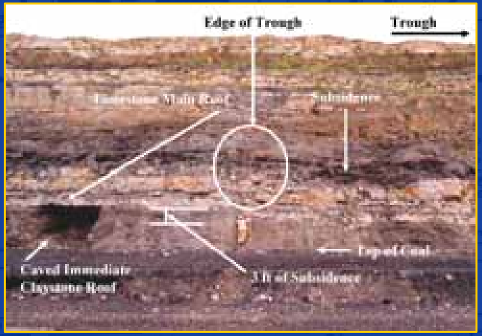

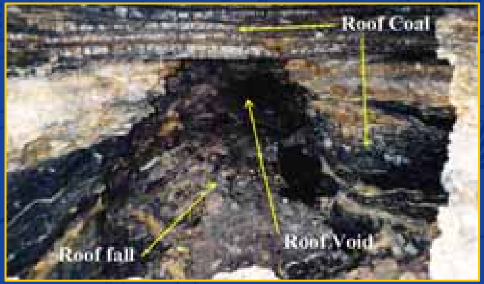

Assessment of Potential Subsidence Impacts from Coal Mining Using Test Borings, Mine Maps, and Empirical Methods

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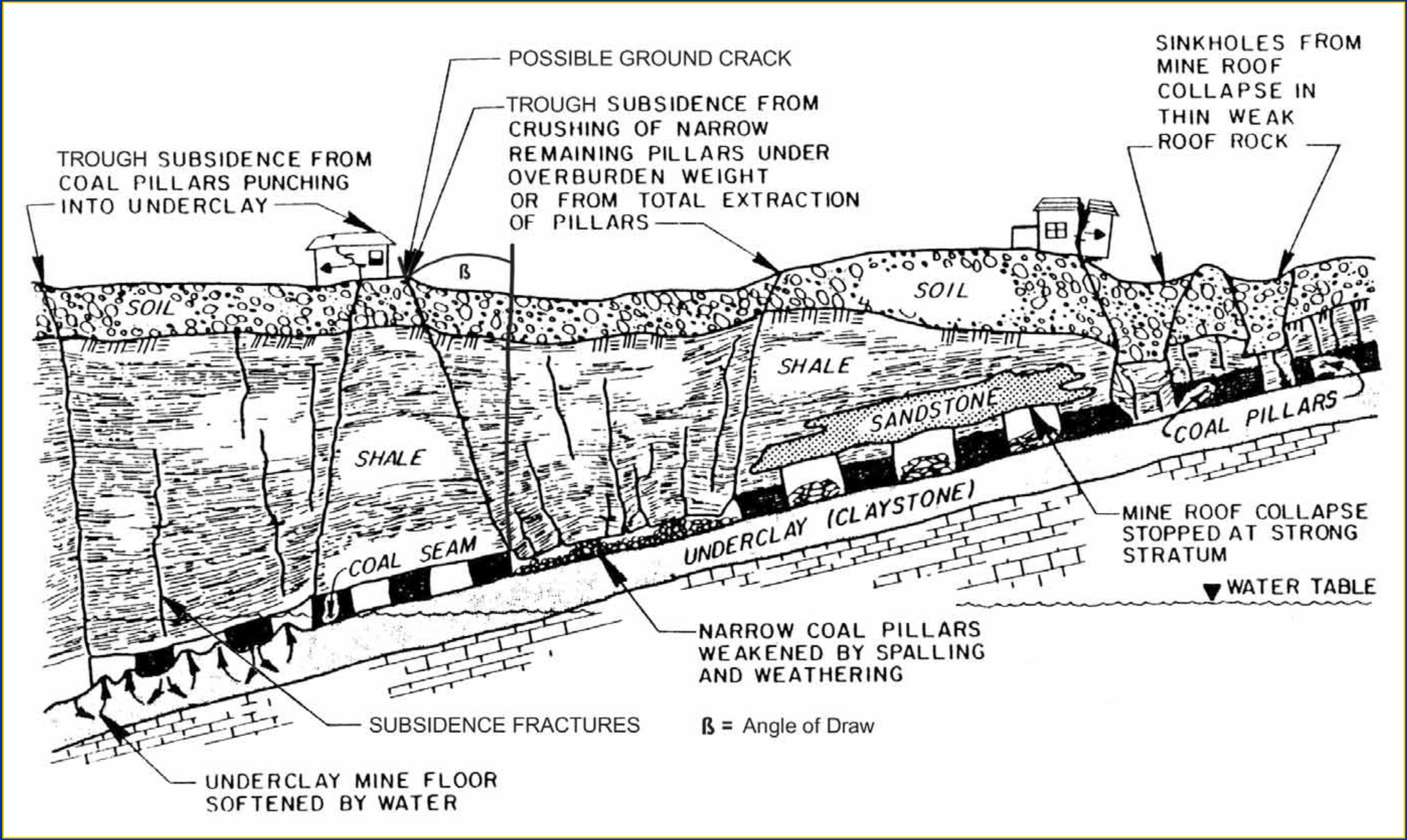
"Mine subsidence is the downward movement of the ground surface due to gravity in response to a loss of support at mine level. The ground surface and whatever is constructed upon it is supported by a structural system that comprises the overburden (the soil-mantled sequence of rock strata situated between ground surface and mine level), the coal pillars, and mine floor. Excessive deformation or failure of one or more of these components over time can result in mine subsidence." (Bruhn et al., 1995).

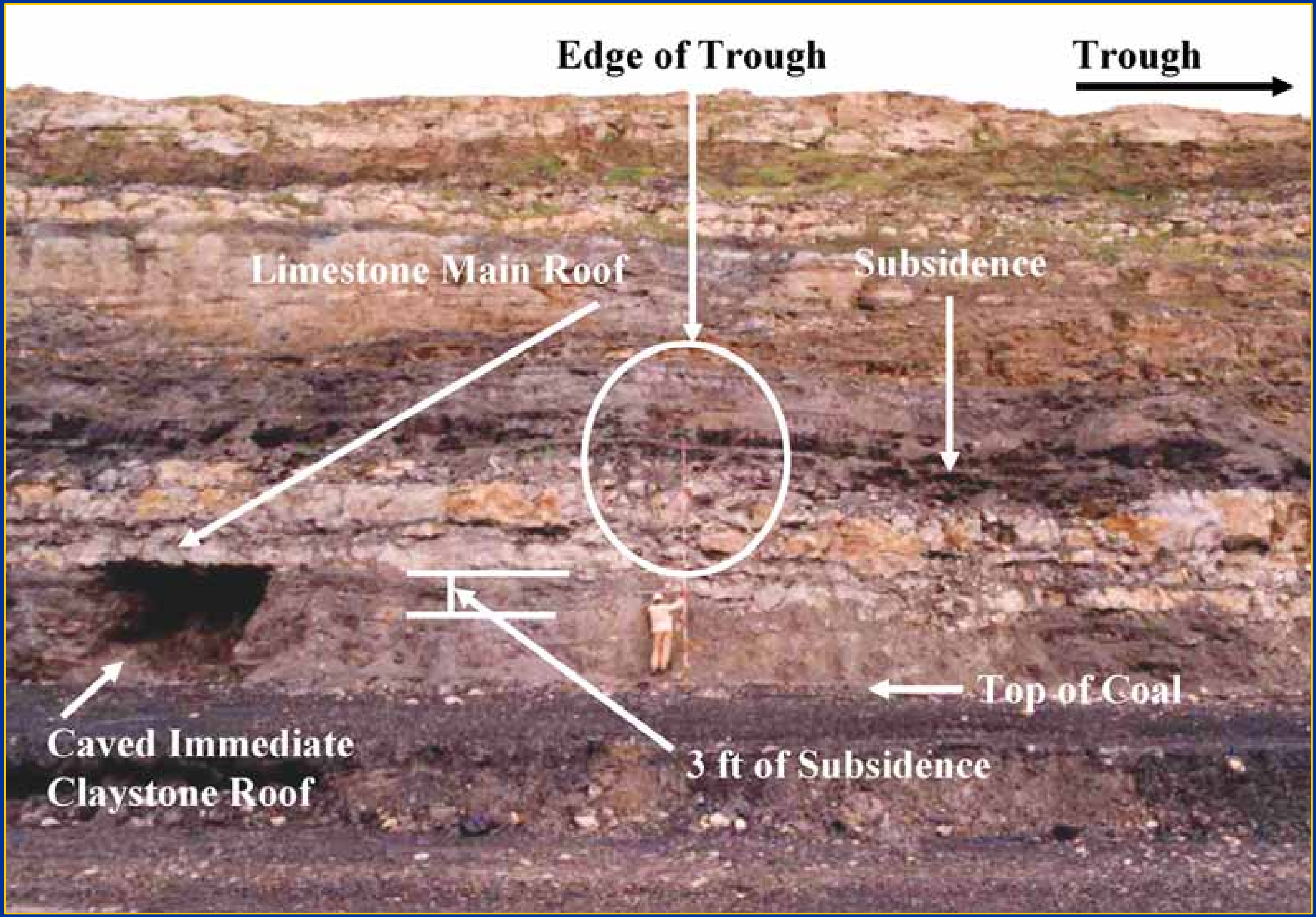
Types of Subsidence (modified from Bruhn et al, 1978)



Trough subsidence above a longwall mined area at a depth of about 1,000 feet in southwest Virginia. Note the sagging and deformed guide rail and replacement of pavement.

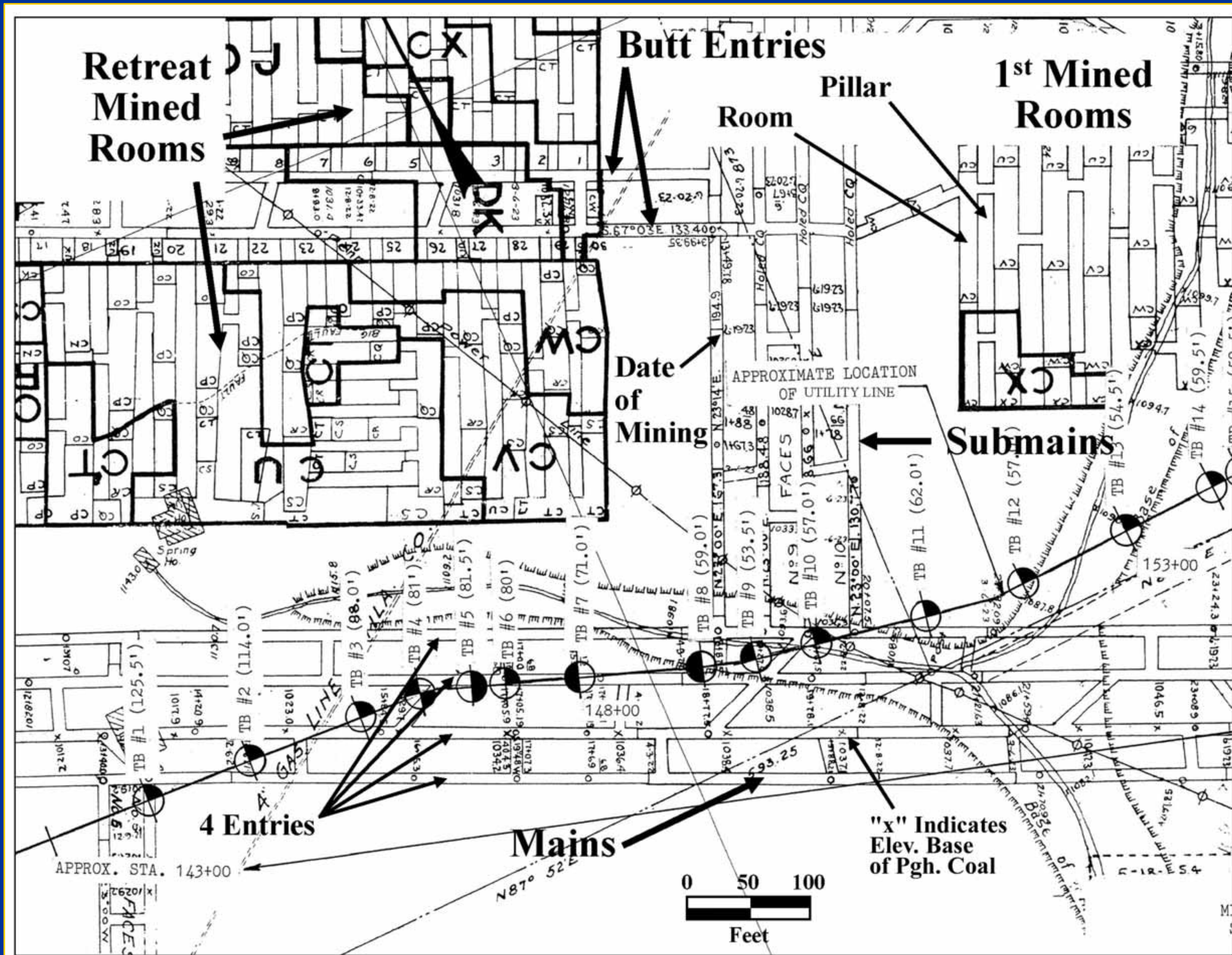
Sinkhole filled with junk above abandoned mine in the Pittsburgh Coal

Trough subsidence and caving of immediate roof resisted by a more competent main roof



Mine Layout

Room and Pillar Mine, Pittsburgh Coal, 1920's



First Mined Room in Early 1900's (modified from Gates, 1990)

Retreat Mining Practice, Pittsburgh Coal, 1920's

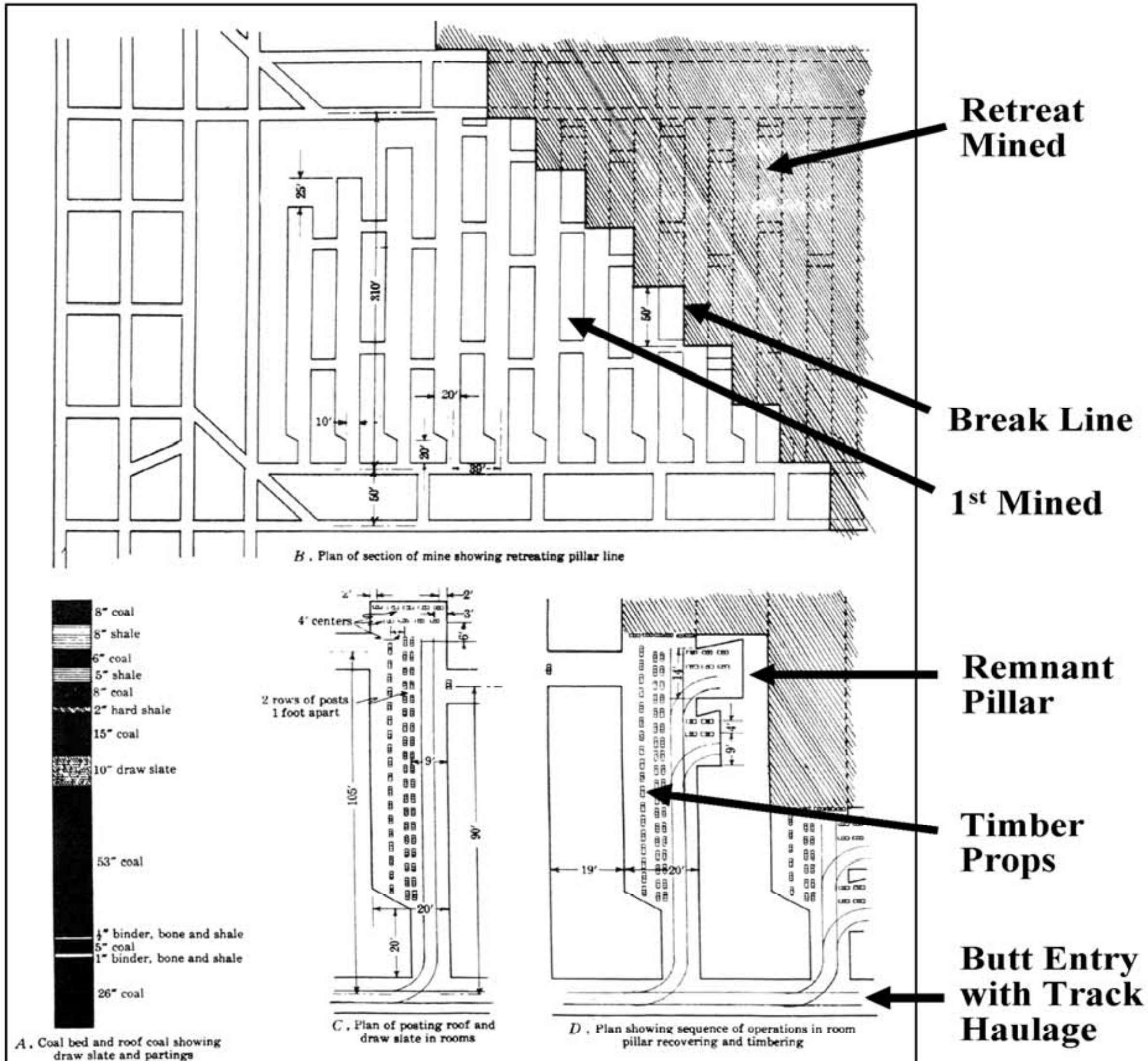
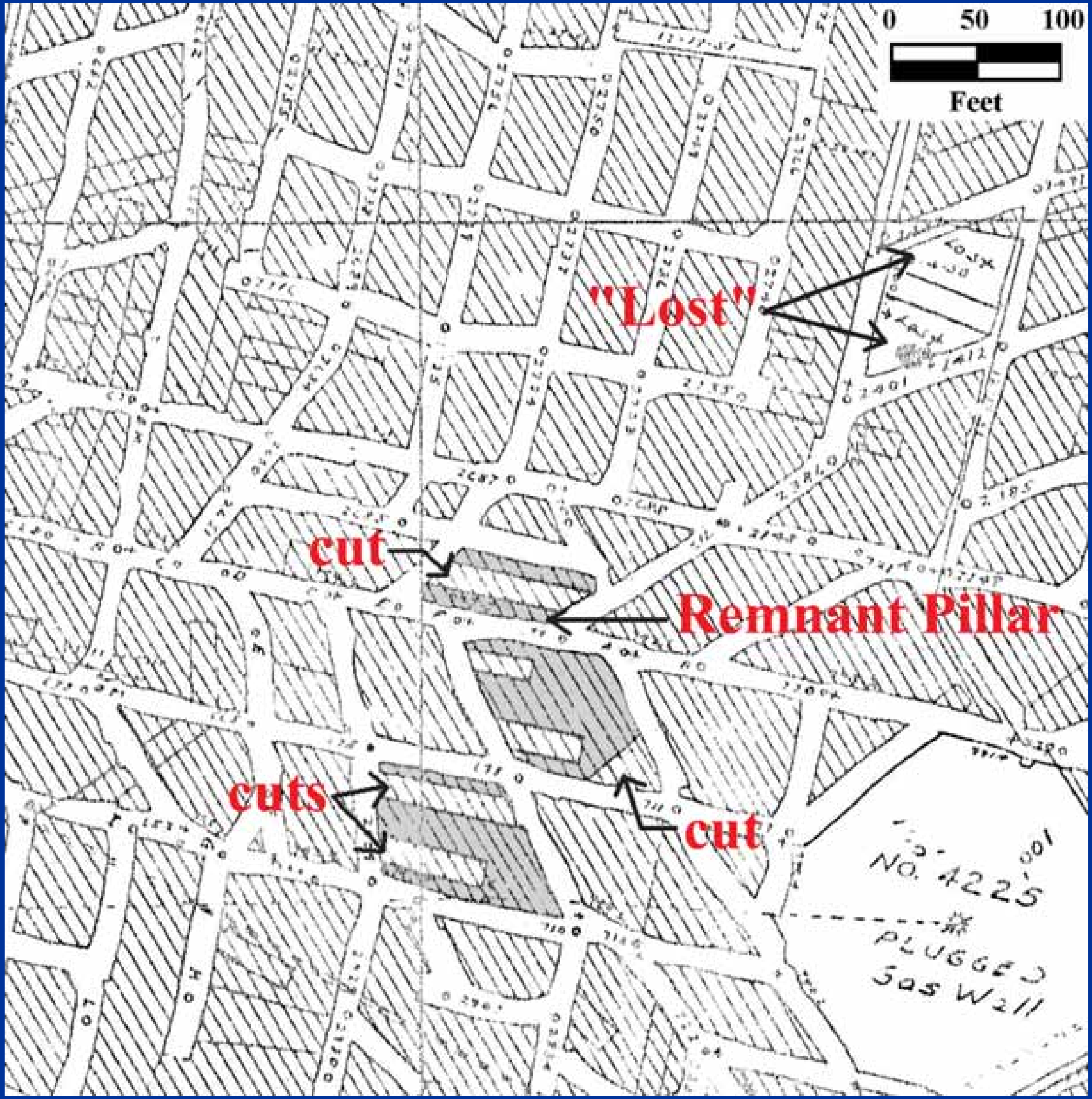


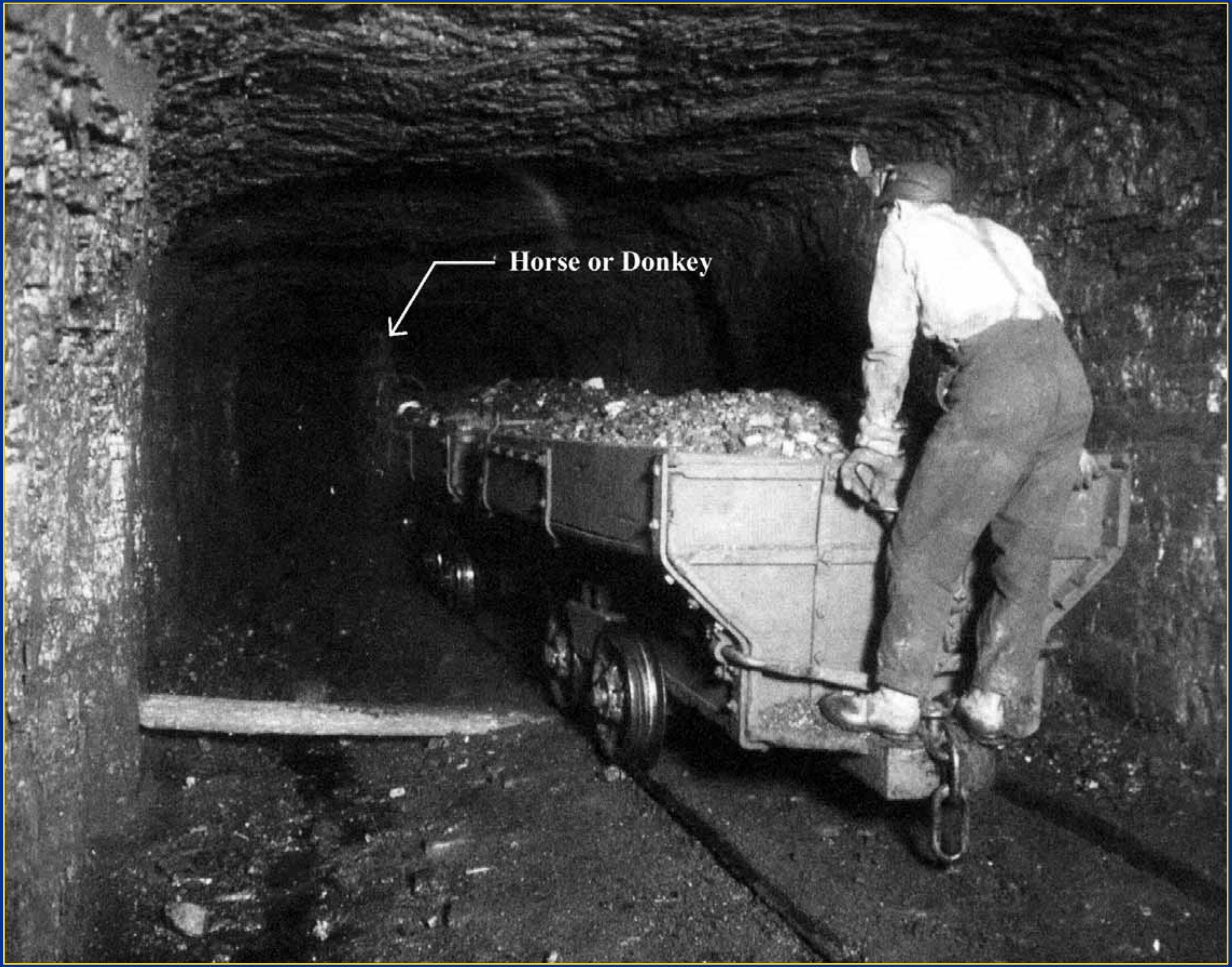
Figure 8.- Mine C, Westmoreland County, showing coal bed and roof, room development and breakline, timbering roof and draw slate in rooms, room pillar recovery and timbering

(RI 3113, 1931)

Portion of Mine Map Indicating Retreat Mining

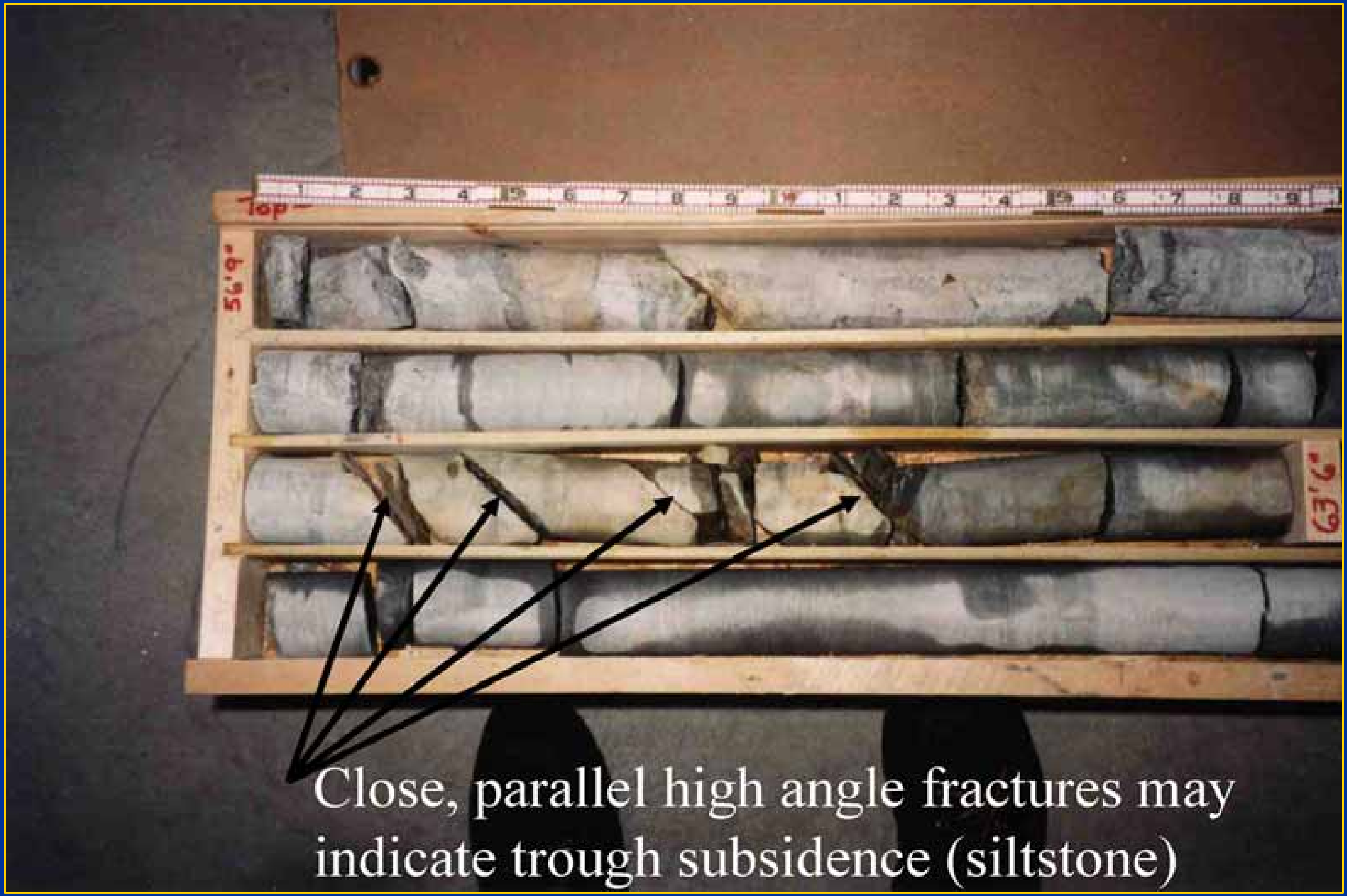


Haulageway in early 1900's (Modified from Gates, 1990)



Potential Subsurface Conditions

View of fracturing possibly indicating trough subsidence above abandoned mine workings in the Pittsburgh Coal



Gob being placed into a mined area (Crowell, 1995)

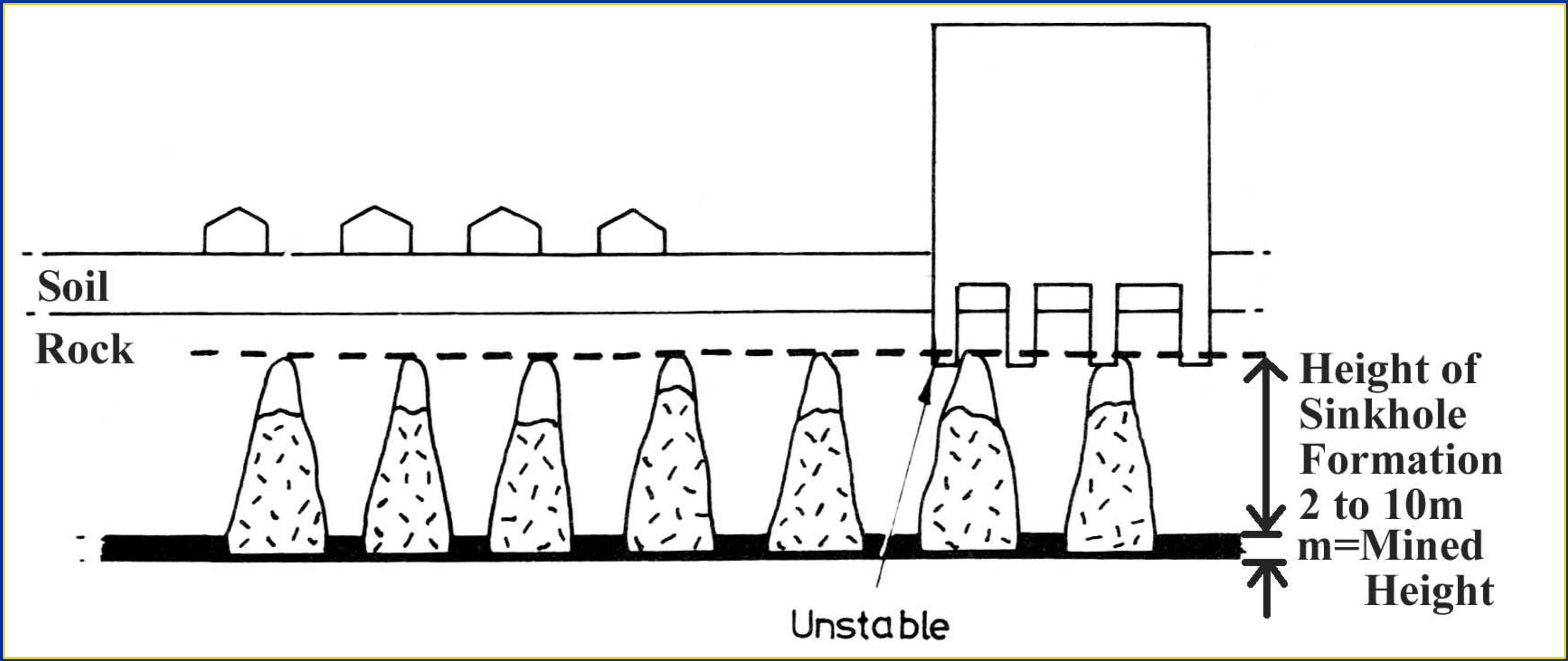
Summary of Potential Subsurface Conditions

Condition in Boring	Rooms			Haulage		
	1st mined	2nd mined (pillar Splitting)	Retreat Mining	Main	Submain	Butt Entry
Mine Roof						
Voids at one or more levels in the main roof due to caving			X			
Voids in the immediate roof due to its collapse beneath the main roof	X	X	X	X	X	X
Highly fractured rock			X			
Steeply dipping parallel fractures (possible trough subsidence)			X			
Loss of water or air return			X			
Cored roof rock strata with relative dip(s) different than the regional dip or in comparison to other borings in the area			X			
Mine Level						
Gob	X	X	X			
Voids at mine level that are full to partial mined height[2]	X	X		X	X	X
Roof fall in a jumble	X	X	X	X	X	X
Intact pillar	X	X		X	X	X
Crushed pillar[3] or remnant pillar			X			
Mined areas filled with floor clay that has heaved due to pillar punching	X	X	X			

Sinkholes

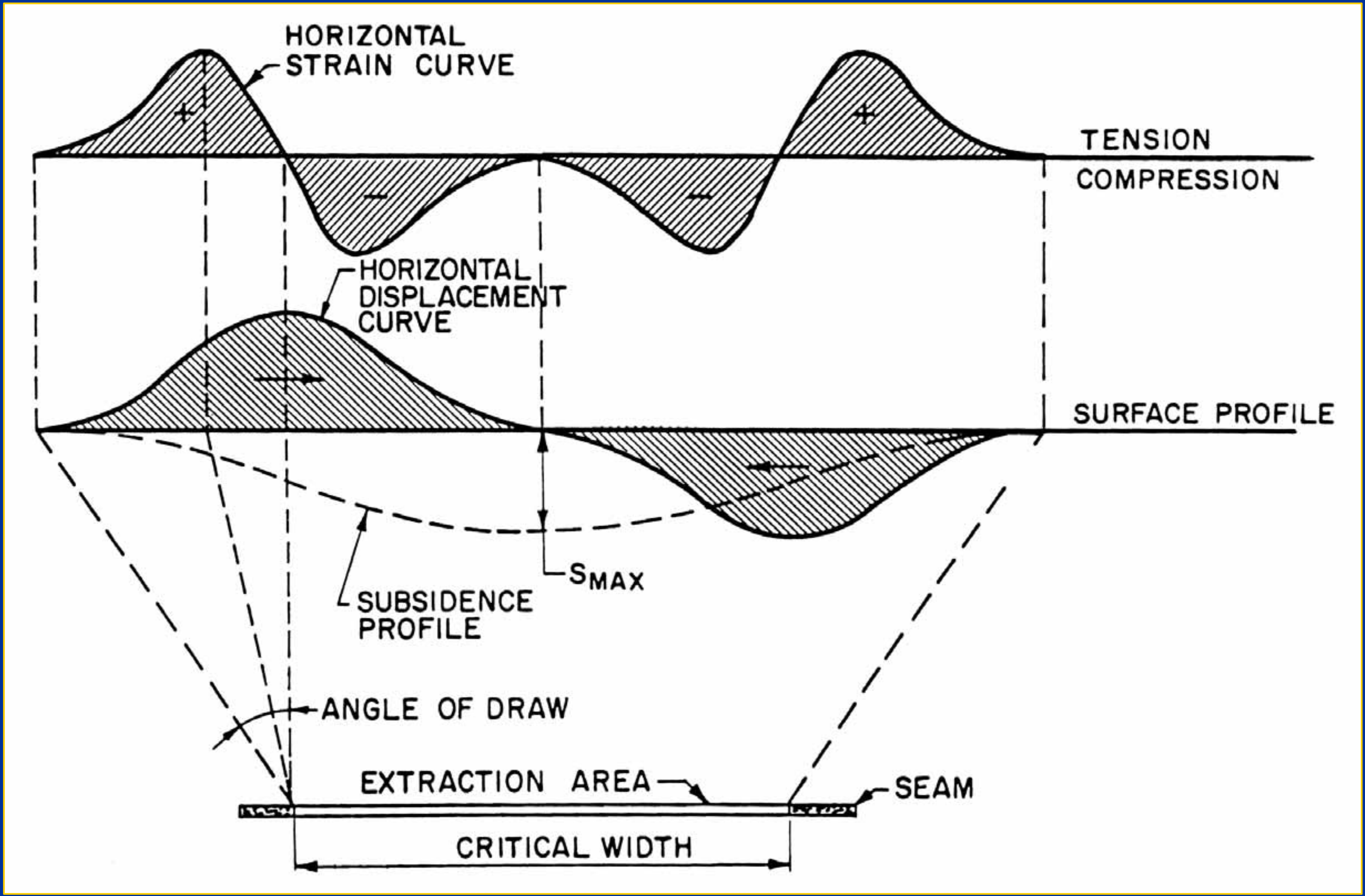
Potential Height of Sinkhole Formation

(modified from Piggott and Eynon, 1977)



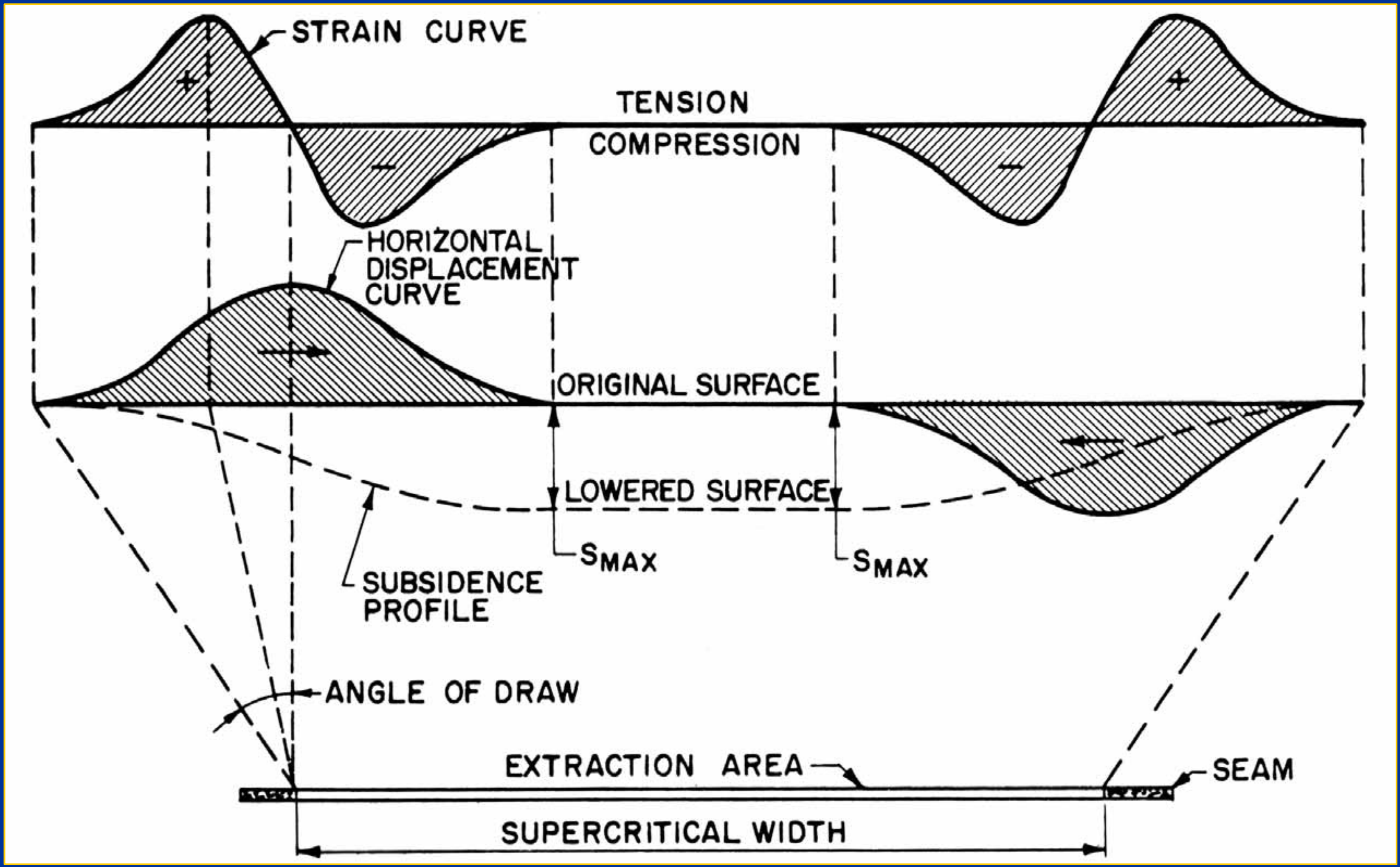
Troughs

Subsidence Profiles – Critical Width



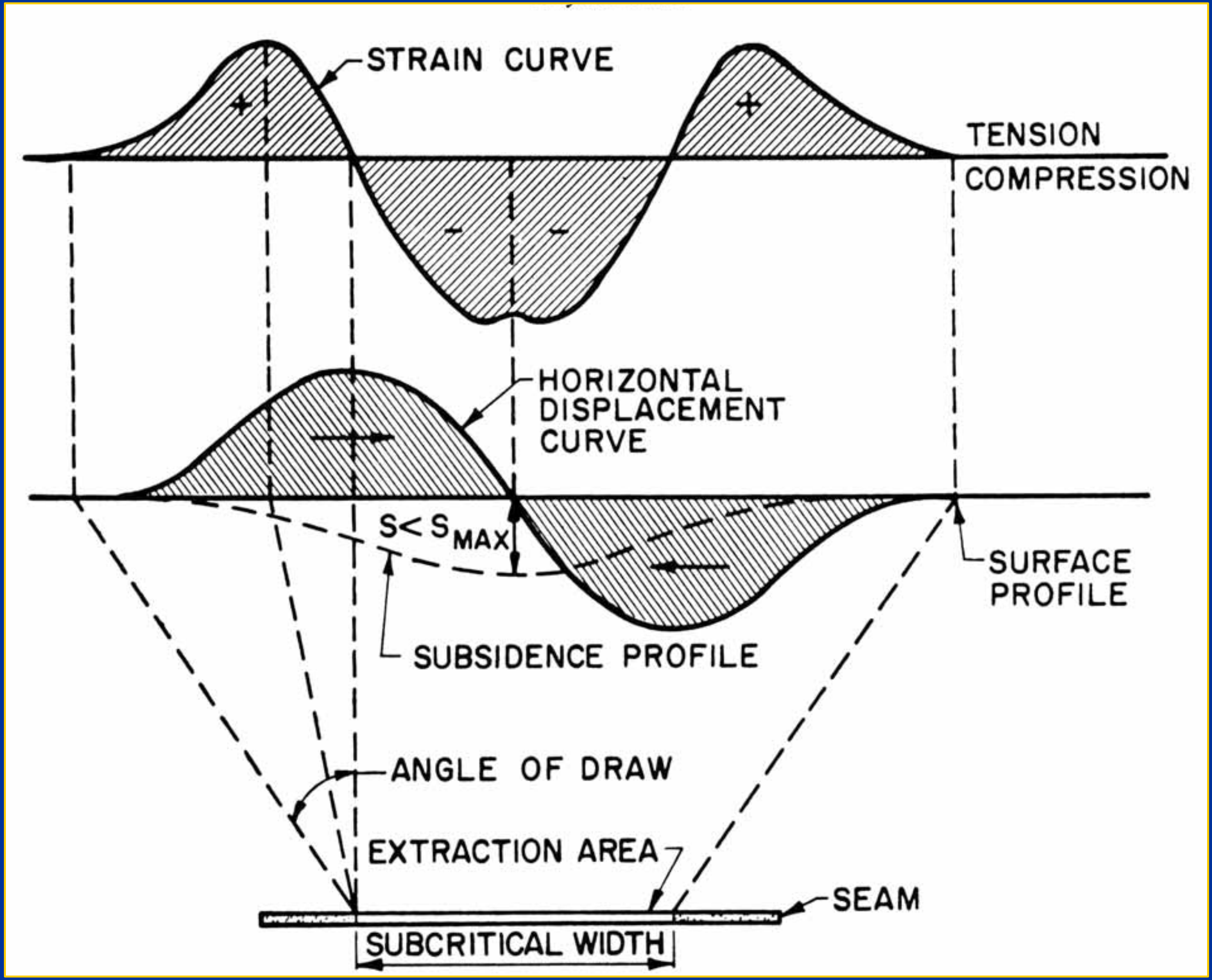
(modified from Gray and Bruhn, 1984)

Subsidence Profiles – Supercritical Width



(modified from Gray and Bruhn, 1984)

Subsidence Profiles – Subcritical Width



(modified from Gray and Bruhn, 1984)

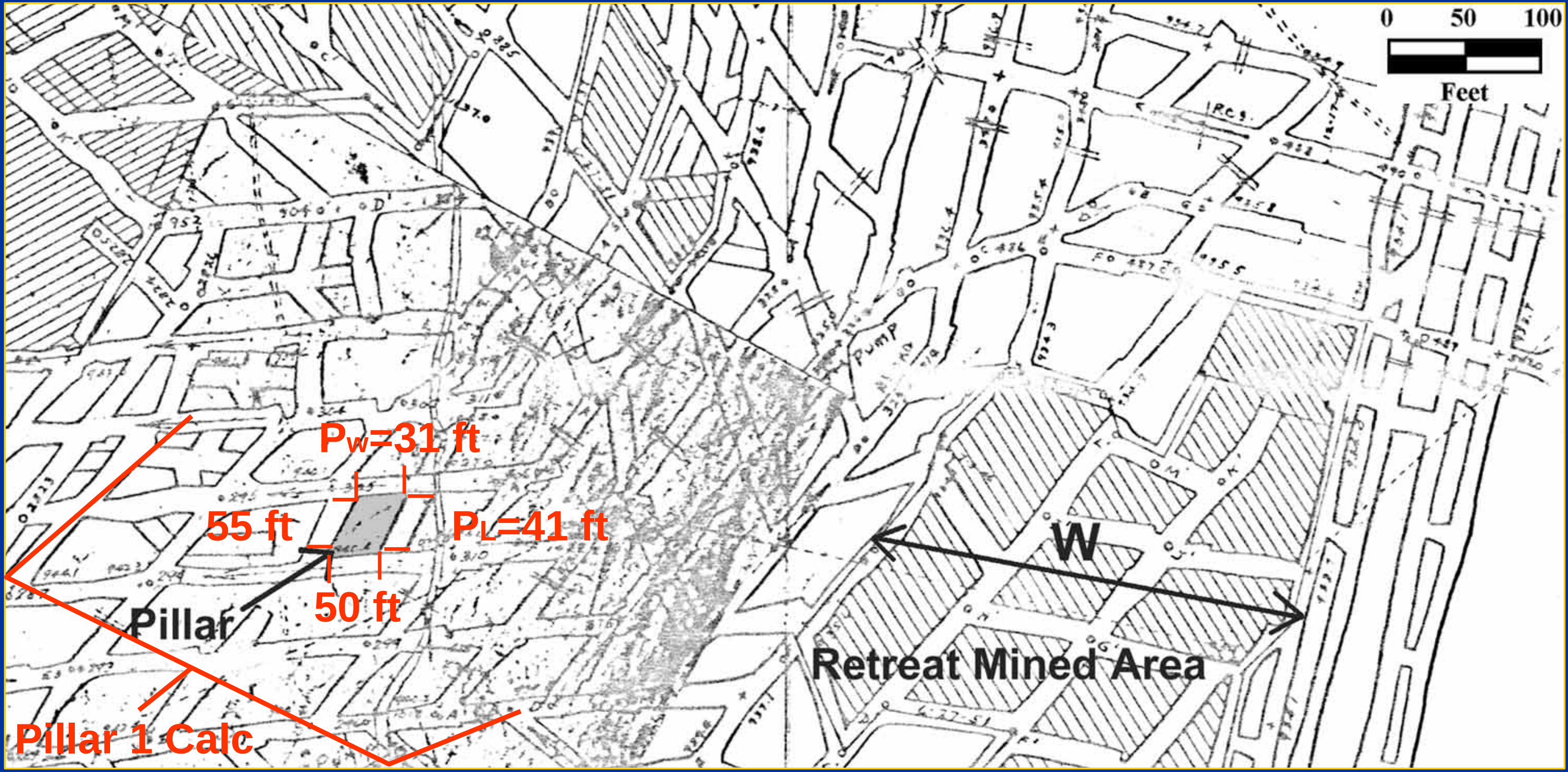
Example Calculations

Consider a site underlain by abandoned mine workings in the Pittsburgh Coal. The mine map is available. The following information was developed from a subsurface investigation

Example Calculations

- General
  - The mined height, m = 8 feet
  - The immediate floor consists of is up to 8.2 feet of underclay, which has a cohesion strength, C_1, of 2 tsf
  - The immediate roof consists of claystone, and it has collapsed
  - The main roof is intact
  - The soil zone is 10 feet thick
  - The percentage of hard rock is 70%.
- First Mined Areas
  - Voids were encountered at mine level and below the main roof.
  - The total overburden H_T = ground surface elevation – mine roof elevation = 1047.6 [939.6 + 8 feet] = 100.4 feet where 939.6 is the elevation of the mine floor from the mine map and the 8 feet is the mined height that needs to be added to the floor elevation to get the mine roof elevation.
- Retreat Mined Areas
  - Voids were encountered below the main roof.
  - The total overburden H_T is 150 feet
  - Remnant pillars remain in retreat mined areas.

Mine Map for Example Calculation



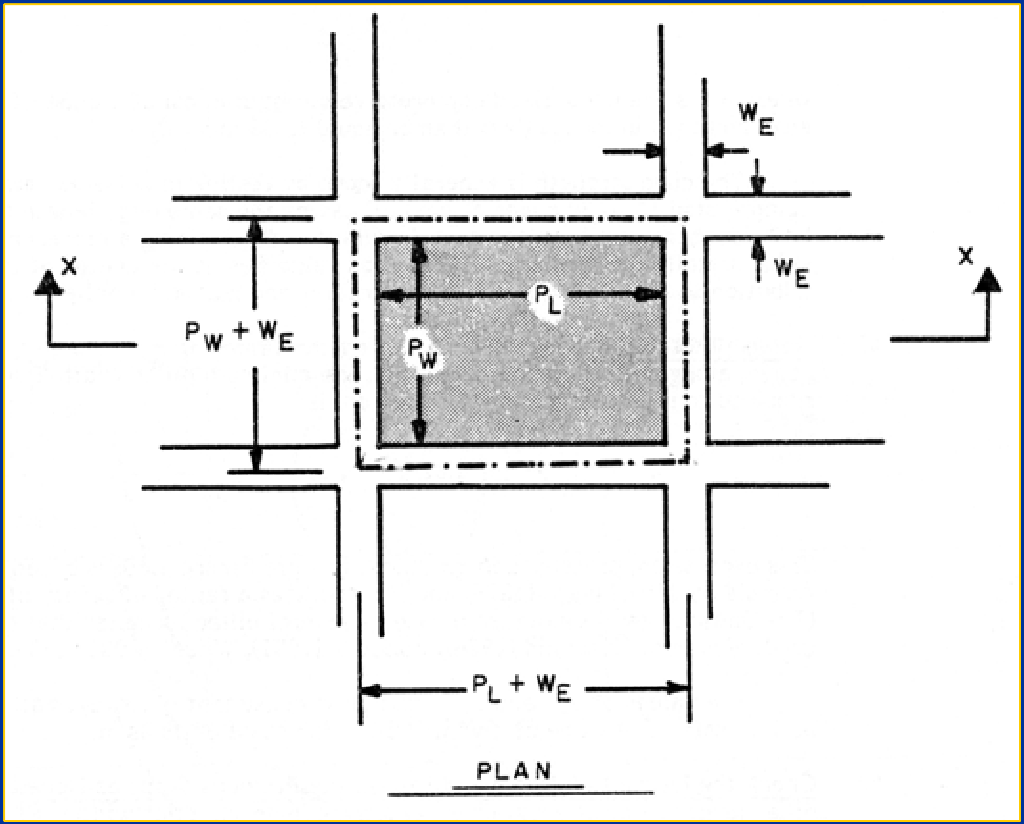
Tributary Area Method

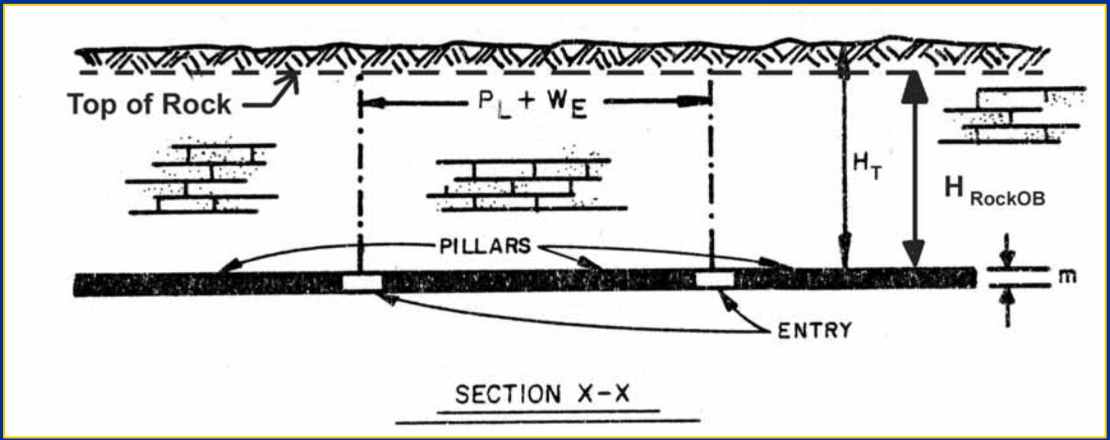
Where

W_E = **Width of Entry**

P_L = **Pillar Length**

P_W = **Pillar Width**





(Bruhn and Turka, 1986)

1. Calculate the Bearing Capacity of Pillar 1

The mine map indicates that the pillar is in a first mined area.

From Figure 12, measure $P_L = 41$ feet; $P_W = 31$ feet
Pillar Area, $A_p = P_L P_W = (41 \text{ feet})(31 \text{ feet}) = 1{,}271 \text{ feet}^2$
Tributary Area, $A_T = (55 \text{ feet})(50 \text{ feet}) = 2{,}750 \text{ feet}^2$

Calculate the Pillar Ultimate Bearing Capacity
From EQ15

$$\begin{aligned} Qult &= 5.14C_1 \\ &= 5.14 \, (2 \text{ tsf}) \\ &= 10.3 \text{ tsf} \end{aligned}$$

Calculate Pillar Overburden Stress

From EQ 11 $\sigma_{OBP} = \gamma H_T \left[\dfrac{A_T}{A_P}\right]$

$$= (1.1 \text{ psi/foot})(100.4 \text{ feet}) \left[\frac{2{,}750 \text{ feet}^2}{1{,}271 \text{ feet}^2}\right]$$

$$= 17.3 \text{ tsf} = 240 \text{ psi}$$

1. Calculate the Bearing Capacity of Pillar 1

Calculate the Pillar Bearing Capacity Factor of Safety
From EQ 18

$$FS_{BEARING\ CAPACITY} = \frac{Q_{ult}}{\sigma_{OBP}}$$

$$= \frac{10.3\ \text{tsf}}{17.3\ \text{tsf}}$$

$$= 0.6$$

This indicates that the pillar has probably punched into the underclay.

Punching of narrow split pillar into underclay

2. Calculate Crushing Strength of Pillar 1

From EQ 13

$$S_P = \sigma_C \left[0.64 + 0.36 \left[\frac{P_W}{H_P} \right] \right]$$

$$= (900 \text{ psi}) \left[0.64 + 0.36 \left[\frac{31 \text{ ft}}{8 \text{ ft}} \right] \right]$$

$$= 1831.5 \text{ psi}$$

Calculate Pillar Factor of Safety

From EQ 14

$$FS_P = \frac{S_P}{\sigma_{OBP}}$$

$$= \frac{1{,}831.5 \text{ psi}}{240 \text{ psi}}$$

$$= 7.6 \qquad > 2 \qquad \text{OK}$$

3. Determine Potential Height of Sinkhole Formation

From Piggott and Eynon (1977) the potential height of sinkhole formation is 2 to 10 times the mined height, m

The height of sinkhole formation = 2m to 10m
= 2(8 feet) to 10(8 feet)
= 16 to 80 feet
80 feet is more reasonable, based on experience in the region (Bruhn, et al., 1980)

$H_{ROCK\ OB} = H_T - H_{SOIL}$
= 100.4 feet – 10 feet
= 90.4 feet

4. Determine Maximum Subsidence in the Retreat Mined Area

Since this is an abandoned mine in the Pittsburgh Coal and no further mining will be performed, S_{max} could be estimated from data in Bruhn et al. (1980). However, to illustrate the methods presented, calculate the subsidence factor, a, from Figure 7 and Figure 8

From Figure 7 for $H_{ROCK\ OB} = H_T$ – soil thickness

$$H_{ROCK\ OB} = 150 \text{ feet} - 10 \text{ feet}$$

$$= 140 \text{ feet}$$

$$W = 280 \text{ feet}$$

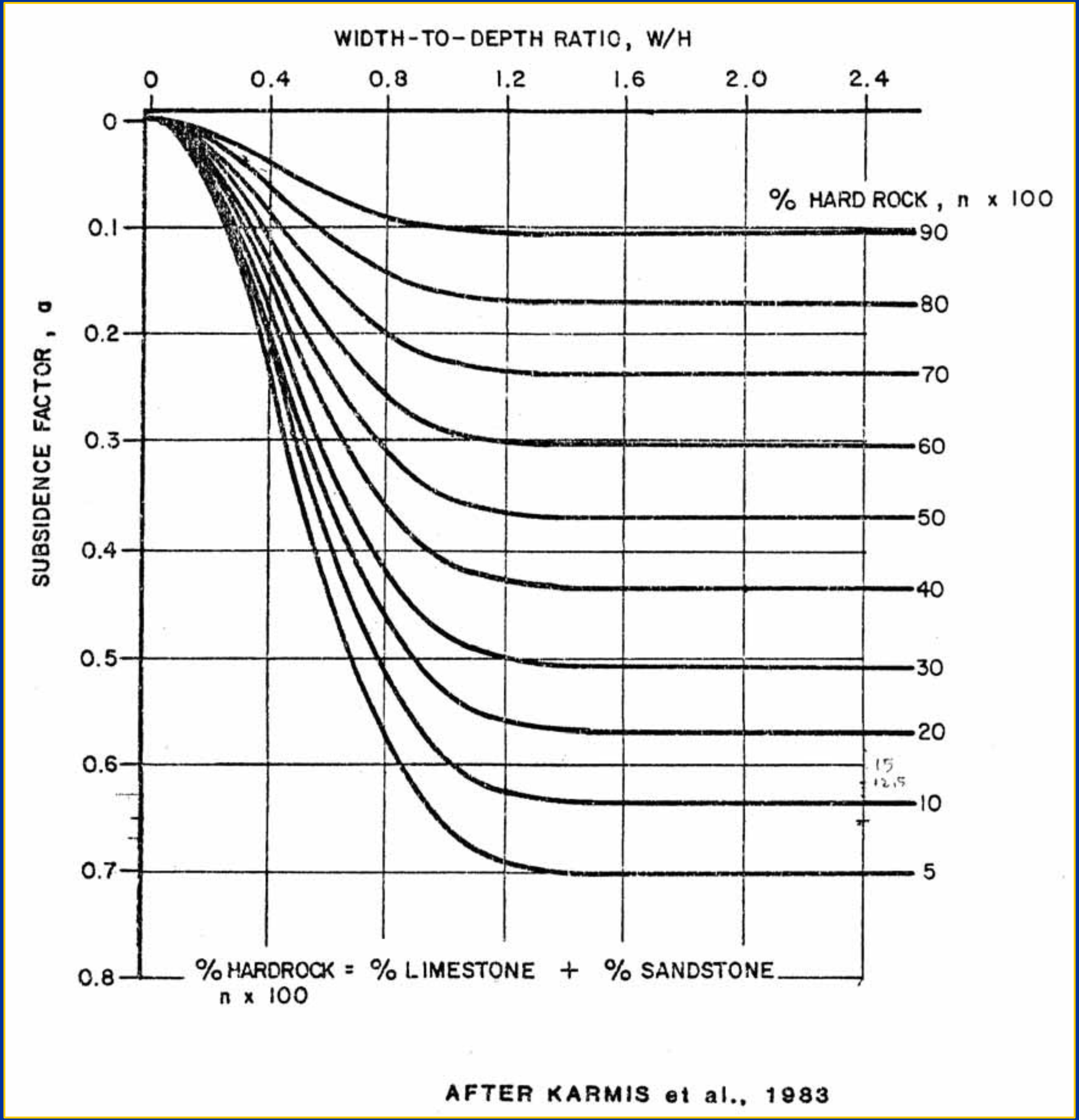
The width of the mined area is measured from Figure 12, and since some remnant pillars remain, consider 80% coal removal.

$$\frac{W}{H_{ROCK\ OB}} = \frac{280 \text{ feet}}{140 \text{ feet}} = 2$$

use a = 0.55, which is near the middle range for total extraction room and pillar

The Subsidence Factor, a

- can be calculated several ways
- is a function of mine width to depth and percent hardrock in overburden



4. Determine Maximum Subsidence in the Retreat Mined Area

From EQ 1

$S_{max} = am$

$S_{max} = (0.55)(8 \text{ feet}) = 4.4 \text{ feet}$

From Figure 8, with $\dfrac{W}{H_{ROCK\ OB}} = 2$, and the percentage of hardrock = 70%

$a = 0.23$

From EQ 1

$S_{max} = (0.23)(8 \text{ feet}) = 1.8 \text{ feet}$

Use S_{max} = 1.8 feet, which is more in line with data from Bruhn, et al. (1980)

5. Check Critical Width, Wc

This will determine which subsidence trough profile would be expected

W = 280 feet, measured from mine map, rock overburden

$H_{ROCK\ OB}$ = 140 feet, as determined in (4)

$$\frac{W}{H_{ROCK\ OB}} = 2 > 1.1$$ Trough is supercritical, See Figure 6B

for $W_C/H_{ROCK\ OB} = 1.1$, gives $\frac{W_C}{140\ \text{feet}} = 1.1$, $\Rightarrow W_C = 154$ feet

6. Determine Subsidence Profile

Use the subsidence functions in Table 2

From ④ $S_{max} = 1.8$ feet and $H_{ROCK\ OB} = 140$ feet

$$W_1 = W_2 = \frac{(W - W_c)}{2} = \frac{(280 \text{ feet} - 154 \text{ feet})}{2} = 63 \text{ ft}$$

$L_1 = L_2 = H_{ROCK\ OB}\ \text{Tan}\beta = 140 \text{ feet } (\tan 15^o) = 37.5$ feet

The limb of the trough width = w_L

$w_{L\ 1} = w_{L\ 2} = W_1 + L_1 = 63 \text{ feet} + 37.5 \text{ feet} = 100.5$ feet

Figure 14 shows a plot of the subsidence profile for the total trough, and Figure 13 shows the profiles for all functions.

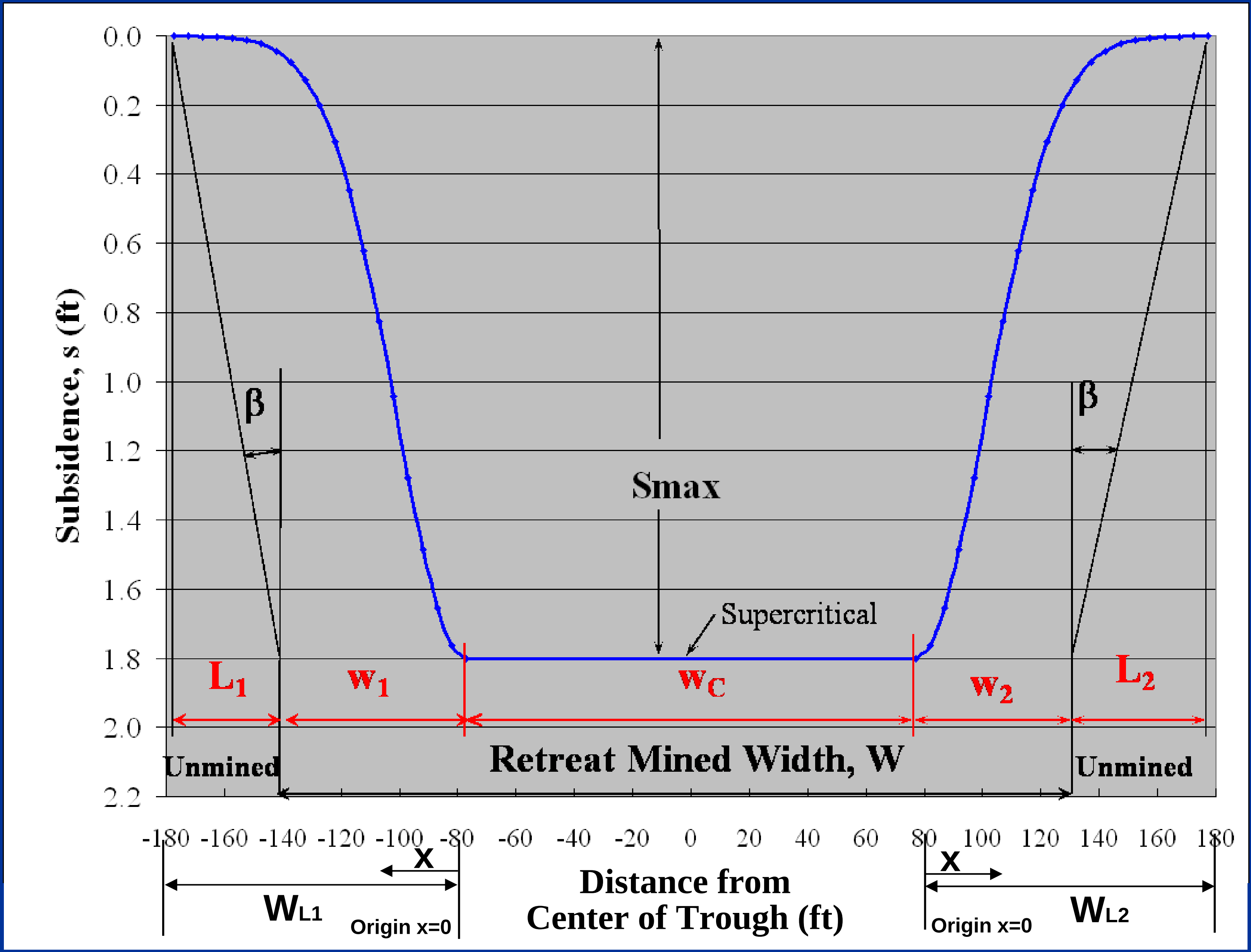
Function Values for Estimating Subsidence Parameters Along the Trough Profile for the Negative Exponential Function:

- **Subsidence**
- **Slope**
- **Curvature**
- **Horizontal Displacement**
- **Strain**

$$S(x)=S_{MAX}(f_{Subsidence})$$

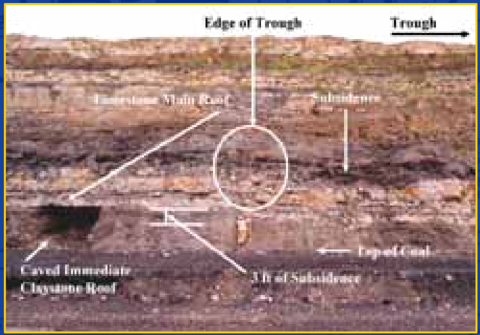
Distance along the trough limb x/w_L	Subsidence Function, $f_{Subsidence}$	Slope Function, f_{Slope}	Curvature Function, $f_{Curvature}$	Horizontal Displacement Function, $f_{Horizontal\ Displacement}$	Strain Function, f_{Strain}
0	1	0	-18	0	-2.117
0.05	0.98	-0.815	-16.117	-0.096	-1.924
0.1	0.92	-1.563	-13.442	-0.184	-1.605
0.15	0.826	-2.132	-9.14	-0.251	-1.091
0.2	0.71	-2.465	-4.141	-0.29	-0.494
0.25	0.58	-2.55	0.63	-0.3	0.075
0.3	0.459	-2.419	4.44	-0.284	0.53
0.35	0.345	-2.129	6.884	-0.25	0.822
0.4	0.248	-1.754	7.912	-0.206	0.945
0.45	0.17	-1.358	7.756	-0.16	0.926
0.5	0.111	-0.992	6.8	-0.117	0.812
0.55	0.07	-0.685	5.452	-0.08	0.651
0.6	0.042	-0.447	4.046	-0.053	0.483
0.65	0.024	-0.277	2.8	-0.033	0.334
0.7	0.013	-0.163	1.816	-0.019	0.217
0.75	0.007	-0.091	1.107	-0.011	0.132
0.8	0.003	-0.048	0.637	-0.006	0.076
0.85	0.002	-0.024	0.346	-0.003	0.041
0.9	0.001	-0.012	0.178	-0.001	0.021
0.95	0	-0.005	0.086	-0.001	0.01
1	0	-0.002	0.04	0	0.005

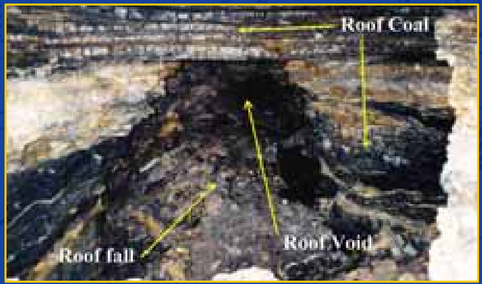
Full Trough Subsidence Profile



Comments of Subsidence Assessment

- First Mined Area
  - If enough pillars can fail by punching, trough subsidence could occur in this area.
  - The ground surface is just above the predicted height for sinkhole formation. However, due to the caving of the immediate roof, the height for sinkhole formation could increase, since the void height (mined height, m,) has increased and the roof fall materials provide no support.
- Retreat Mined Area
  - Trough subsidence can occur, since the main roof is still up and remnant pillars remain.
  - S_{max} = 1.8 feet





QUESTIONS?

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