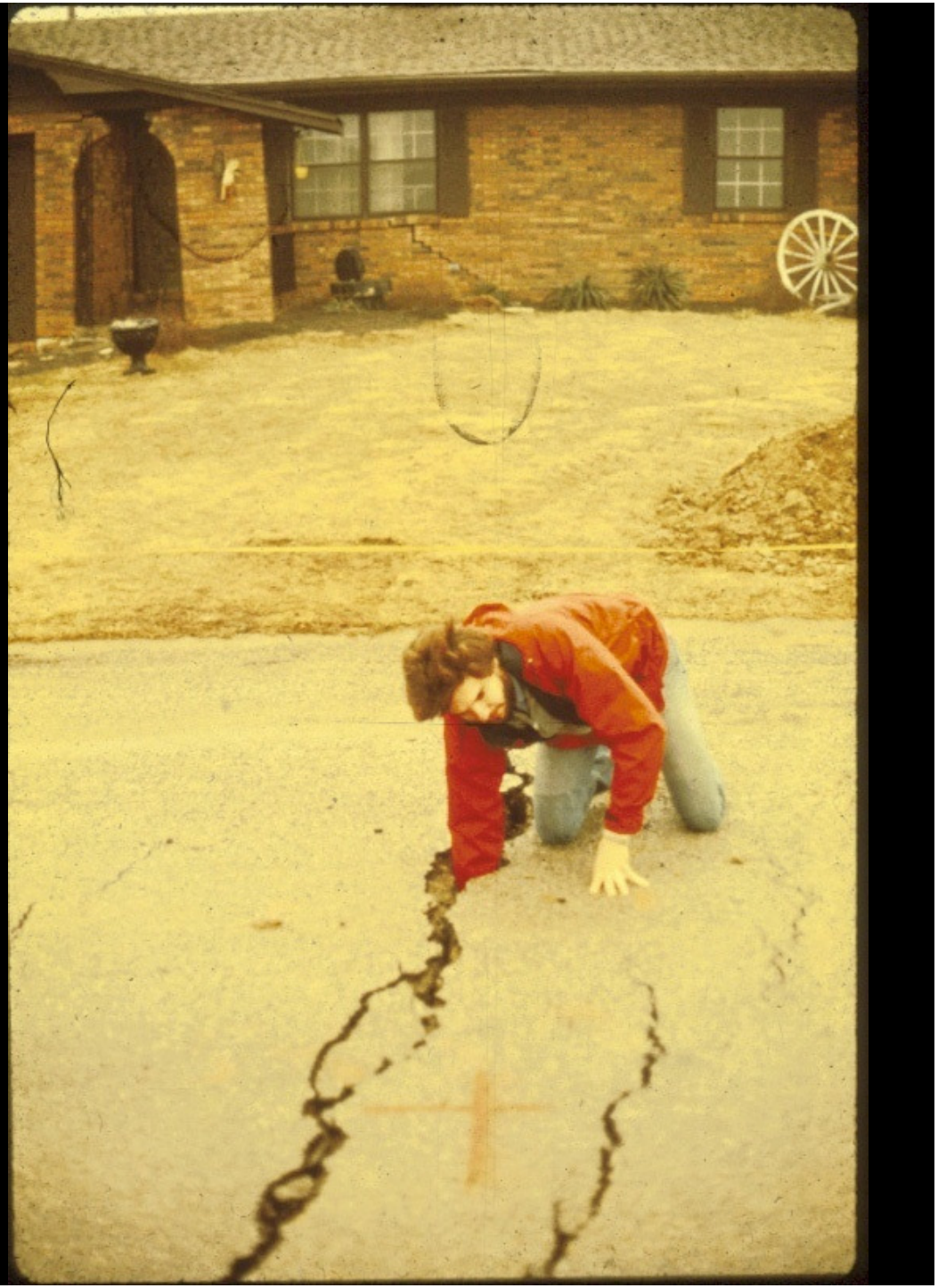
Schematic and Air Photograph



A bowl shaped depression, several hundred feet in diameter, forms as the ground warps downward in response to a room-and-pillar mine failure.

Tension Damages

Near the perimeter of the affected area, the ground stretches causing breaks to form.

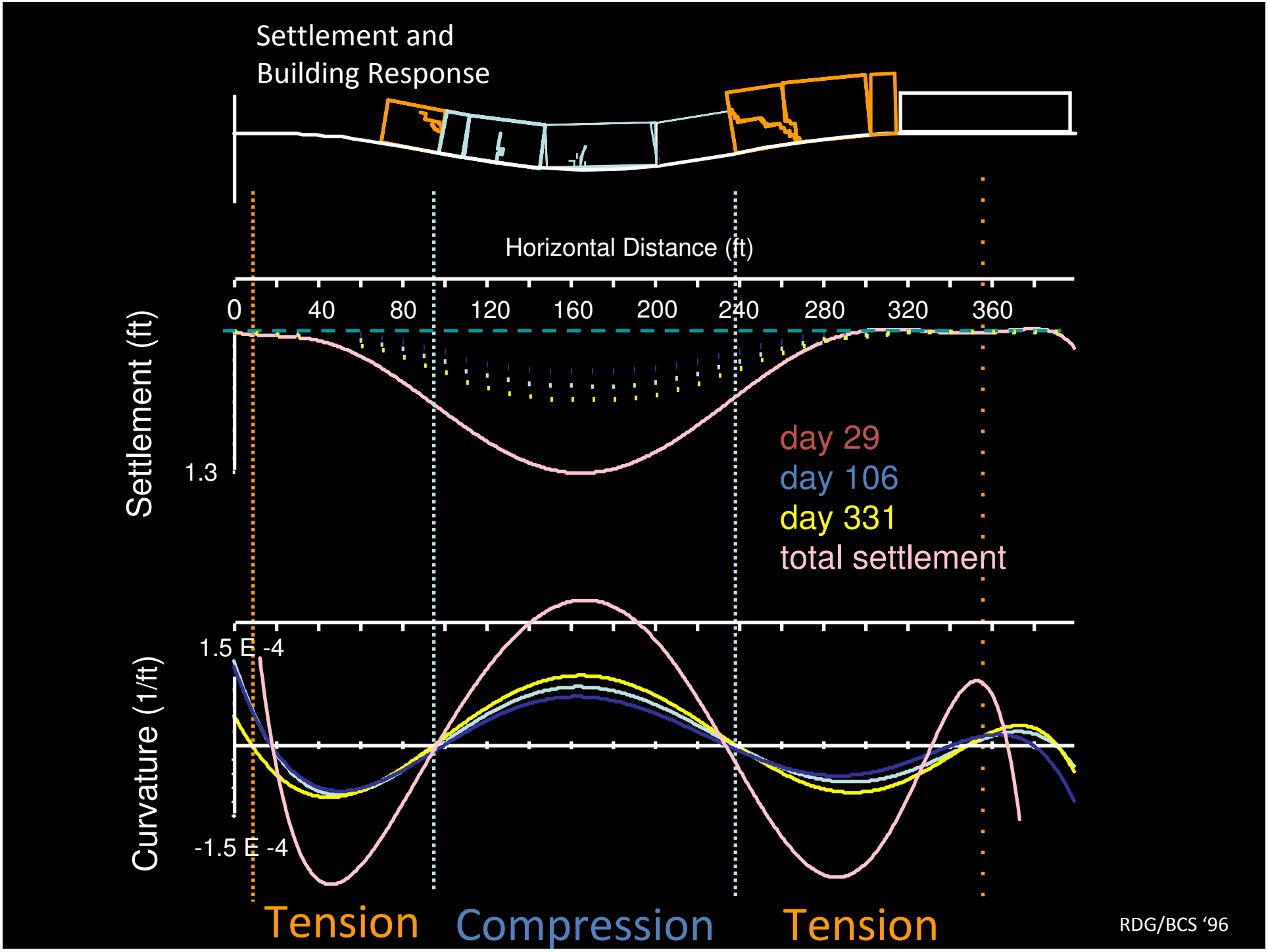


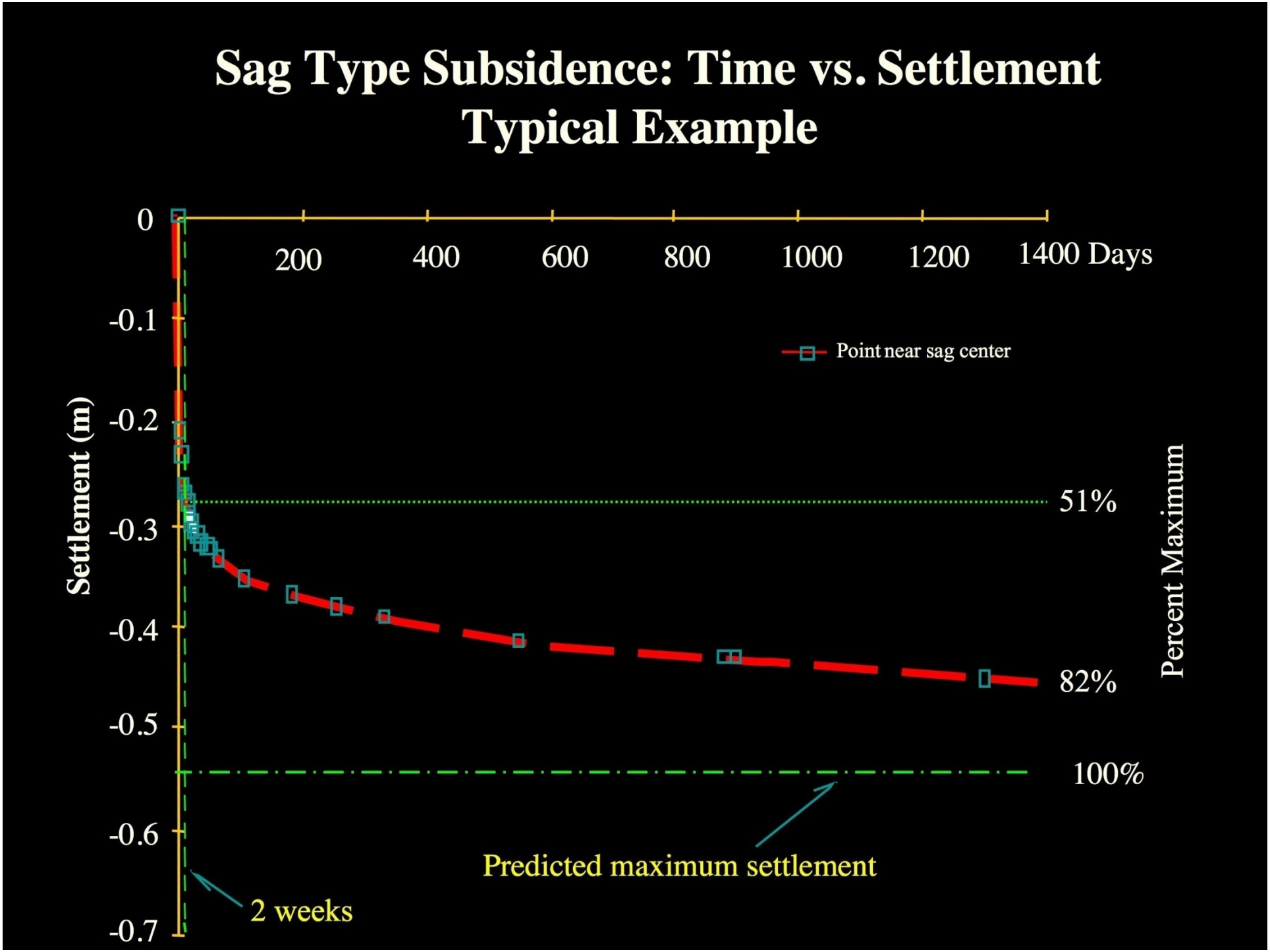
Compression

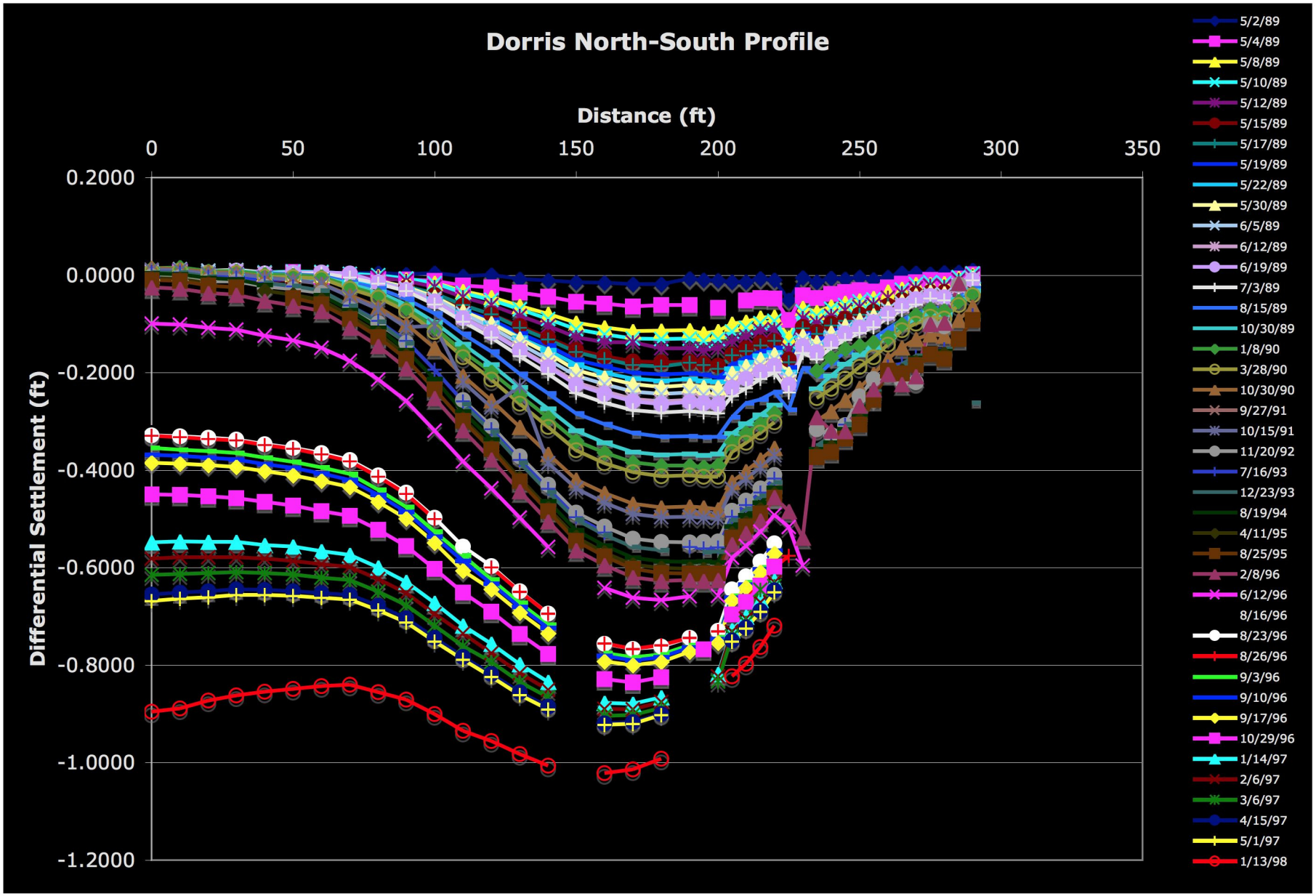
Near the center, compressive forces are created causing objects such as these tracks to buckle.

Compression

Shown here by the ground pushing the foundation inward.


Settlement and
Building Response
Horizontal Distance (ft)
0
40
80
120
160
200
240
280
320
360
Settlement (ft)
1.3
day 29
day 106
day 331
total settlement
Curvature (1/ft)
1.5 E -4
-1.5 E -4
Tension
Compression
Tension
RDG/BCS '96

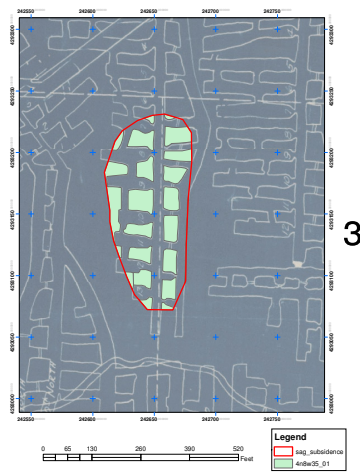

Sag Type Subsidence: Time vs. Settlement
Typical Example
0
200
400
600
800
1000
1200
1400 Days
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
Settlement (m)
Point near sag center
51%
82%
100%
Percent Maximum
Predicted maximum settlement
2 weeks


Dorris North-South Profile
Distance (ft)
0
50
100
150
200
250
300
350
Differential Settlement (ft)
0.2000
0.0000
-0.2000
-0.4000
-0.6000
-0.8000
-1.0000
-1.2000
5/2/89
5/4/89
5/8/89
5/10/89
5/12/89
5/15/89
5/17/89
5/19/89
5/22/89
5/30/89
6/5/89
6/12/89
6/19/89
7/3/89
8/15/89
10/30/89
1/8/90
3/28/90
10/30/90
9/27/91
10/15/91
11/20/92
7/16/93
12/23/93
8/19/94
4/11/95
8/25/95
2/8/96
6/12/96
8/16/96
8/23/96
8/26/96
9/3/96
9/10/96
9/17/96
10/29/96
1/14/97
2/6/97
3/6/97
4/15/97
5/1/97
1/13/98

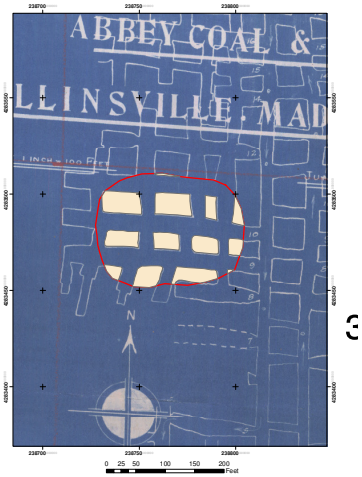
Subsidence Risk Summary

- The type and mechanics of subsidence is related to mine depth, seam thickness, floor characteristics, mine geometries, hydrology, and lithology.

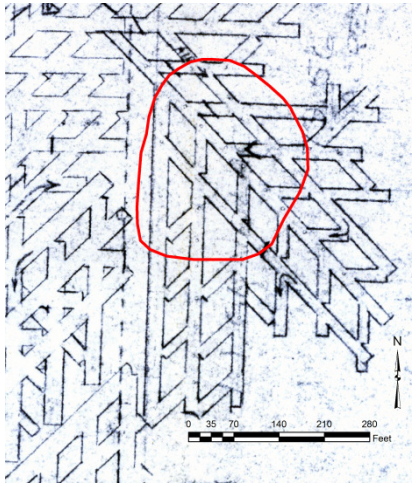
Varying Mine Geometries And Coal Mine Subsidence



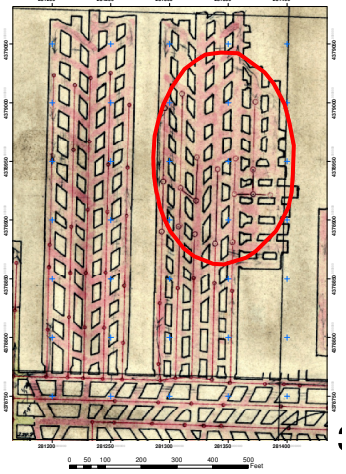
Mined 1914
MD = 240 ft
CT = 6 ft
ET = 90 yrs
Sag Area 2.2 acres
Pillar = 43.6%
Void = 56.4%



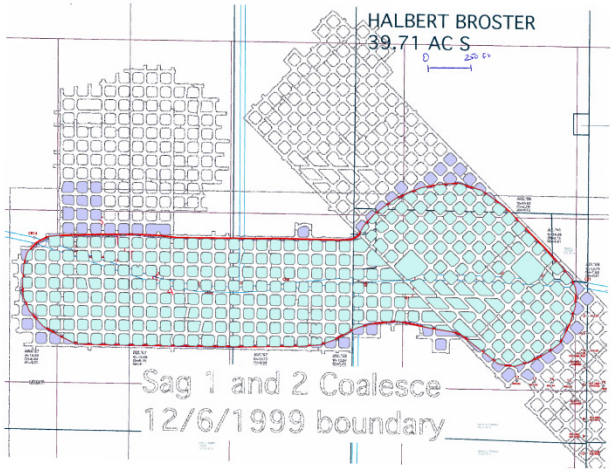
Mined 1917
MD = 185 ft
CT = 6.5 ft
ET = 88 yrs
Sag Area 0.95 acres
Pillar = 34.5%
Void = 65.5%



Mined 1970
MD = 92 ft
CT = 6 ft
ET = 37 yrs
Sag Area = 1.5 acres
Pillar = 48.7%
Void = 51.3%



Mined 1974
MD = 374 ft
CT = 7.25 ft
ET = 4 yrs
Sag Area 4.2 acres
Pillar = 30.6%
Void = 69.4%



Mined 1996
MD = 800 ft
CT = 8.2 ft
ET = 2 yrs
Sag Area 49 acres
Pillar = 58.5%
Void = 41.5%

Subsidence Risk Summary

- The type and mechanics of subsidence is related to mine depth, seam thickness, floor characteristics, mine geometries, hydrology, and lithology.
- Pit type subsidence rarely forms when:
  - Mine depth > 100 ft
  - Rock thickness > 50 ft
  - Limestone * > 3 ft

Subsidence Risk Summary

- The type and mechanics of subsidence is related to mine depth, seam thickness, floor characteristics, mine geometries, hydrology, and lithology.
- Pit type subsidence rarely forms when:
  - Mine depth > 100 ft
  - Rock thickness > 50 ft
  - Limestone * > 3 ft
- A pit subsidence event may reactivate.

Subsidence Risk Summary

- The type and mechanics of subsidence is related to mine depth, seam thickness, floor characteristics, mine geometries, hydrology, and lithology.
- Pit type subsidence rarely forms when:
  - Mine depth > 100 ft
  - Rock thickness > 50 ft
  - Limestone * > 3 ft
- A pit subsidence event may reactivate.
- Deeper mines (> 160 ft) are susceptible only to sag type subsidence.

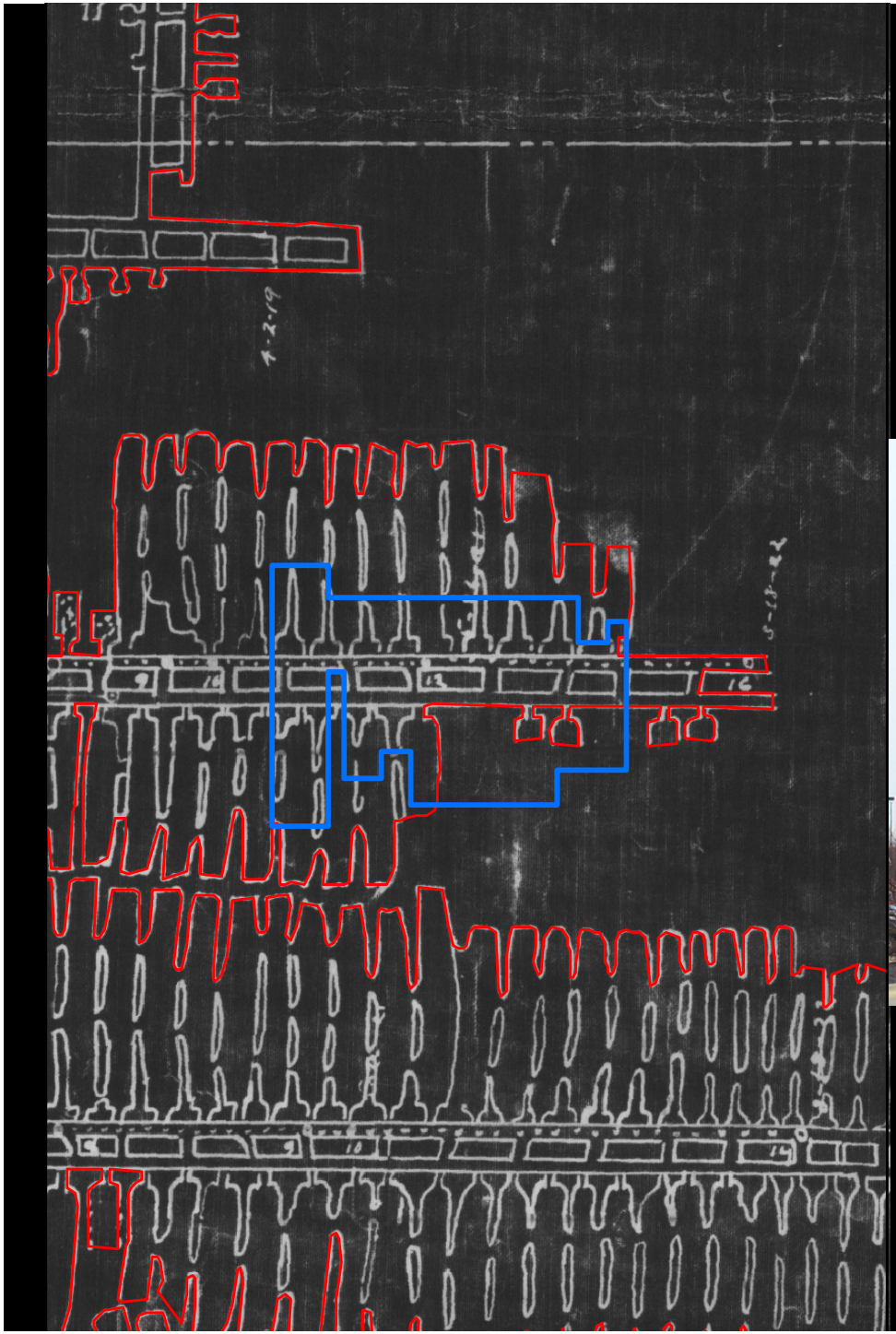
Subsidence Risk Summary

- The type and mechanics of subsidence is related to mine depth, seam thickness, floor characteristics, mine geometries, hydrology, and lithology.
- Pit type subsidence rarely forms when:
  - Mine depth > 100 ft
  - Rock thickness > 50 ft
  - Limestone * > 3 ft
- A pit subsidence event may reactivate.
- Deeper mines (> 160 ft) are susceptible only to sag type subsidence.
- Limited data suggests that once ground movements are complete, sag events do not reactivate.

Subsidence Risk Summary

- The type and mechanics of subsidence is related to mine depth, seam thickness, floor characteristics, mine geometries, hydrology, and lithology.
- Pit type subsidence rarely forms when:
  - Mine depth > 100 ft
  - Rock thickness > 50 ft
  - Limestone * > 3 ft
- A pit subsidence event may reactivate.
- Deeper mines (> 160 ft) are susceptible only to sag type subsidence.
- Limited data suggests that once ground movements are complete, sag events do not reactivate.
- It should be noted that adjacent mined areas may collapse and overlap boundaries of an earlier sag event.

“ Closing Thought ”



- What are the risks?