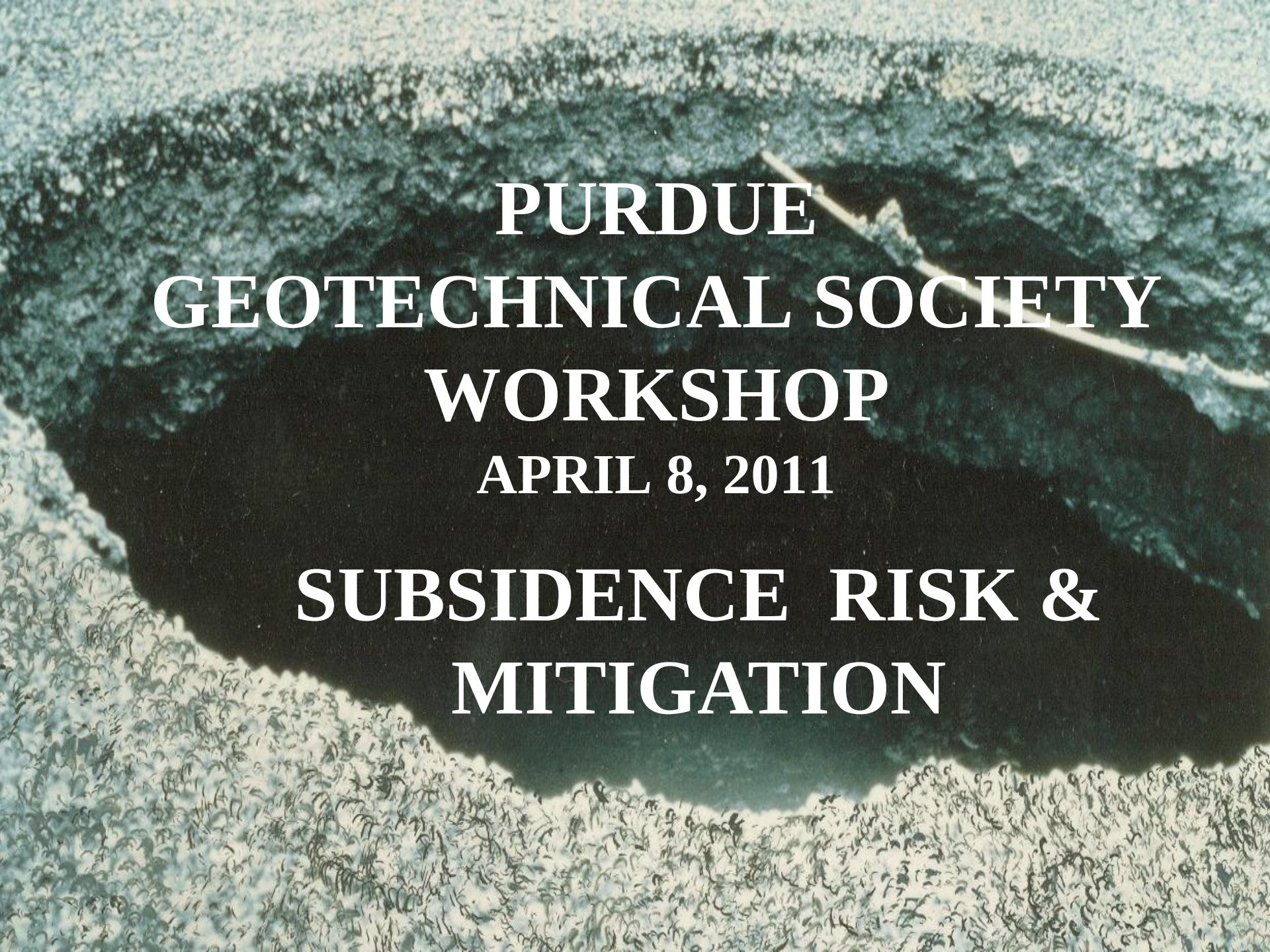
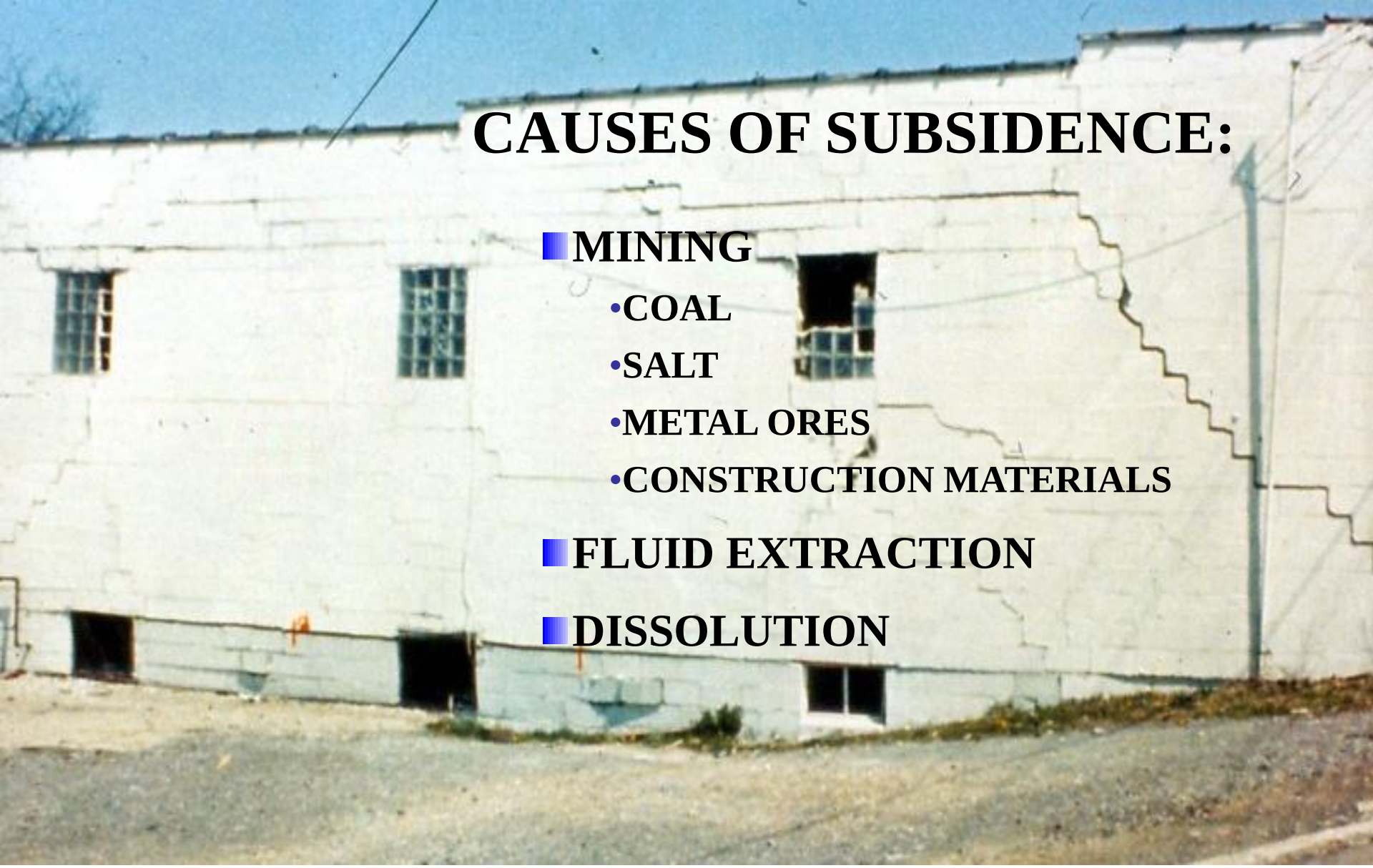


PURDUE GEOTECHNICAL SOCIETY WORKSHOP

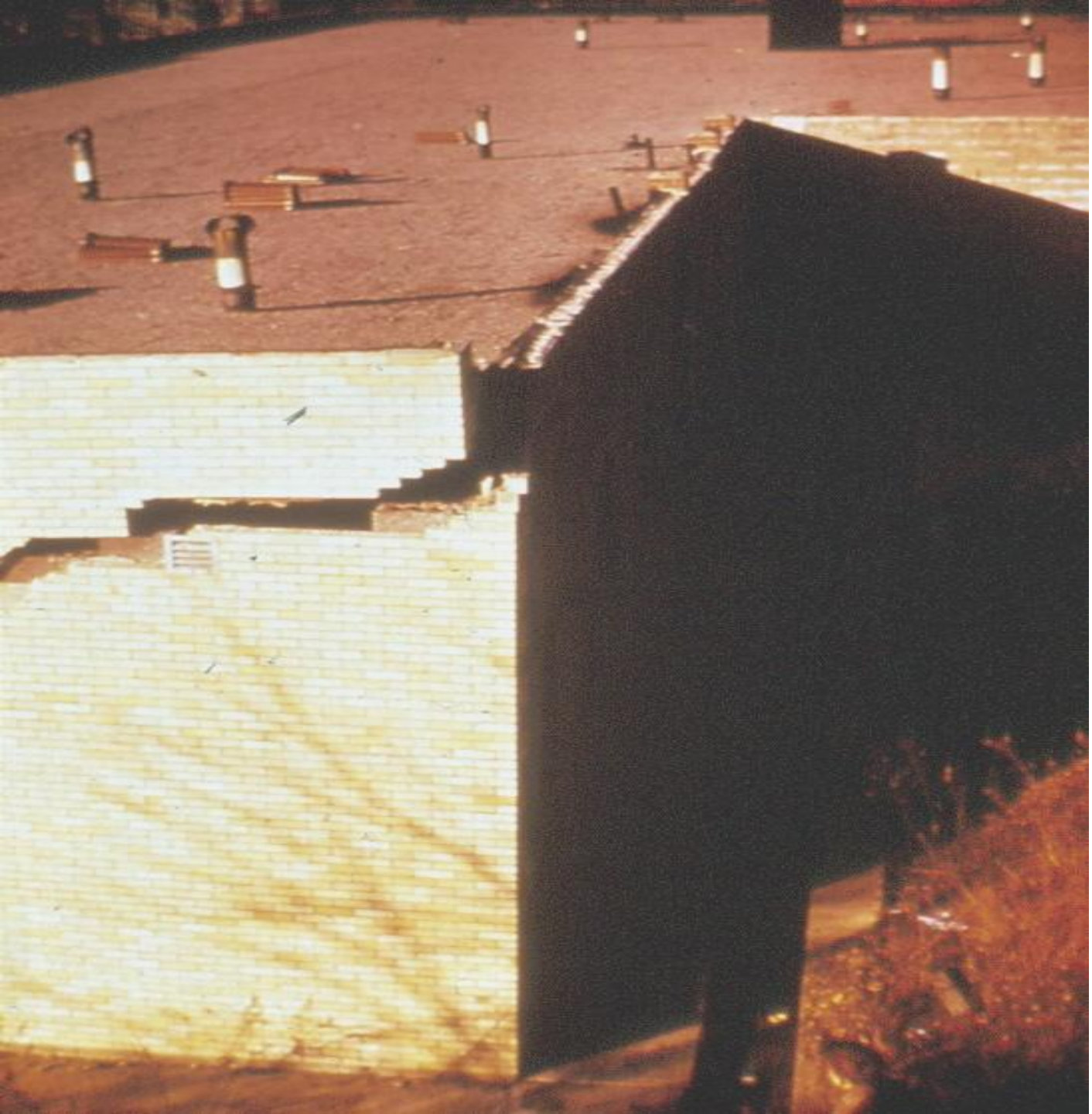
APRIL 8, 2011

SUBSIDENCE RISK & MITIGATION



CAUSES OF SUBSIDENCE:

- **MINING**
  - **COAL**
  - **SALT**
  - **METAL ORES**
  - **CONSTRUCTION MATERIALS**
- **FLUID EXTRACTION**
- **DISSOLUTION**

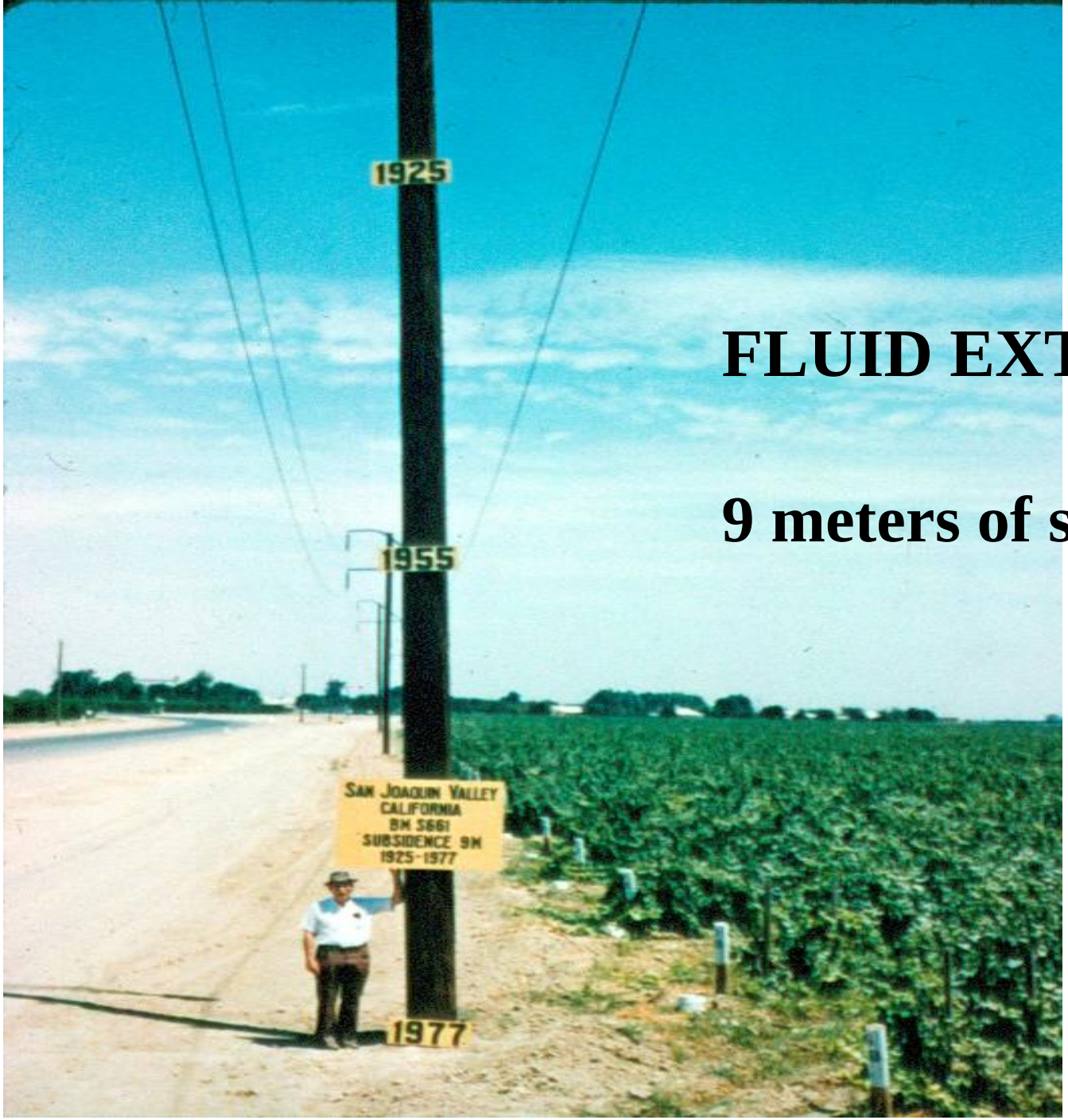


ACTIVE COAL MINE AT DEPTH OF 300 FT.

SALT SOLUTION SINKHOLE

GROS ISLE, MICHIGAN

SALT SOLUTION MINING AT DEPTH OF 1000 FEET.



FLUID EXTRACTION

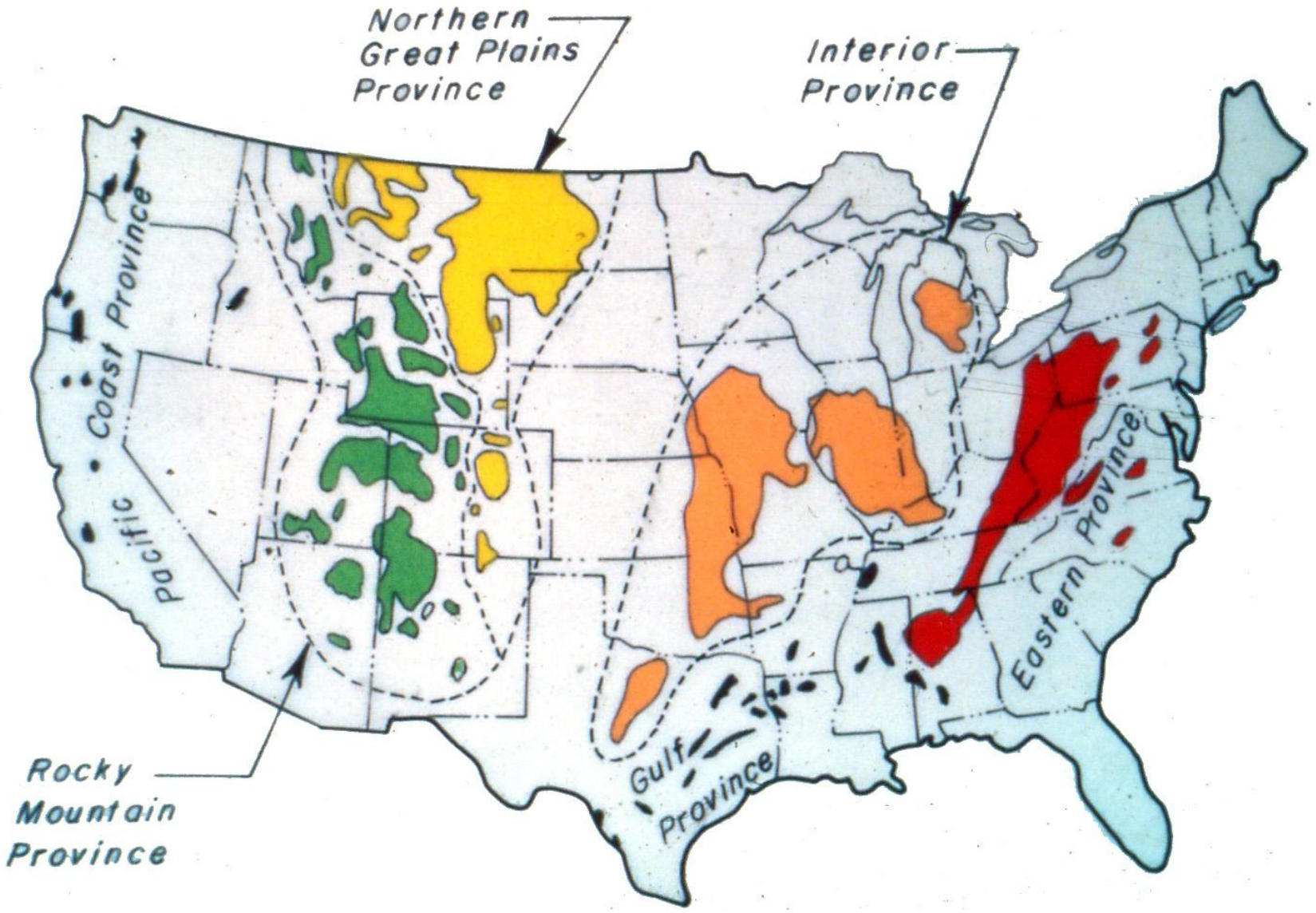
9 meters of subsidence

COPPER MINE BLOCK CAVING

SAN MANUEL MINE – ARIZONA

600 FEET OF SUBSIDENCE

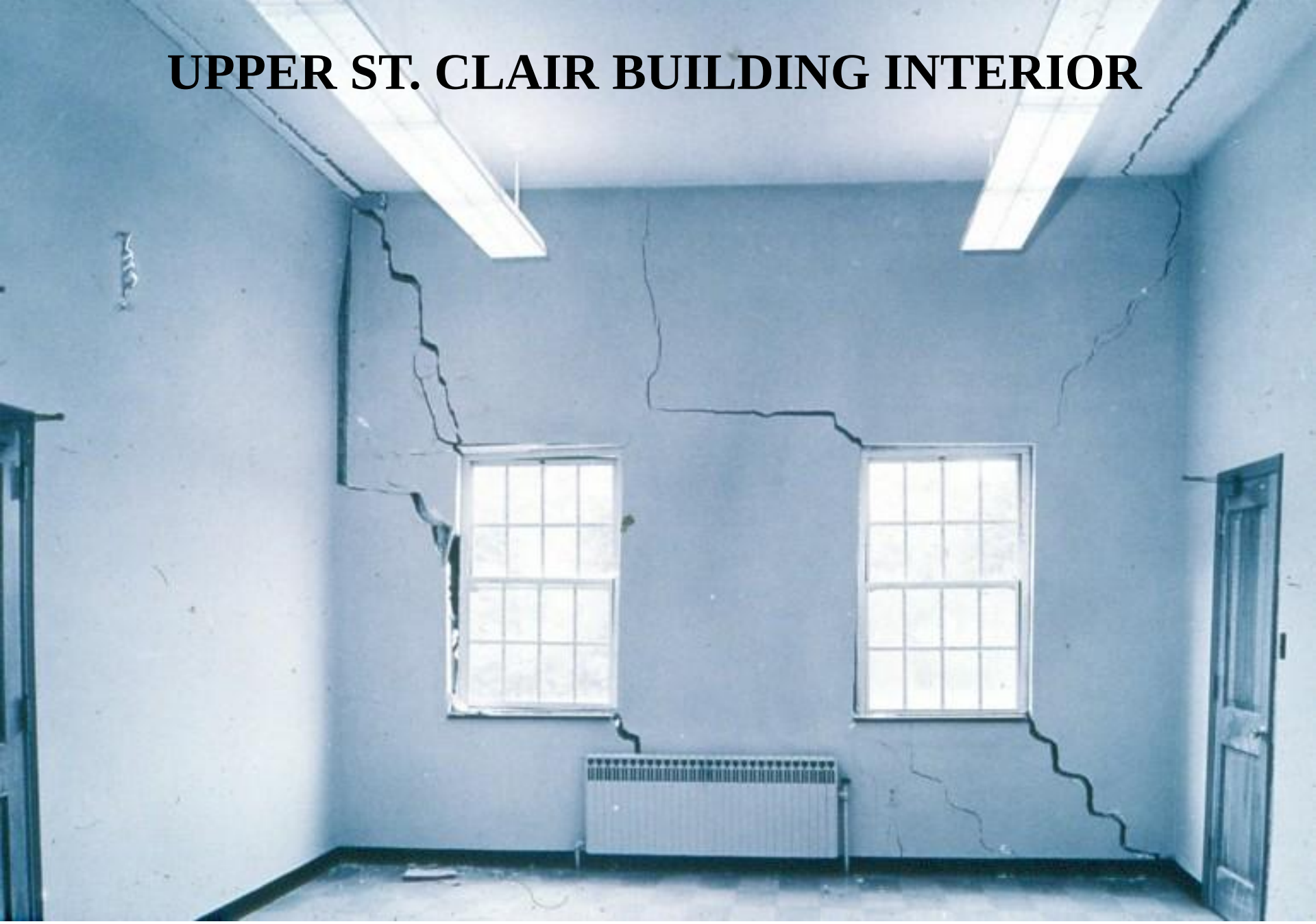
U.S. COAL FIELDS



EXAMPLES OF SUBSIDENCE DAMAGE

DEPTH OF MINE = 110 FEET

UPPER ST. CLAIR BUILDING INTERIOR

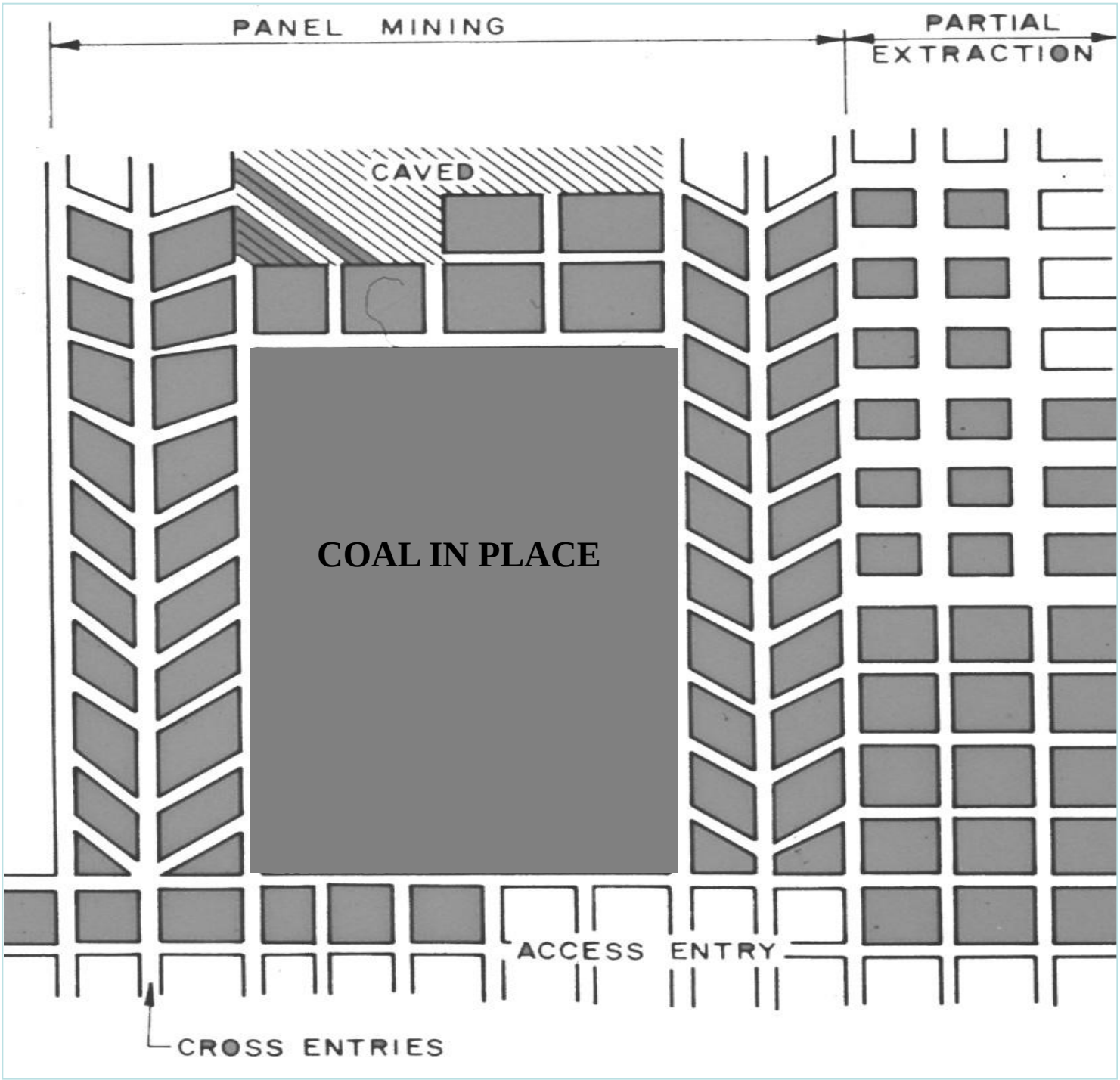


SUBSIDENCE OVER ABANDONED MINE – UPPER FREEPORT

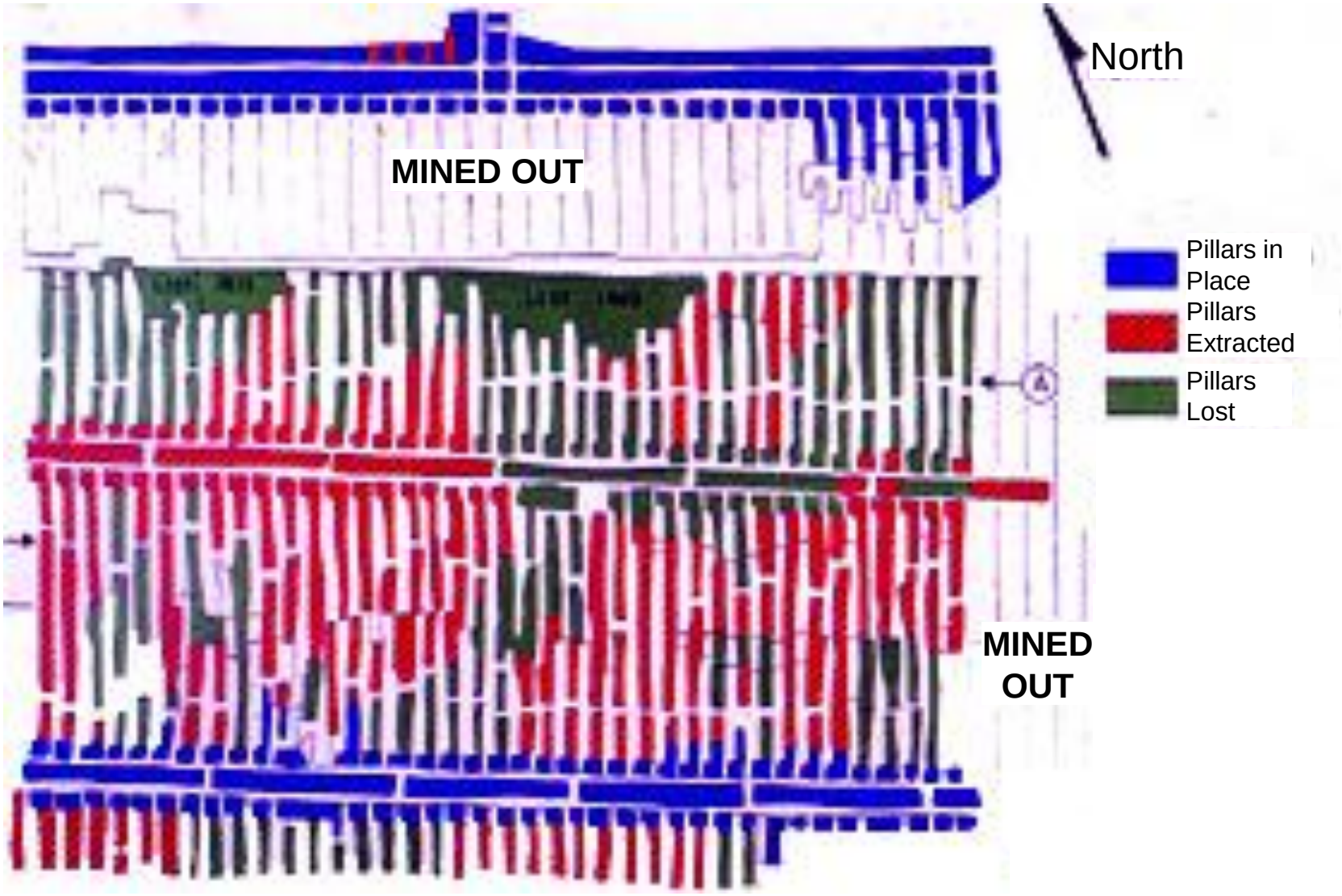
COAL AT DEPTH OF 175 FEET

TYPES OF COAL MINING

- ROOM & PILLAR
- LONGWALL

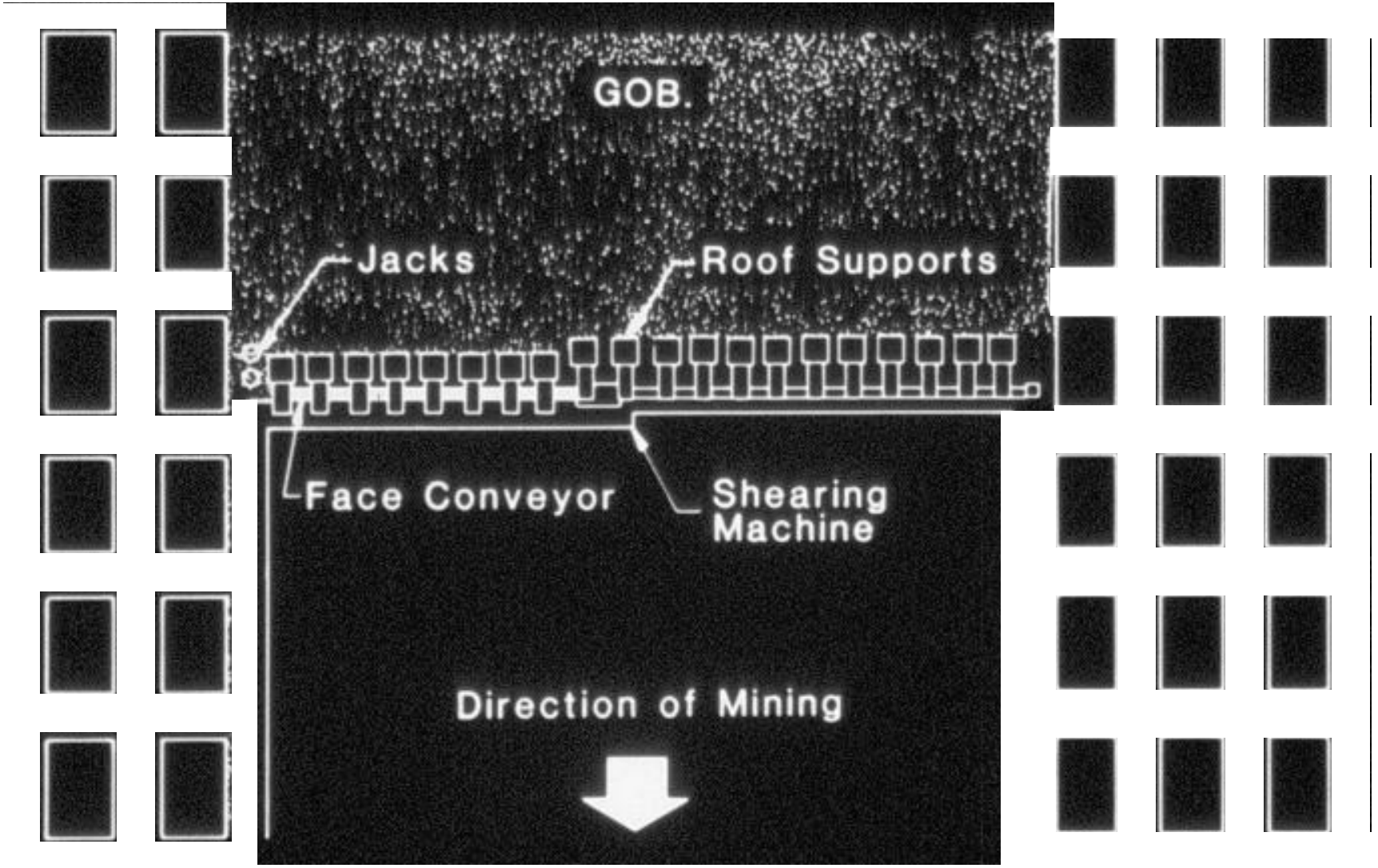


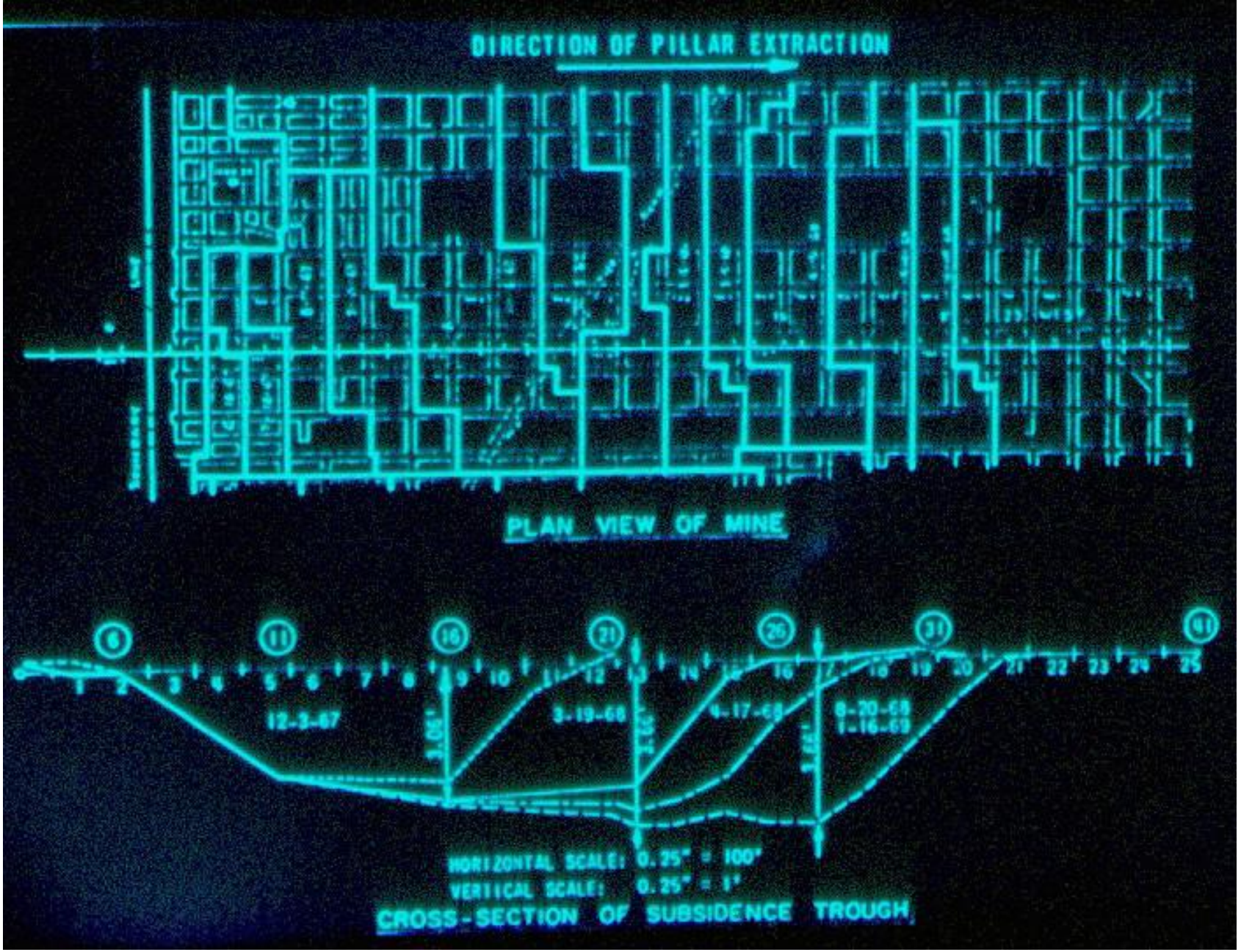
MODERN ROOM AND PILLAR MINE



EARLY ROOM & PILLAR MINE

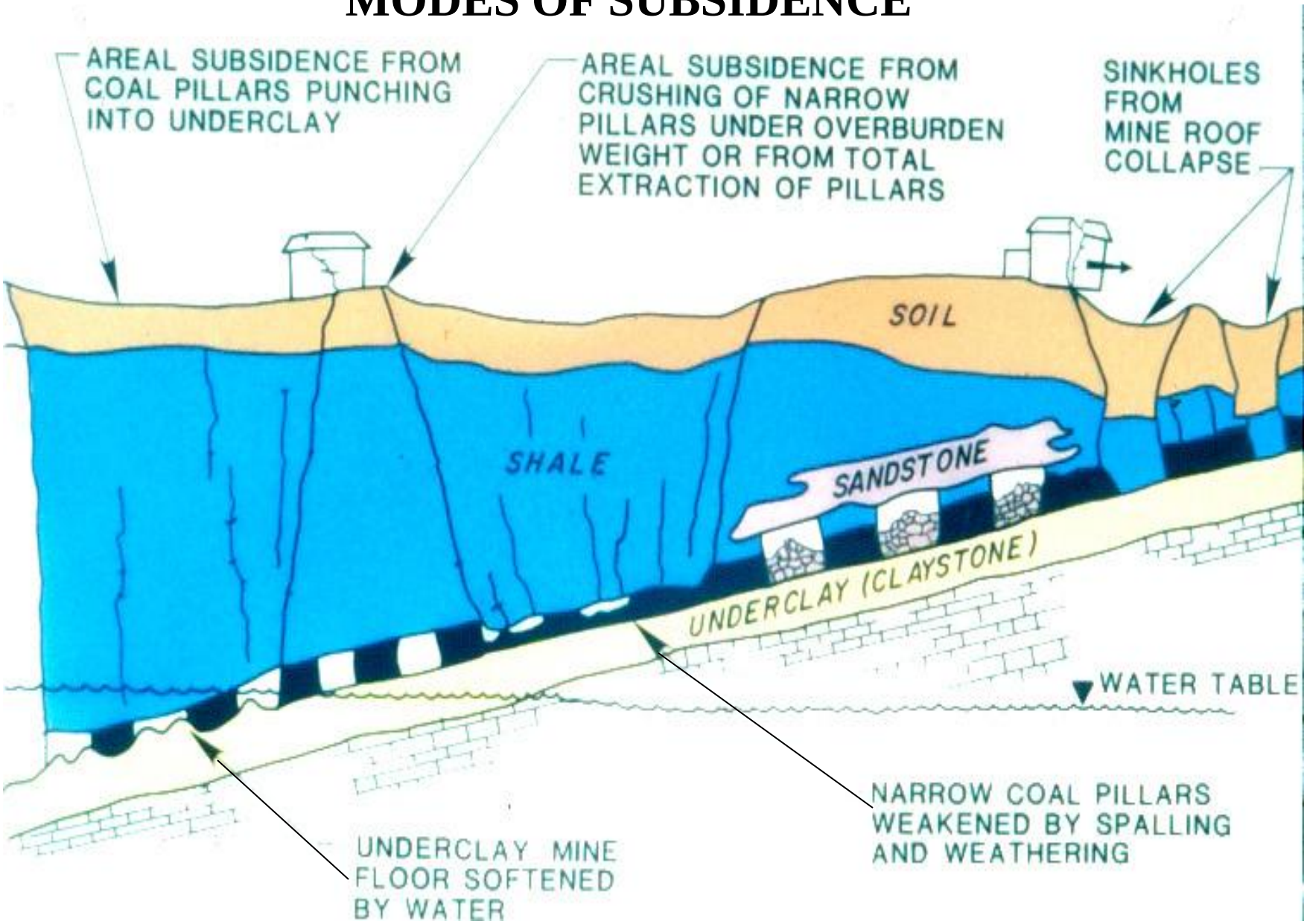
Typical Long Wall Mining Plan



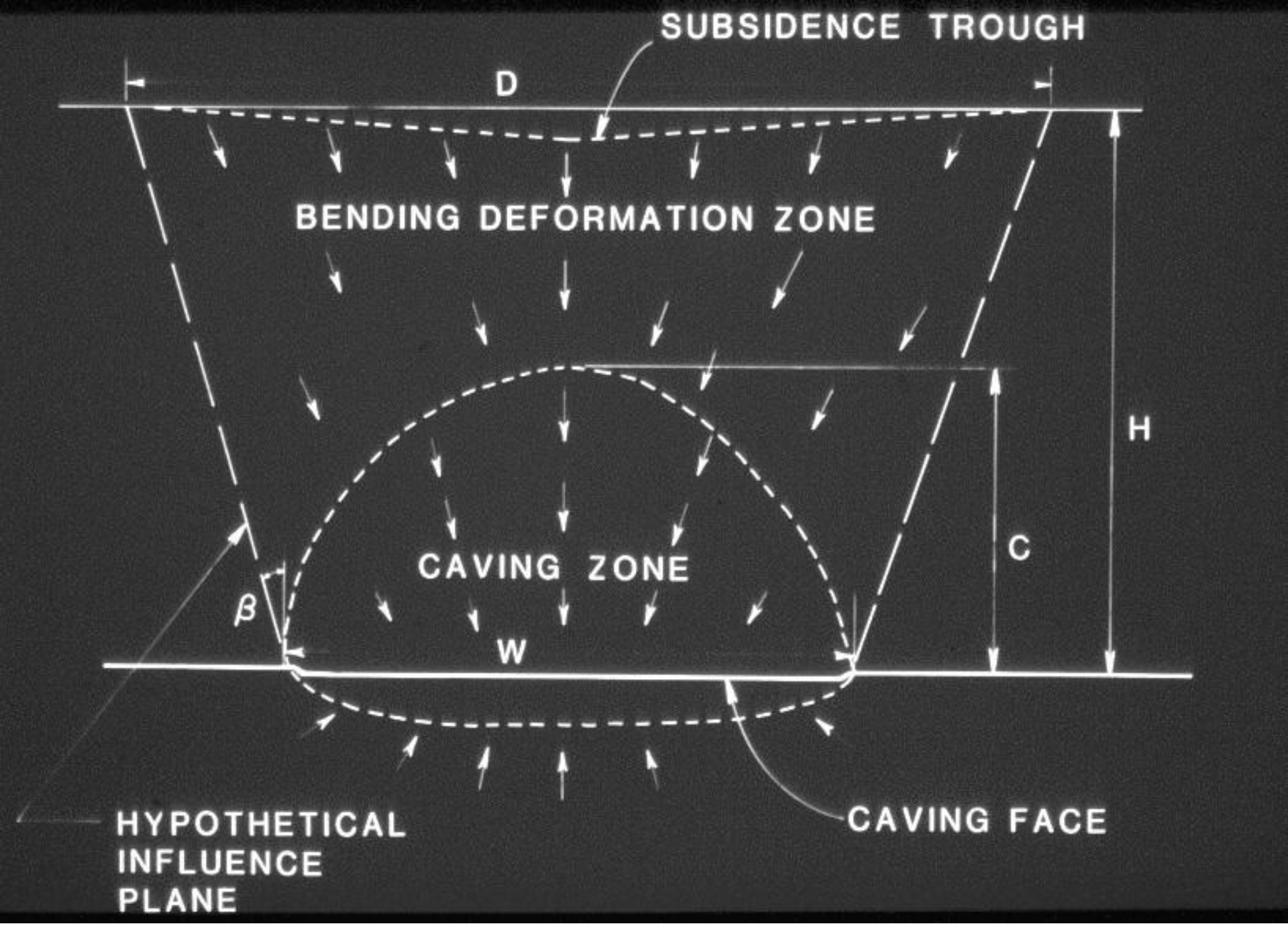


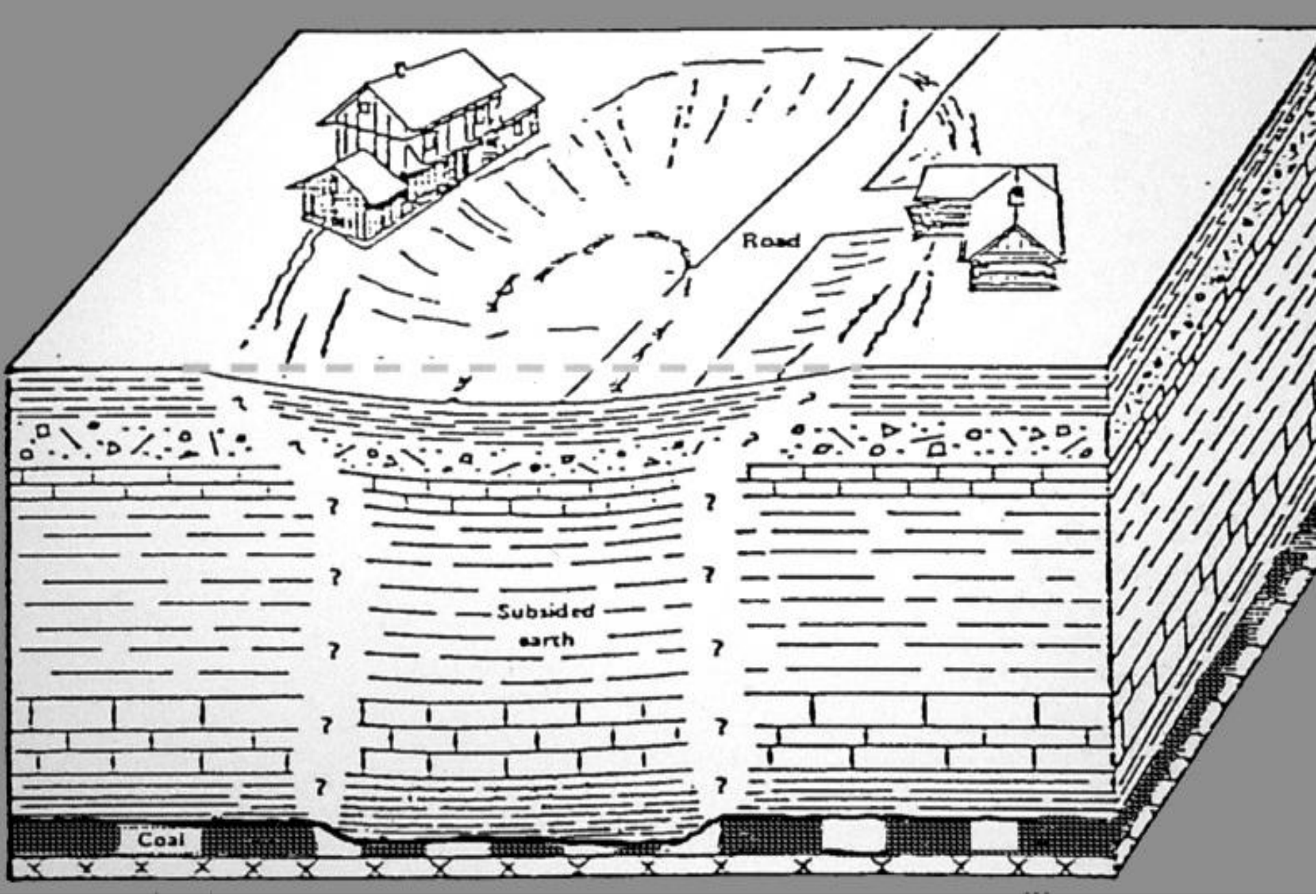
LONGWALL SUBSIDENCE – 90% OF MINED THICKNESS.

MODES OF SUBSIDENCE

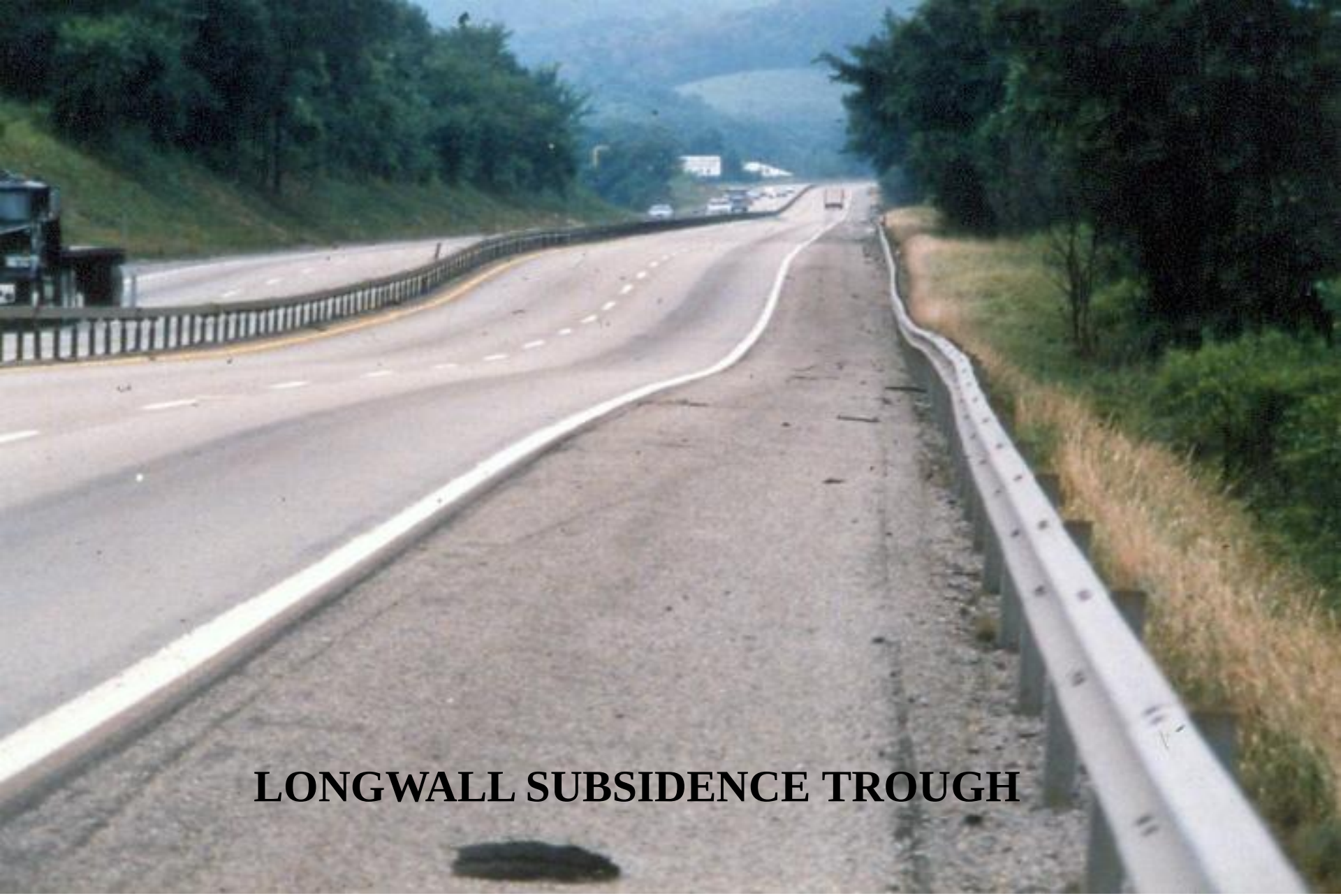


SINKHOLE DAMAGE


SUBSIDENCE TROUGH
D
BENDING DEFORMATION ZONE
H
C
CAVING ZONE
β
W
HYPOTHETICAL
INFLUENCE
PLANE
CAVING FACE



SCHEMATIC OF TROUGH SUBSIDENCE

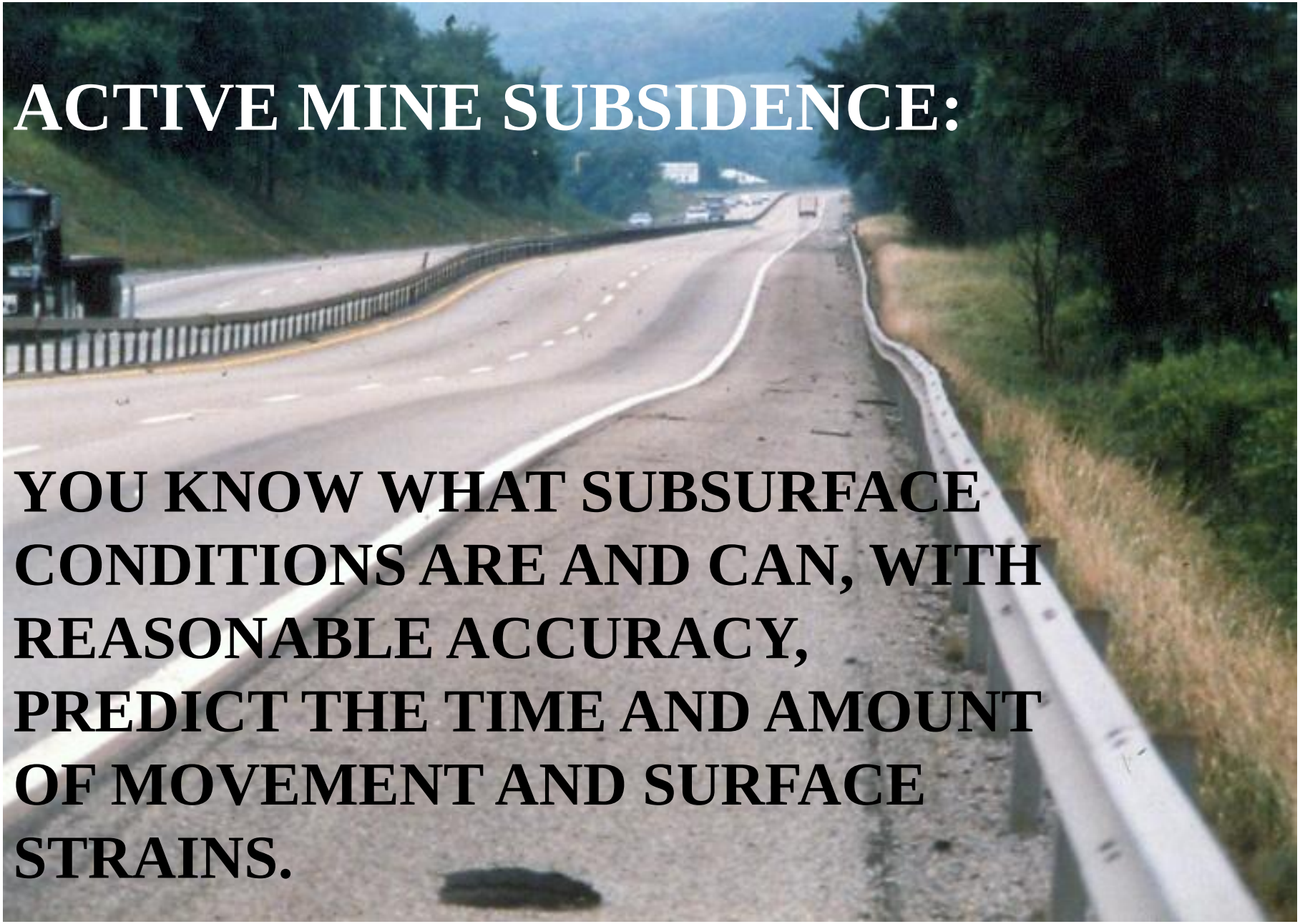


I-70 EAST OF 84, PA

DEPTH TO MINE = 600 FEET

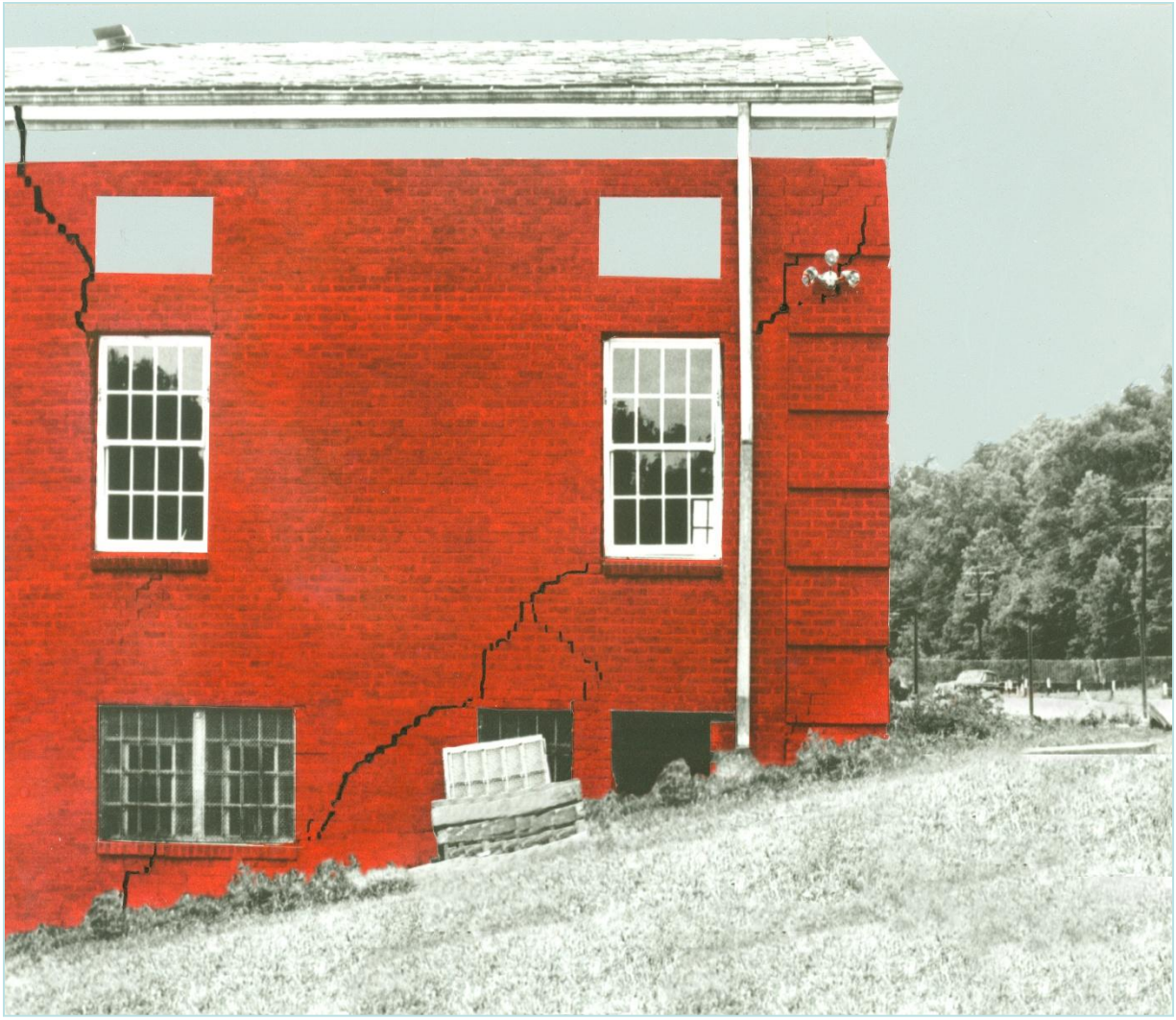
Subsidence Risk Evaluation

- **Will Subsidence Occur? When?**
- **What Mode?**
- **What Magnitude of Movements can be Expected?**
- **Is it Possible to Prevent or Reduce its Effect?**


ACTIVE MINE SUBSIDENCE:
YOU KNOW WHAT SUBSURFACE CONDITIONS ARE AND CAN, WITH REASONABLE ACCURACY, PREDICT THE TIME AND AMOUNT OF MOVEMENT AND SURFACE STRAINS.

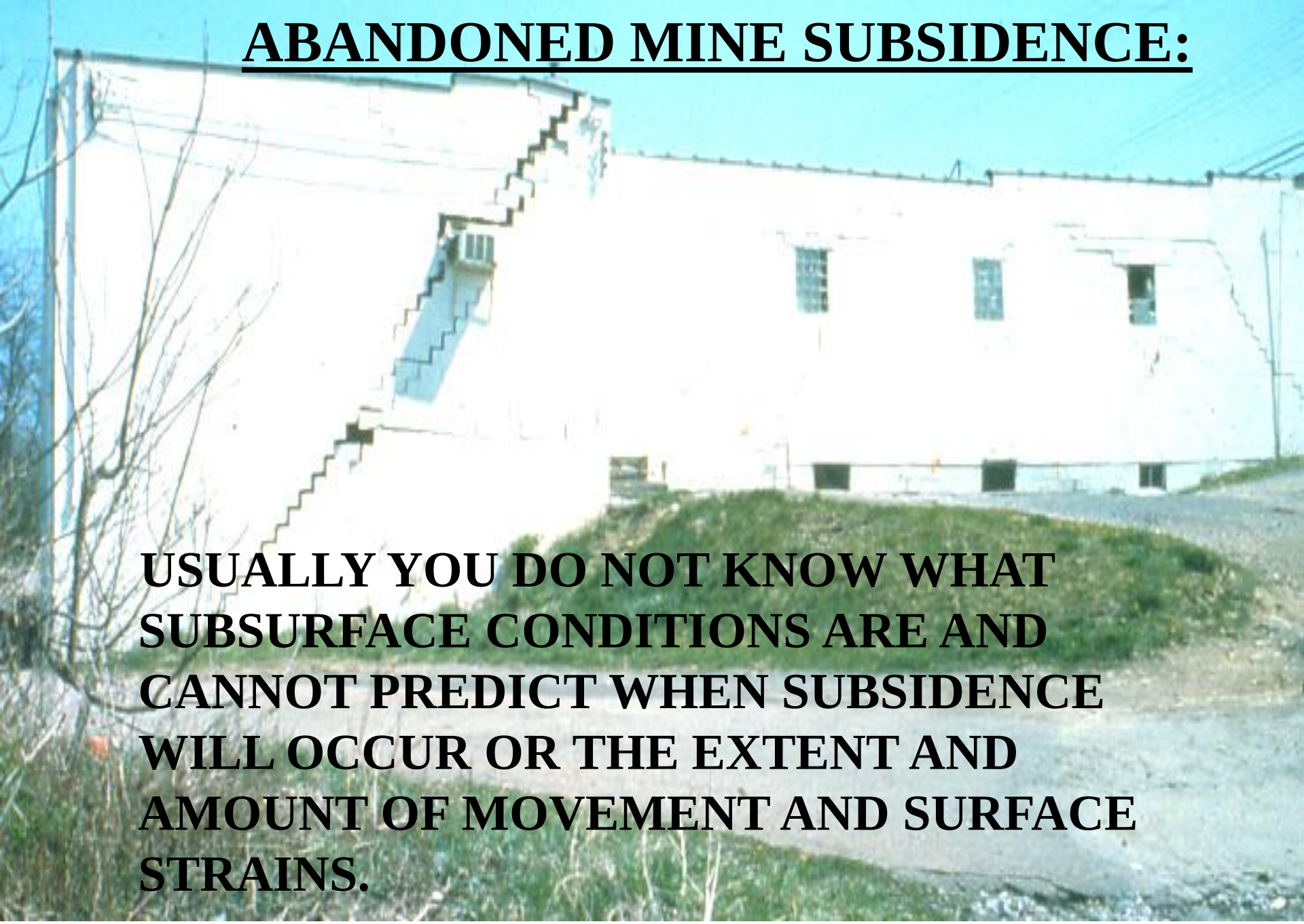
Subsidence over Abandoned Coal Mines

70,000 Abandoned or Inactive Coal Mines in the U.S.



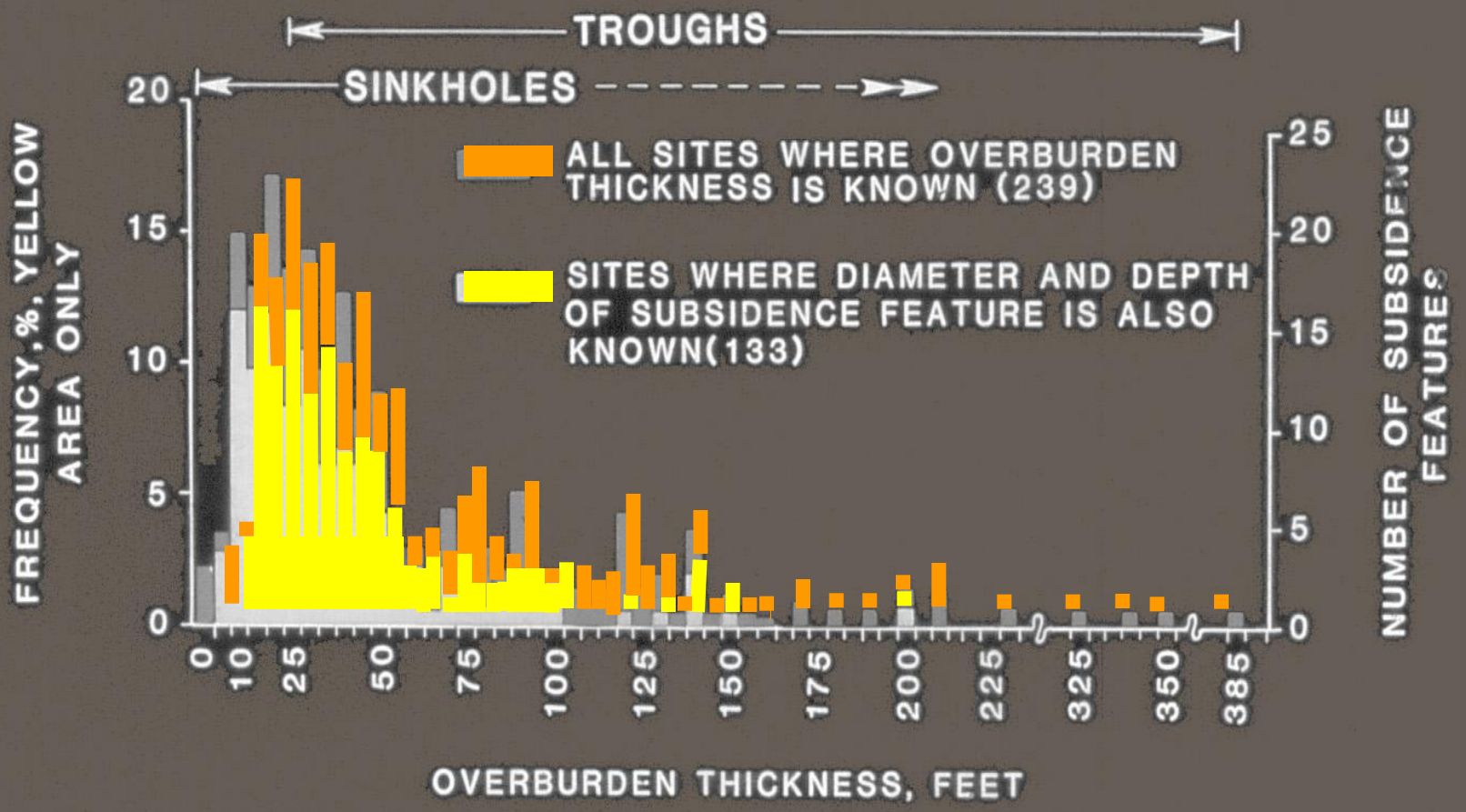
ABANDONED MINE IN PITTSBURGH COAL

ABANDONED MINE SUBSIDENCE:

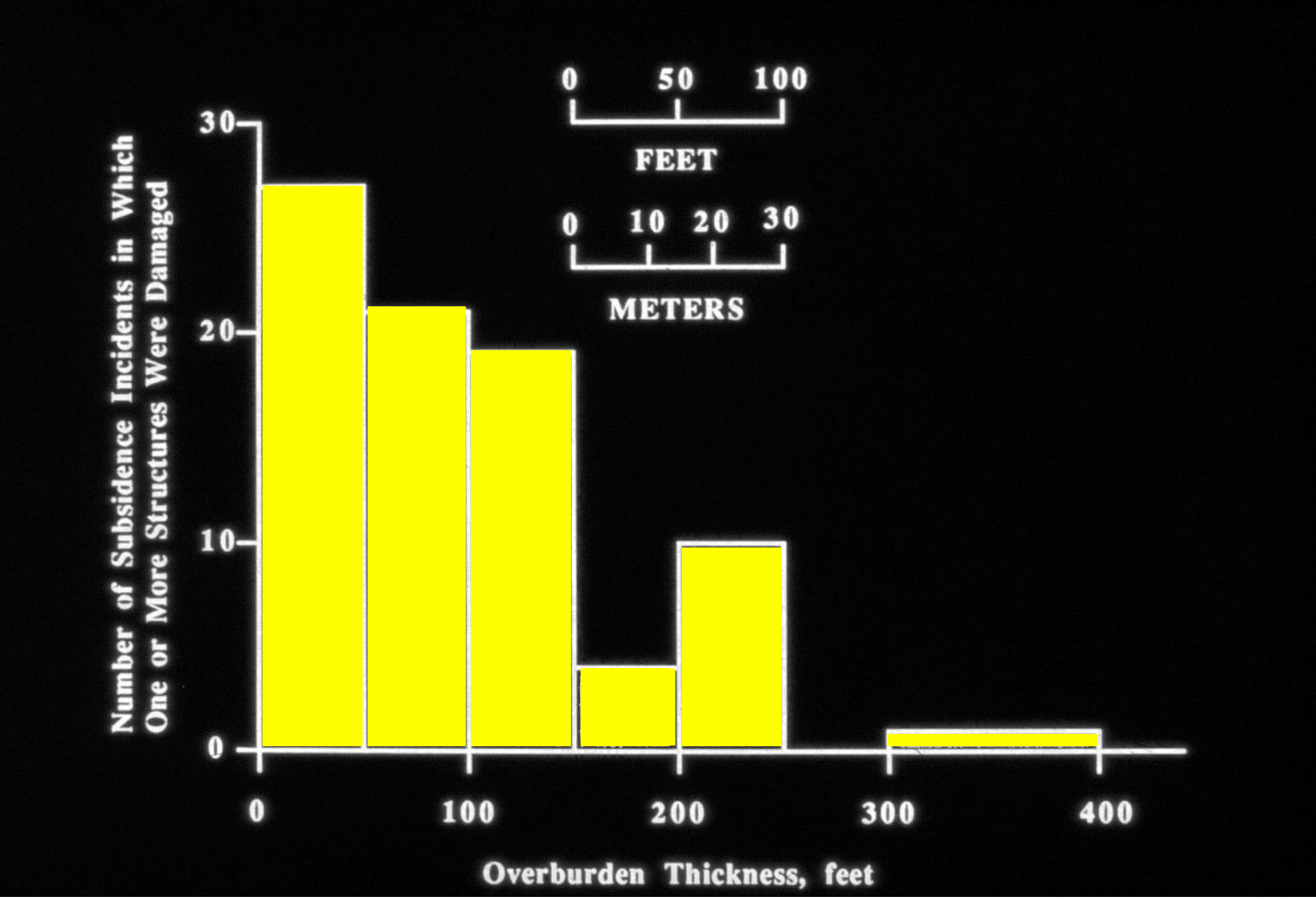


USUALLY YOU DO NOT KNOW WHAT SUBSURFACE CONDITIONS ARE AND CANNOT PREDICT WHEN SUBSIDENCE WILL OCCUR OR THE EXTENT AND AMOUNT OF MOVEMENT AND SURFACE STRAINS.

NOTE:
OVERBURDEN THICKNESSES ARE NOMINAL VALUES FOR THE RESPECTIVE SITES.
THE MAXIMUM OVERBURDEN THICKNESS AT ANY SITE IS 450 FEET.(SITE 1200)



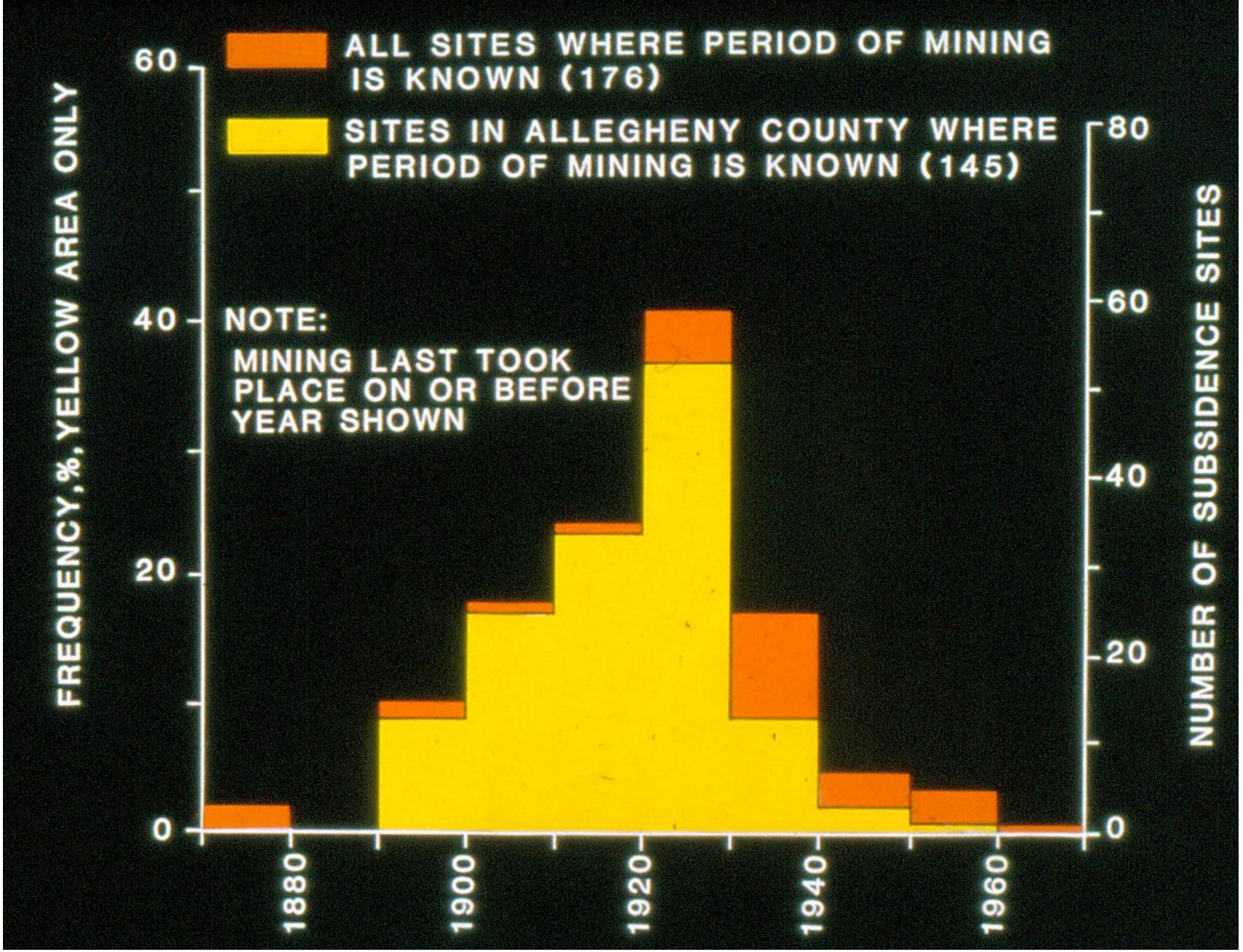
OVERBURDEN THICKNESS AT SUBSIDENCE SITES



OVERBURDEN THICKNESS AT SITES OF STRUCTURAL DAMAGE DUE TO SUBSIDNECE

Concept no. 1 – No Safe Subsidence Intervals

- **Unless total extraction has been achieved, there is no interval above an abandoned mine that is necessarily safe from subsidence, or that reduces severity of damage.**
- **Increased intervals above mine level, however, exhibit a reduced frequency of subsidence.**

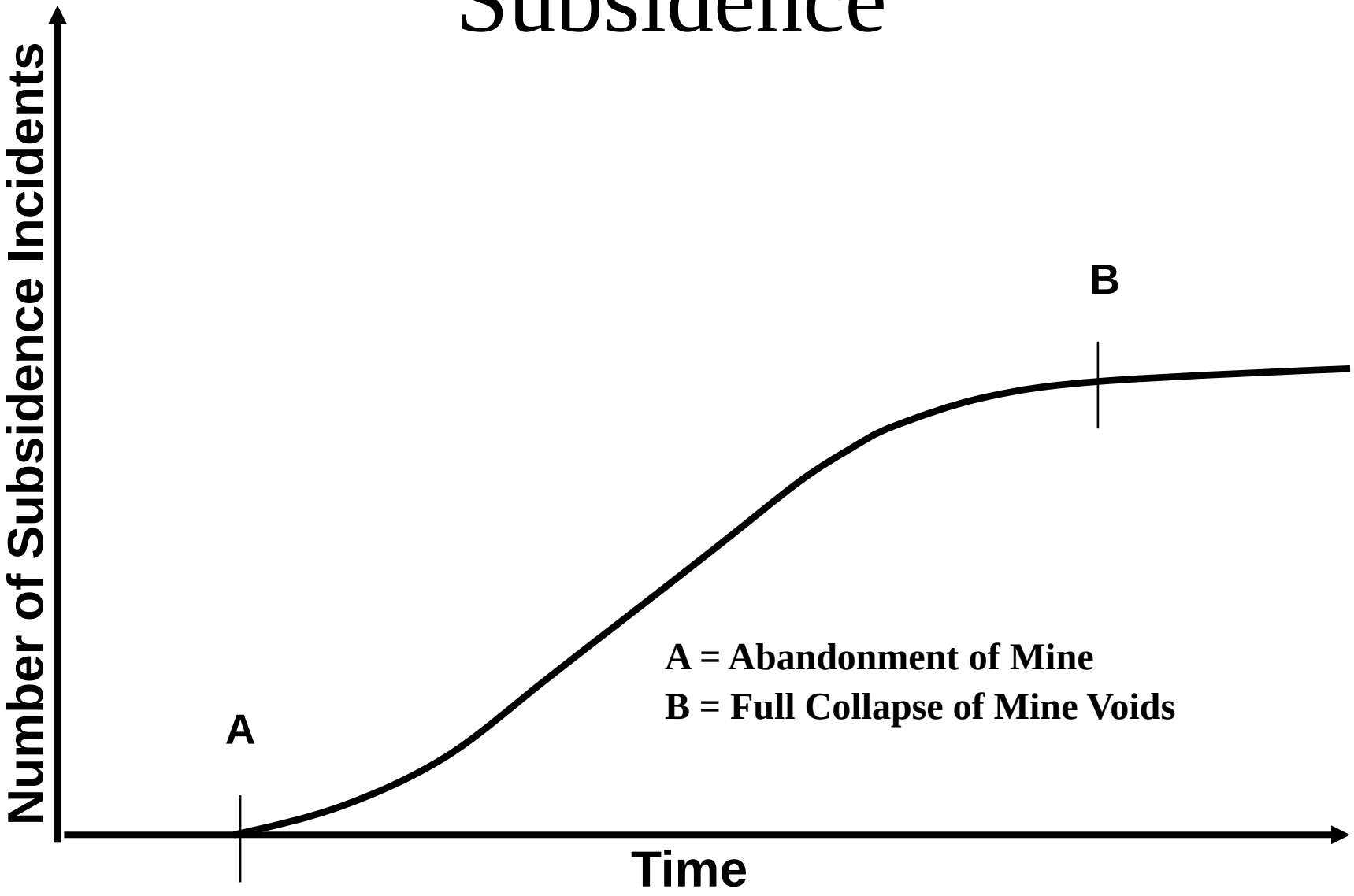


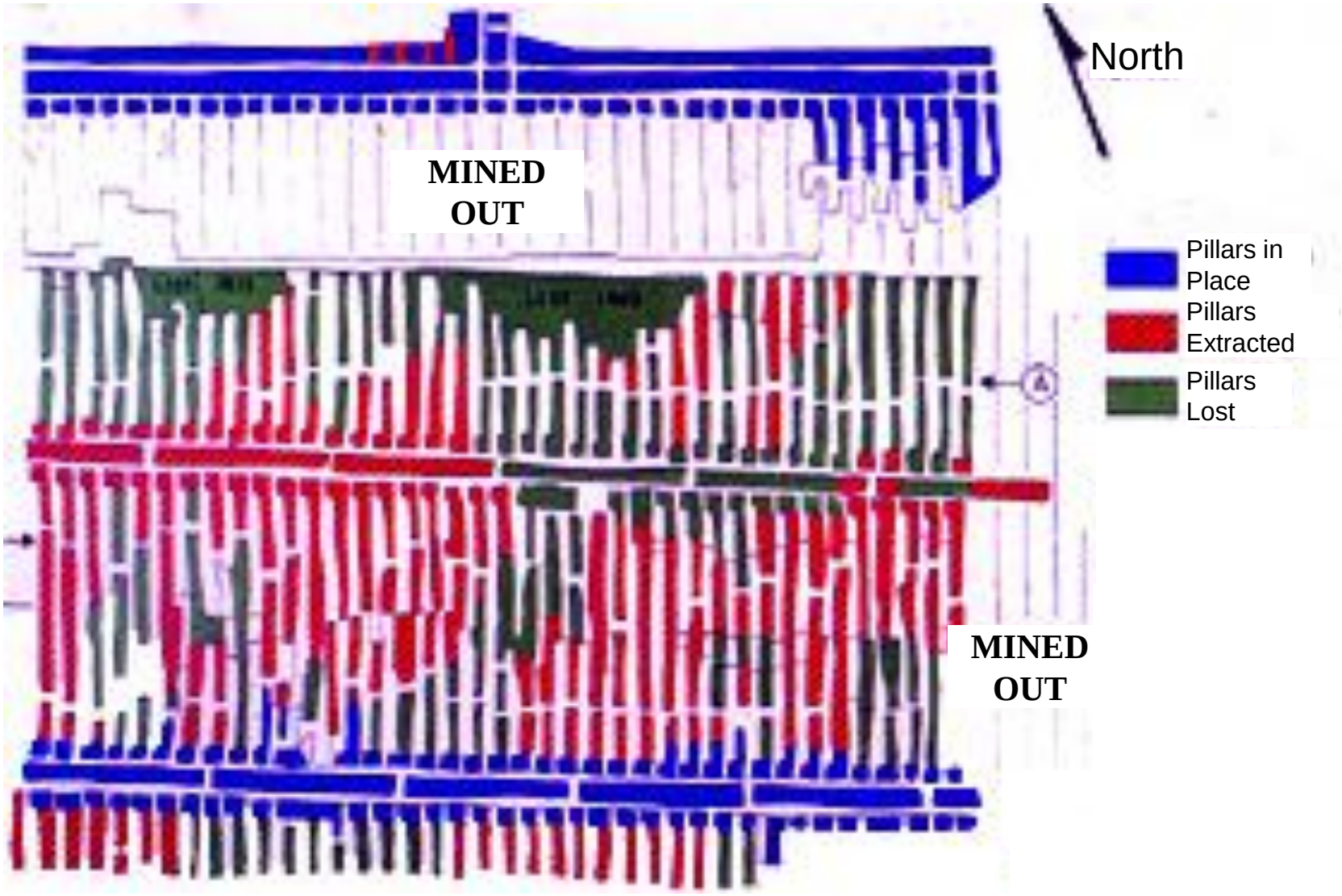
DISTRIBUTION OF PERIODS OF MINING BENEATH SITES THAT LATER EXPERIENCED SUBSIDENCE – PITTSBURGH COAL STUDY

Concept no. 2 – Subsidence Timeline

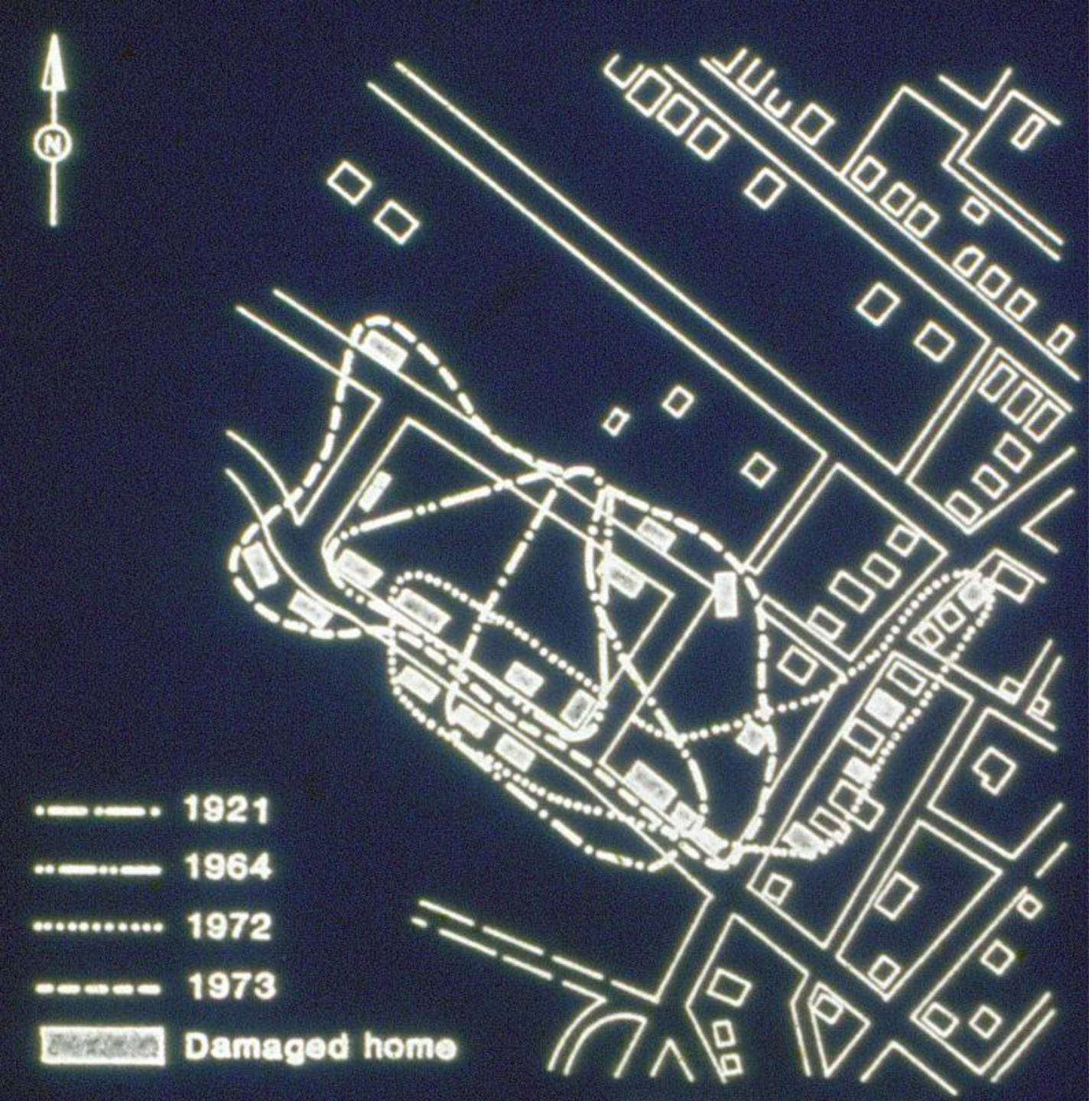
Unless total extraction has been achieved, subsidence may occur long after mining, and subsidence may not be limited to a single episode.

Conceptual Representation of Subsidence

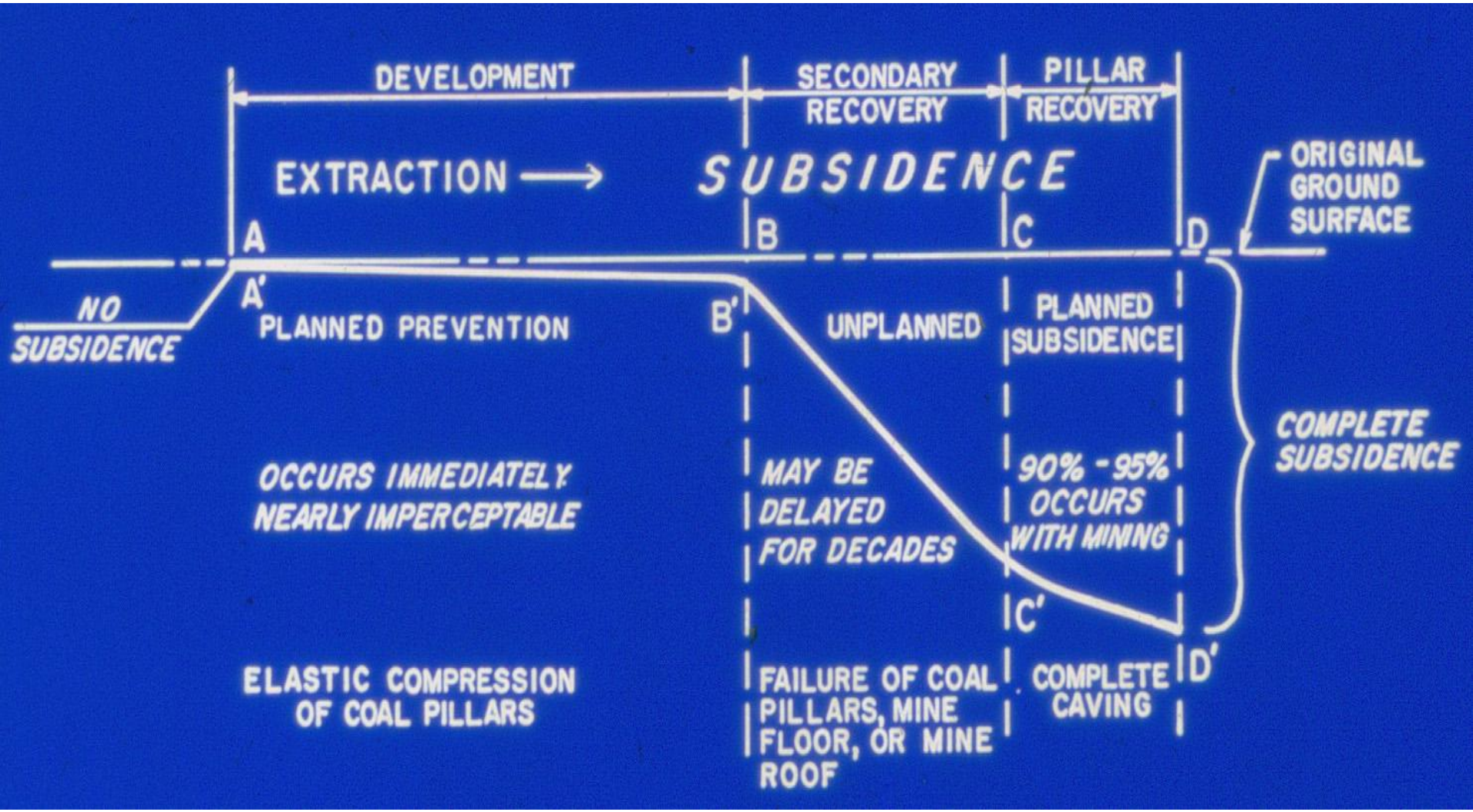




MAP OF 1909 MINE – 78% EXTRACTION



COMMUNITY THAT HAS EXPERIENCED MULTIPLE INCIDENTS OF ABANDONED MINE RELATED SUBSIDENCE


DEVELOPMENT
SECONDARY RECOVERY
PILLAR RECOVERY
EXTRACTION ⟶
SUBSIDENCE
ORIGINAL GROUND SURFACE
A
B
C
D
NO SUBSIDENCE
A'
PLANNED PREVENTION
B'
UNPLANNED
PLANNED SUBSIDENCE
COMPLETE SUBSIDENCE
OCCURS IMMEDIATELY
NEARLY IMPERCEPTABLE
MAY BE DELAYED FOR DECADES
90% - 95% OCCURS WITH MINING
C'
D'
ELASTIC COMPRESSION OF COAL PILLARS
FAILURE OF COAL PILLARS, MINE FLOOR, OR MINE ROOF
COMPLETE CAVING

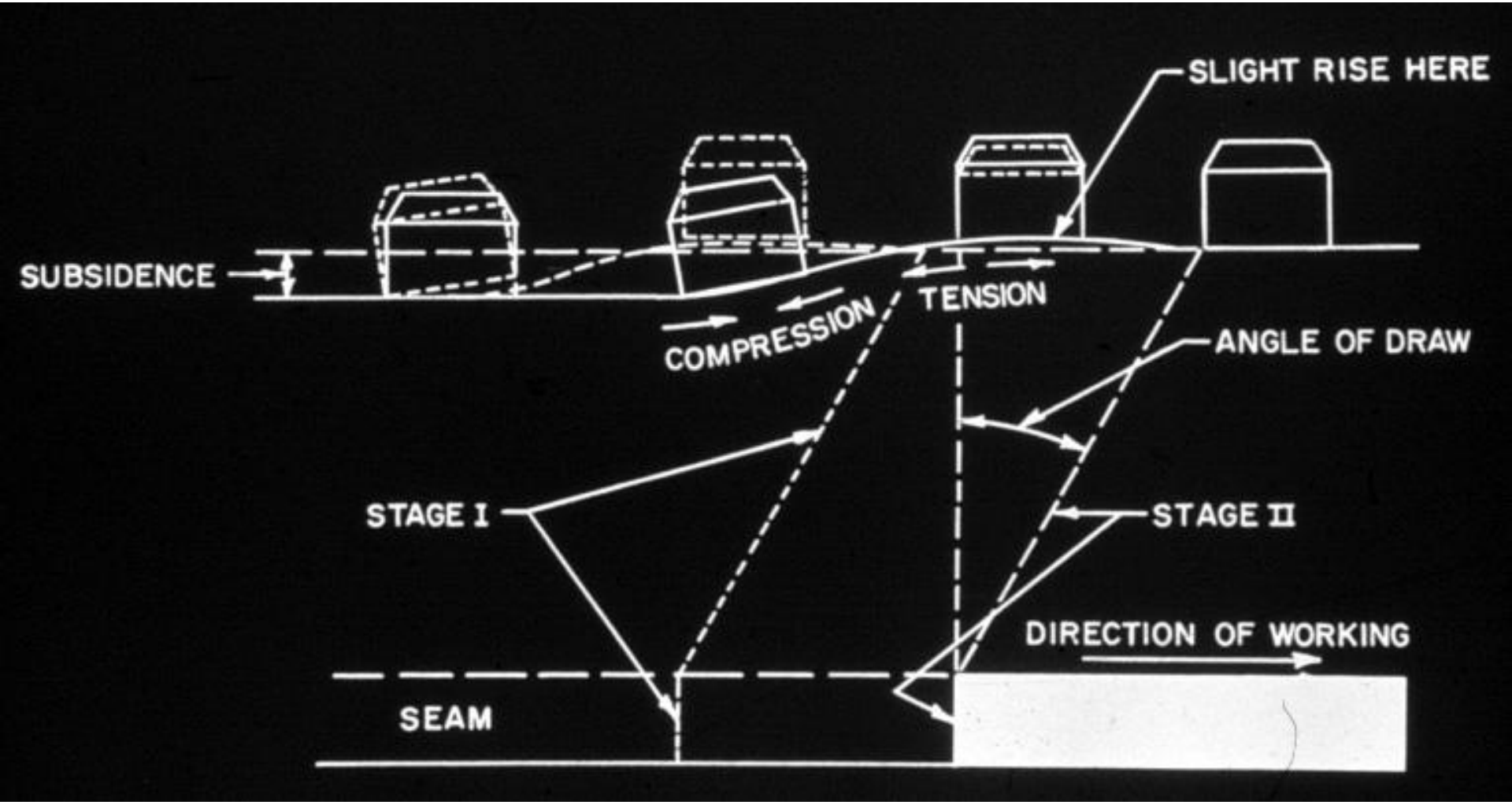
Summary for Abandoned Mines

Above abandoned mines there are no means available as yet to predict exactly when or where subsidence might take place; and so subsidence must generally be expected anywhere unless it can be proved that the area has not been mined, that long term pillar support has been provided or that the mine voids are fully collapsed.

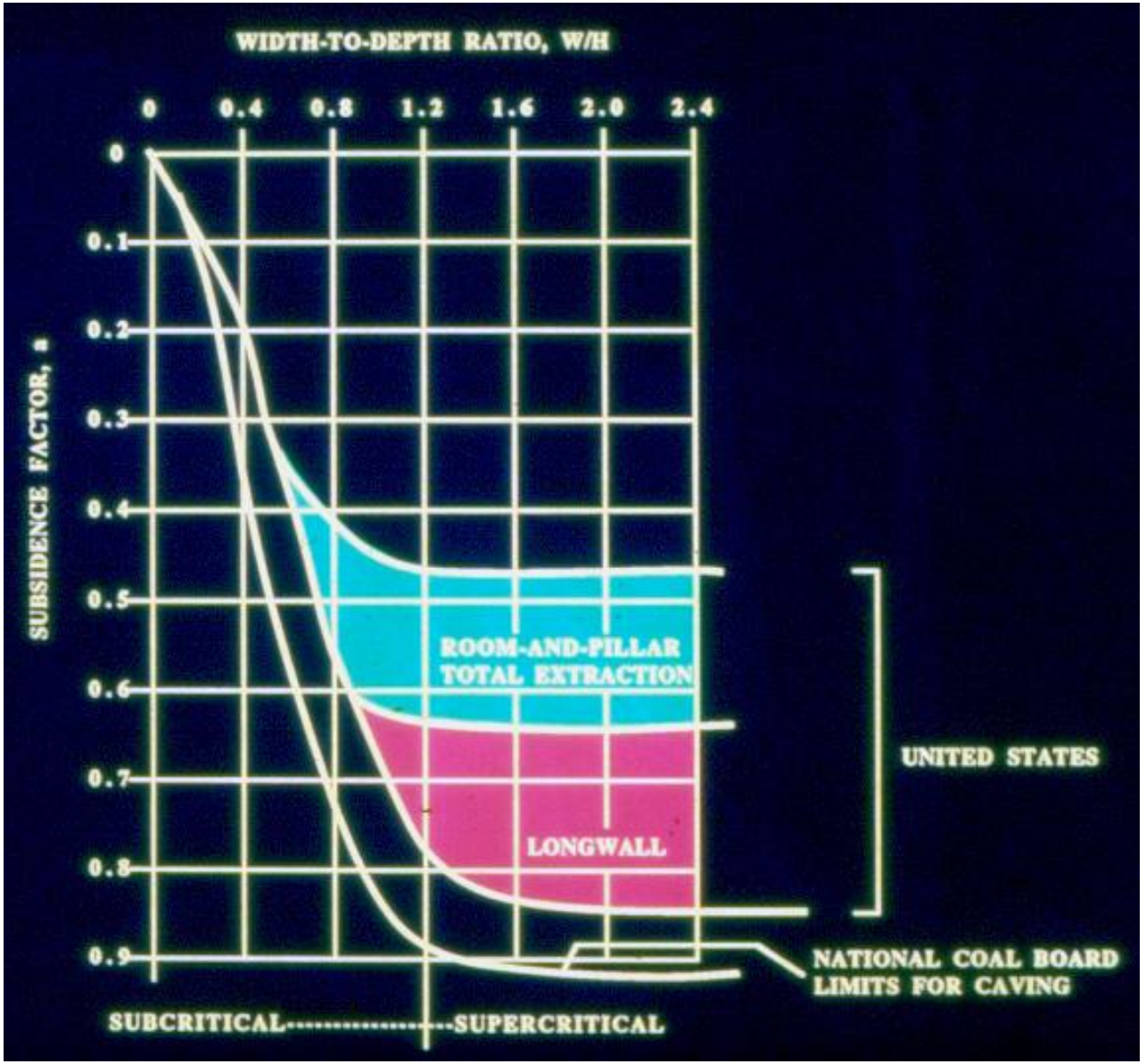
Active Coal Mines

- **Damage is similar to abandoned mines but more predictable.**

- **Longwall mining results in about 50% of U.S. underground production.**



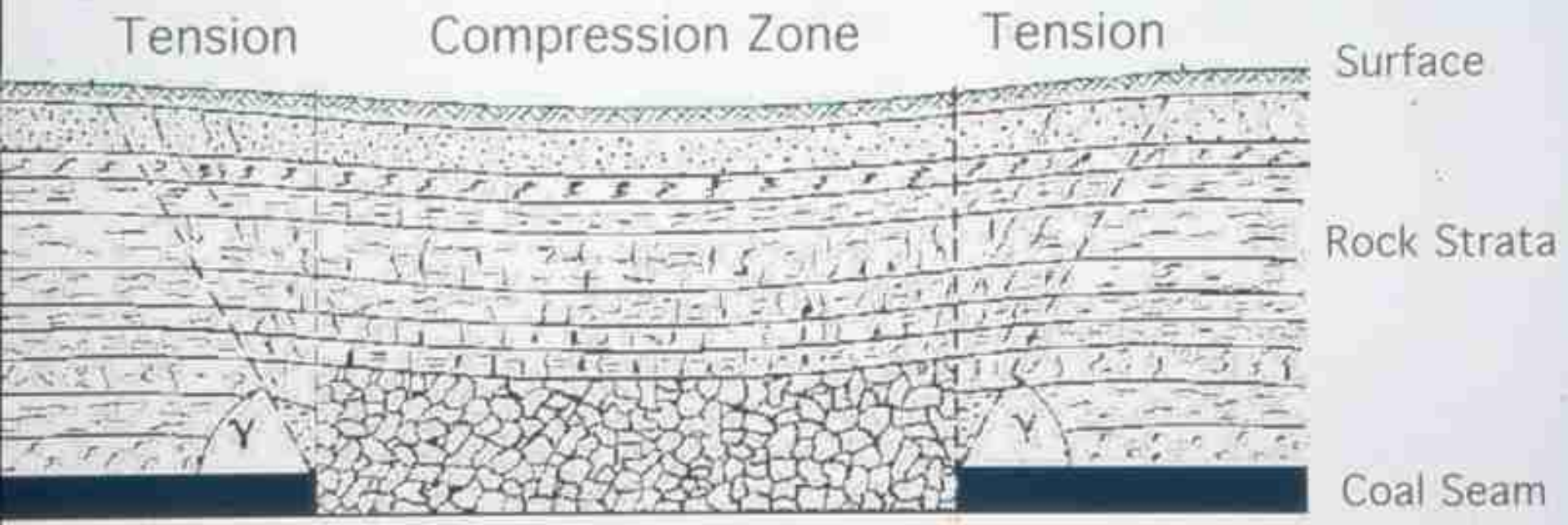
DEVELOPMENT OF SUBSIDENCE TROUGH AND CHANGES IN STRAIN WITH MINING ADVANCE



SUBSIDENCE FACTOR

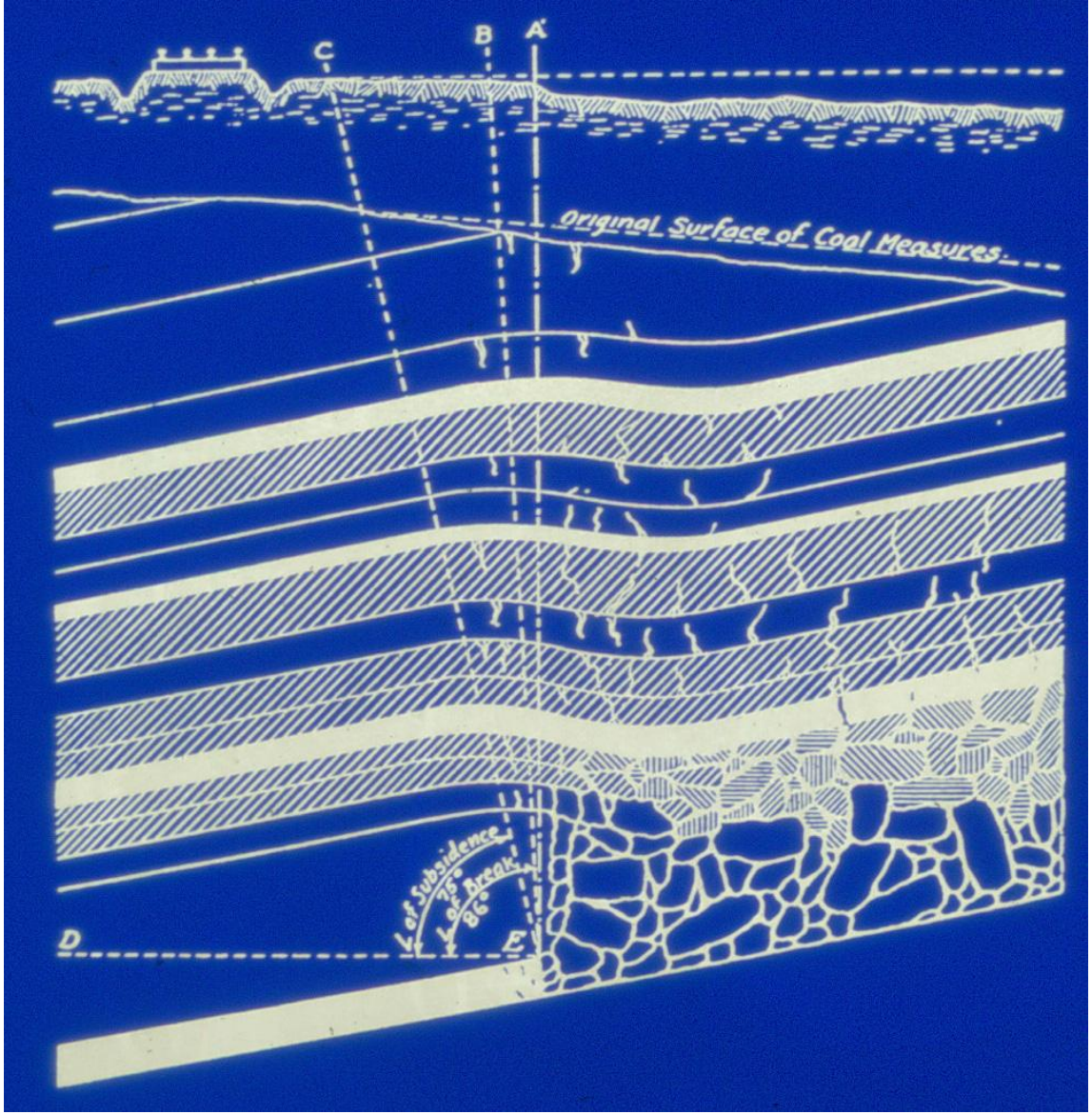
STRATA MOVEMENT

Subsidence Trough



Mined Out

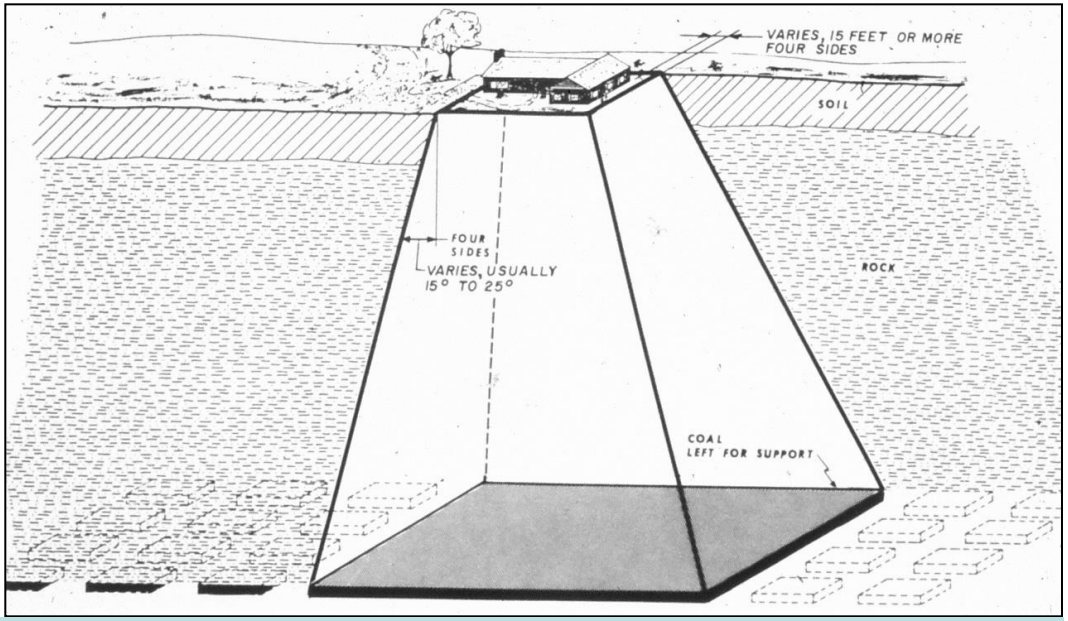
MODIFIED AFTER MINING SUBSIDENCE ENGINEERING, 1983



WITH FULL EXTRACTION EITHER LONGWALL OR RETREAT ROOM AND PILLAR, SURFACE SUBSIDENCE OCCURS REGARDLESS OF THE DEPTH OF THE MINE. SUBSIDENCE OVER LONGWALL MINES AT DEPTHS OF 2000 FEET CAN BE 90 PERCENT OF THE MINE SEAM THICKNESS.

Subsidence Prevention & Control Alternatives

- Selective Support
- Mine Filling
- Subsidence Resistant Designs
- Avoidance
- Mineral Abandonment



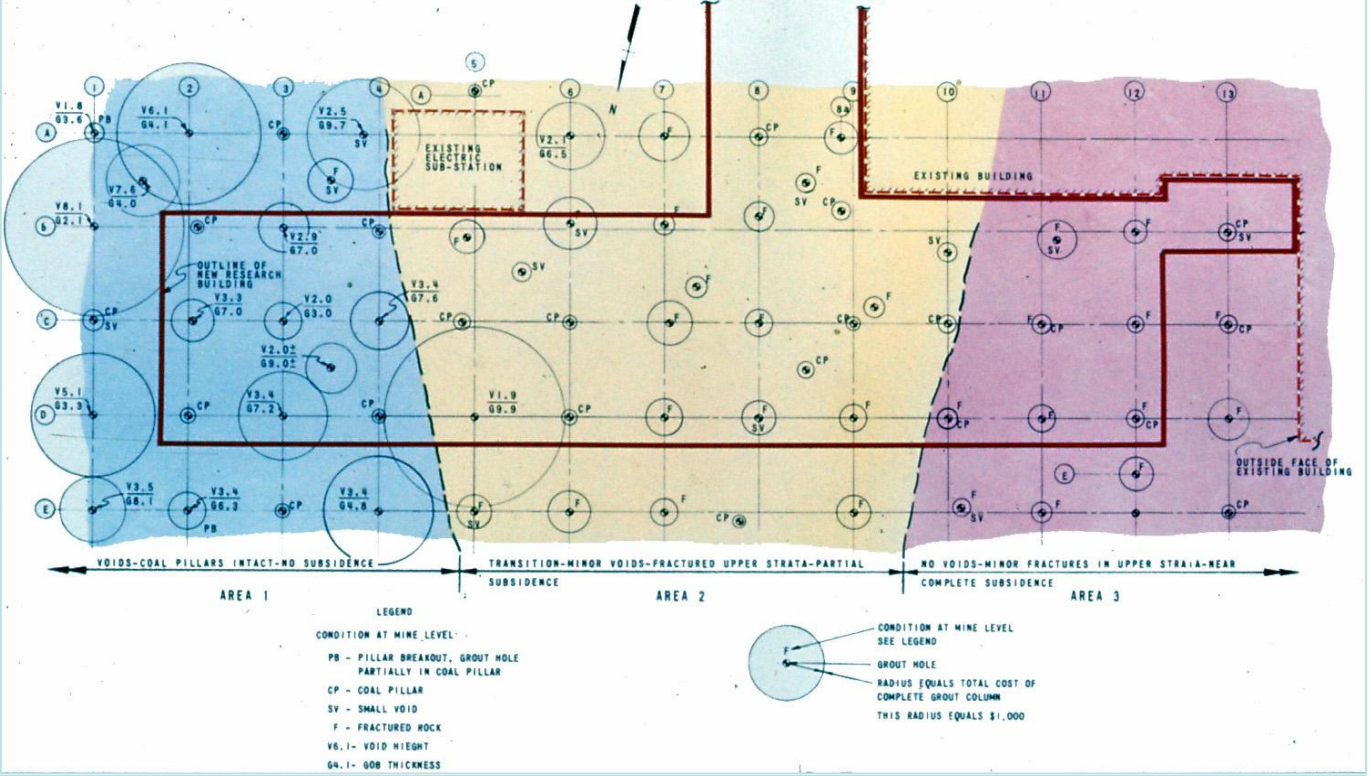
Mineral Abandonment for Surface Support

Subsidence prevention and control alternatives are site specific depending on:

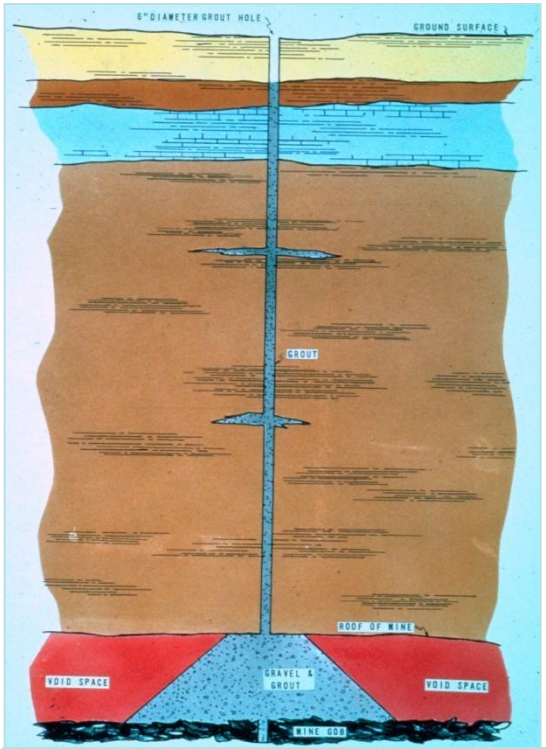
- Geology
- Amount of coal mined – extraction ratio
- Conditions at mine level
- Proposed land use
- Acceptable risk

Selective Support Methods

- Grout Columns
- Piers Built within the Mine
- Deep Foundations
  - Drilled Piers
  - Piles



Plan of Grout Columns



Grout Column

Filling Methods for Void Elimination

- Hydraulic Backfilling
  - Controlled Flushing
  - Remote Flushing
  - Pumped Slurry Injection
- Pneumatic Backfilling
  - Controlled Backfilling
  - Remote Backfilling
- Grouting
- Over-excavation and Backfill
- Dynamic Compaction
- Blasting

Subsidence Prevention and Control Summary

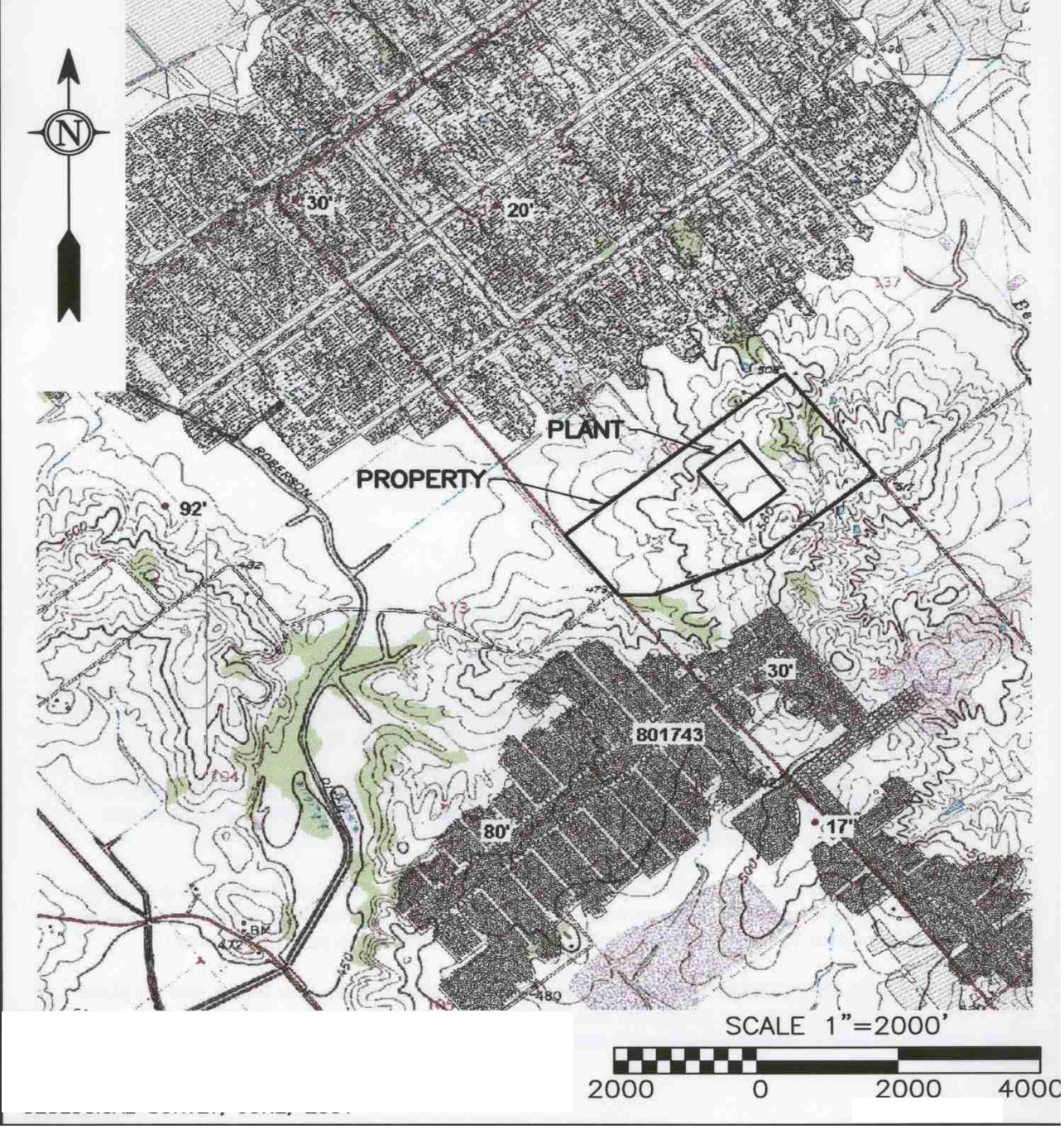
- The subsidence specialist should present the owner with the technical facts, the estimated risk, and the costs of alternates.

- The owner must decide how to spend the available funds.

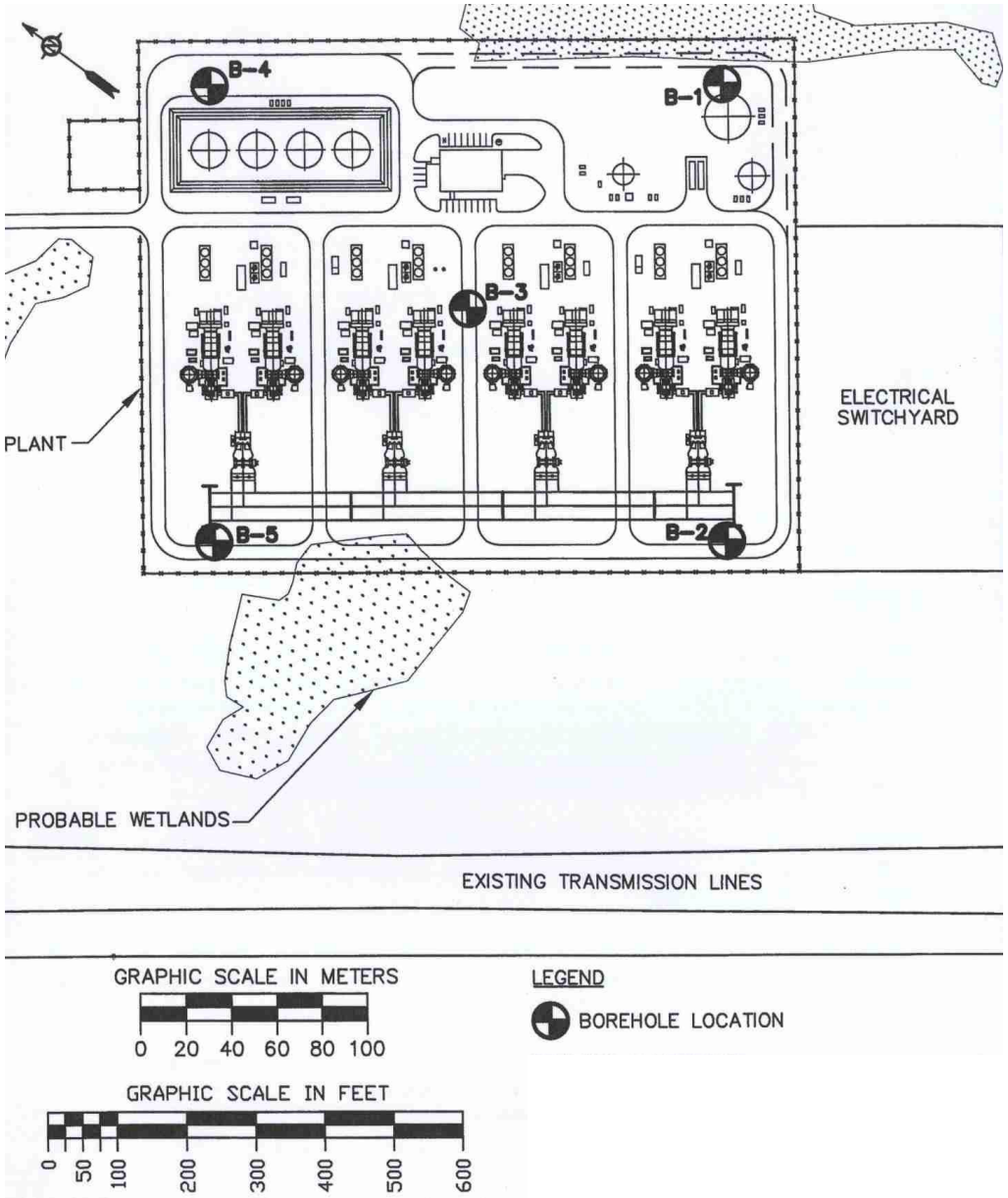
EXPLORATION

MOST GEOPHYSICAL TECHNIQUES ARE OF LITTLE VALUE IN COAL MINE SUBSIDENCE EVALUATIONS.

ONE THAT CAN BE USEFUL IS THE STOLAR RADIO IMAGING METHOD (RIM). IN THIS METHOD AN ELECTROMAGNETIC (EM) WAVE TRAVELS THROUGH THE COAL BETWEEN THE CONDUCTIVE ROOF AND FLOOR MATERIAL. THE WAVE TRAVELS FROM TRANSMITTER TO A COMPANION RECEIVER, DECAYING IN SIGNAL STRENGTH AS A FUNCTION OF DISTANCE. IN A HOMOGENEOUS COAL SEAM THE EM WAVE DECAYS WITH DISTANCE TRAVELED AT A FIXED RATE. IF ANOMALIES EXIST ALONG THE WAVE PATH AN INCREASED DECAY RATE WILL BE MEASURED.



AT A PROPOSED PLANT SITE IN INDIANA LOCATED BETWEEN TWO MINED PARCELS A RIM SURVEY WAS VERY HELPFUL. GEOLOGY INFORMATION INDICATED THE COAL THINNED IN THE AREA OF THE PROPOSED PLANT.



FIVE BORINGS ON A SITE 900 BY 800 FEET CONFIRMED THE COAL WAS PROBABLY TOO THIN TO MINE. HOWEVER, POOR CORE RECOVERY IN ONE HOLE COULD HAVE BEEN DUE TO MINING. A RIM SURVEY THRUGH THE COAL SEAM FROM THE FIVE BORINGS SHOWED THE COAL WAS CONTINUOUS. THE INTERVAL BETWEEN BORINGS WAS UP TO 750 FEET.