A short history of changes in reclamation of Central Appalachian coal mined lands over the last 45 years.

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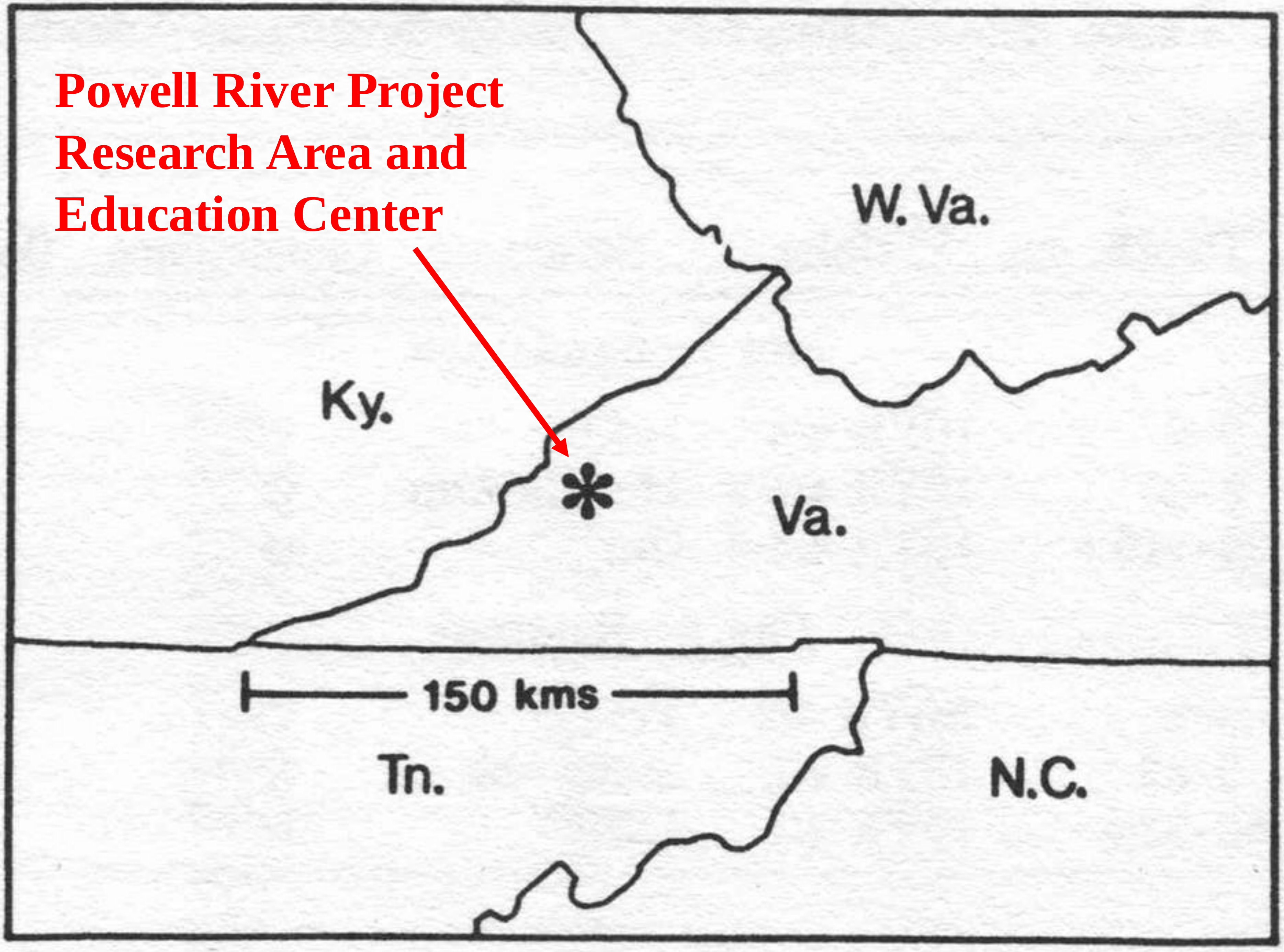
Objectives for Today

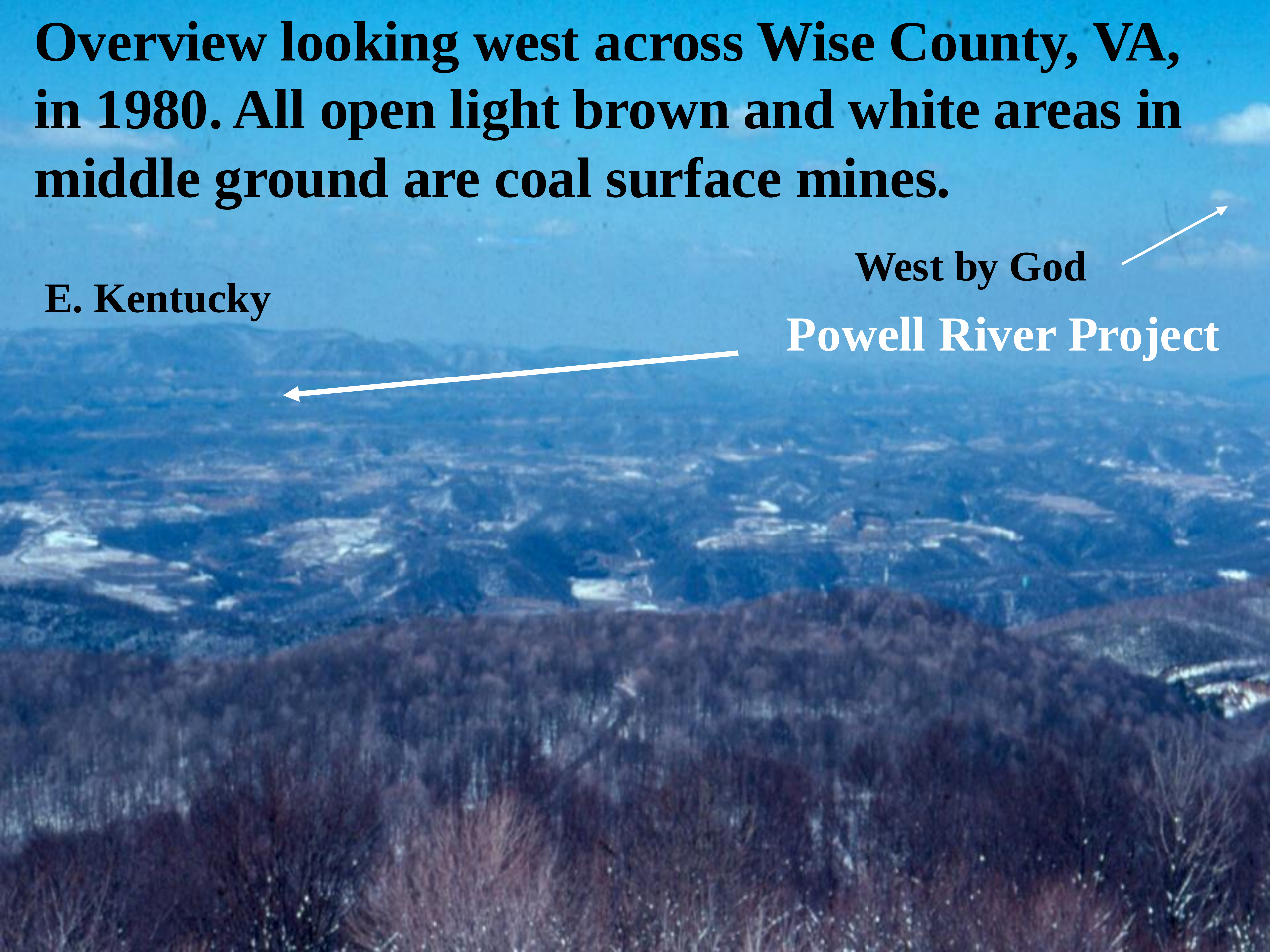
- **1. Provide a brief (~45 year) history of surface coal mine reclamation and associated research in the central Appalachians**

- **2. Discuss many of the intended and unintended consequences of SMCRA (1977) on integrated mining & reclamation practices, mine soil properties and water quality**

- **3. Present a very narrow/biased view based on the KY/VA/WV border region, ignoring our colleagues' good work in AL, MD, PA, and TN**


Powell River Project
Research Area and
Education Center
W. Va.
Ky.
Va.
150 kms
Tn.
N.C.

Overview looking west across Wise County, VA, in 1980. All open light brown and white areas in middle ground are coal surface mines.



Coal Mining Legislation (Before SMCRA):

State coal-mining legislation:

1939 - West Virginia

By 1955 - Indiana, Pennsylvania, Ohio, Kentucky and Maryland had enacted similar legislation.

By 1967 – Also Virginia and Illinois.

1965–1972 - 16 major coal-producing states took a total of 28 major legislative actions.

By 1975 - 38 states had established programs, with 32 taking action between 1970 and 1975.

Inconsistencies among state laws became an issue …

"... restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or higher or better uses of which there is reasonable likelihood." [Sec. 515(b)2]

Commonly termed as "equal or better" post-mining land use capability.

"except as provided [elsewhere], backfill, compact (where advisable to insure stability or to prevent leaching of toxic materials), and grade in

order to restore the *approximate original contour* of the land with all highwalls, spoil piles, and depressions eliminated."
[Sec. 515(b)3]

"stabilize and protect all surface areas including spoil piles affected by the surface coal mining and reclamation operation to effectively control erosion and attendant air and water pollution;" [Sec. 515(b)4]

"assume the responsibility for successful revegetation, … for a period of five* full years after the last year of augmented seeding, fertilizing, irrigation, or other work." [Sec. 515(b)20]

* 10 years if annual rain < 26 inches

"… remove the topsoil from the land in a separate layer, replace it on the backfill area … or if other strata* can be shown to be more suitable for vegetation requirements, then the operator shall remove, segregate, and preserve in a like manner such other strata which is best able to support vegetation …" [Sec. 515(b)5]

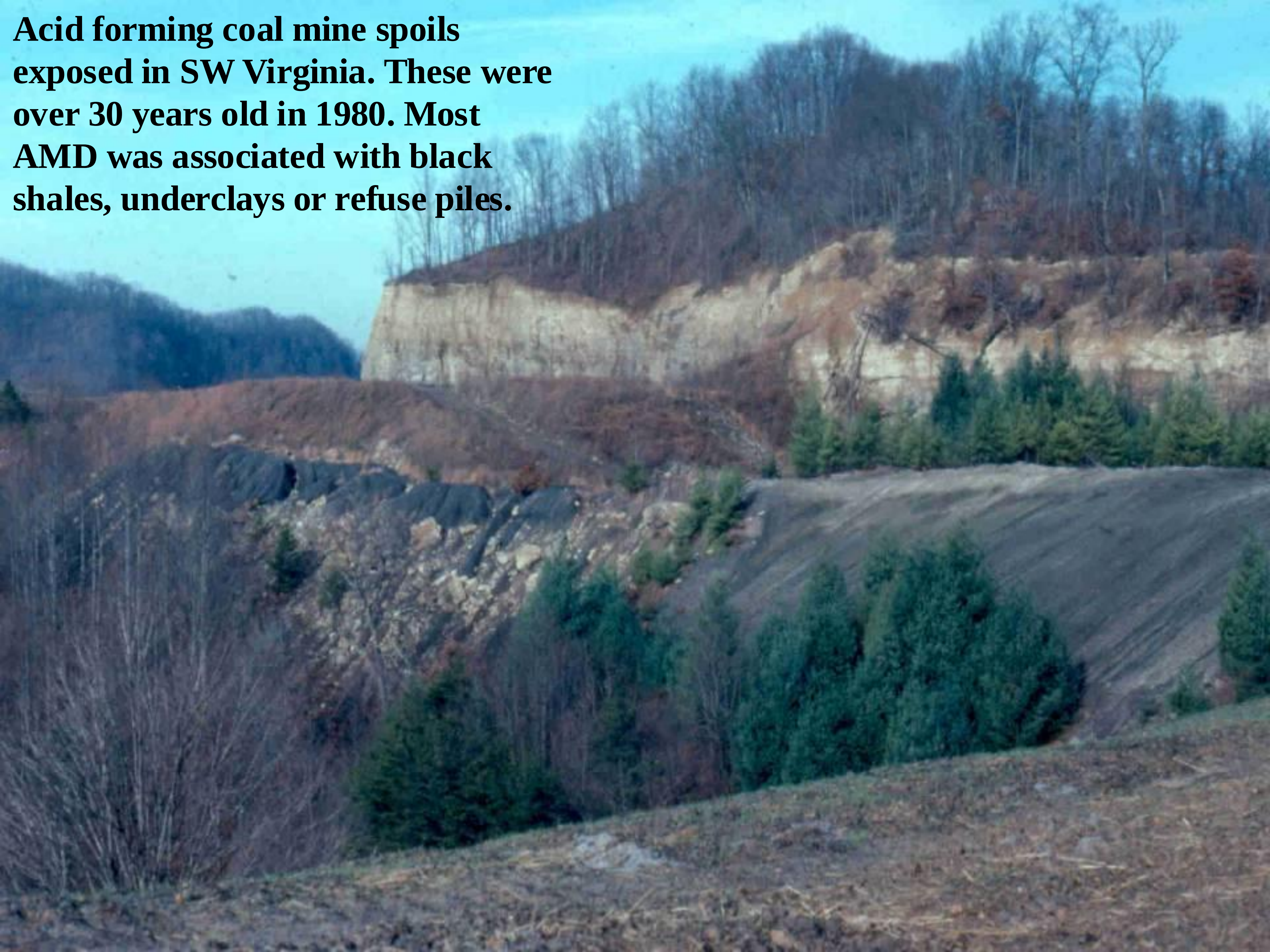
"Topsoil substitutes" are commonly used in reclamation "establish on the regraded areas, and all other lands affected, a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area;

except, that introduced species may be used in the revegetation process where desirable and necessary to achieve the approved postmining land use plan;" [Sec. 515(b)19]

"Avoiding acid or other toxic mine drainage by such measures as …

(i) preventing or removing water from contact …

(ii) treating drainage to reduce toxic content which adversely affects downsteram water …"



Acid forming coal mine spoils exposed in SW Virginia. These were over 30 years old in 1980. Most AMD was associated with black shales, underclays or refuse piles.

Potential Acidity Estimators for Water Quality Prediction

Acid-Base Accounting - ***Smith et al., 1976*** **- WVU**

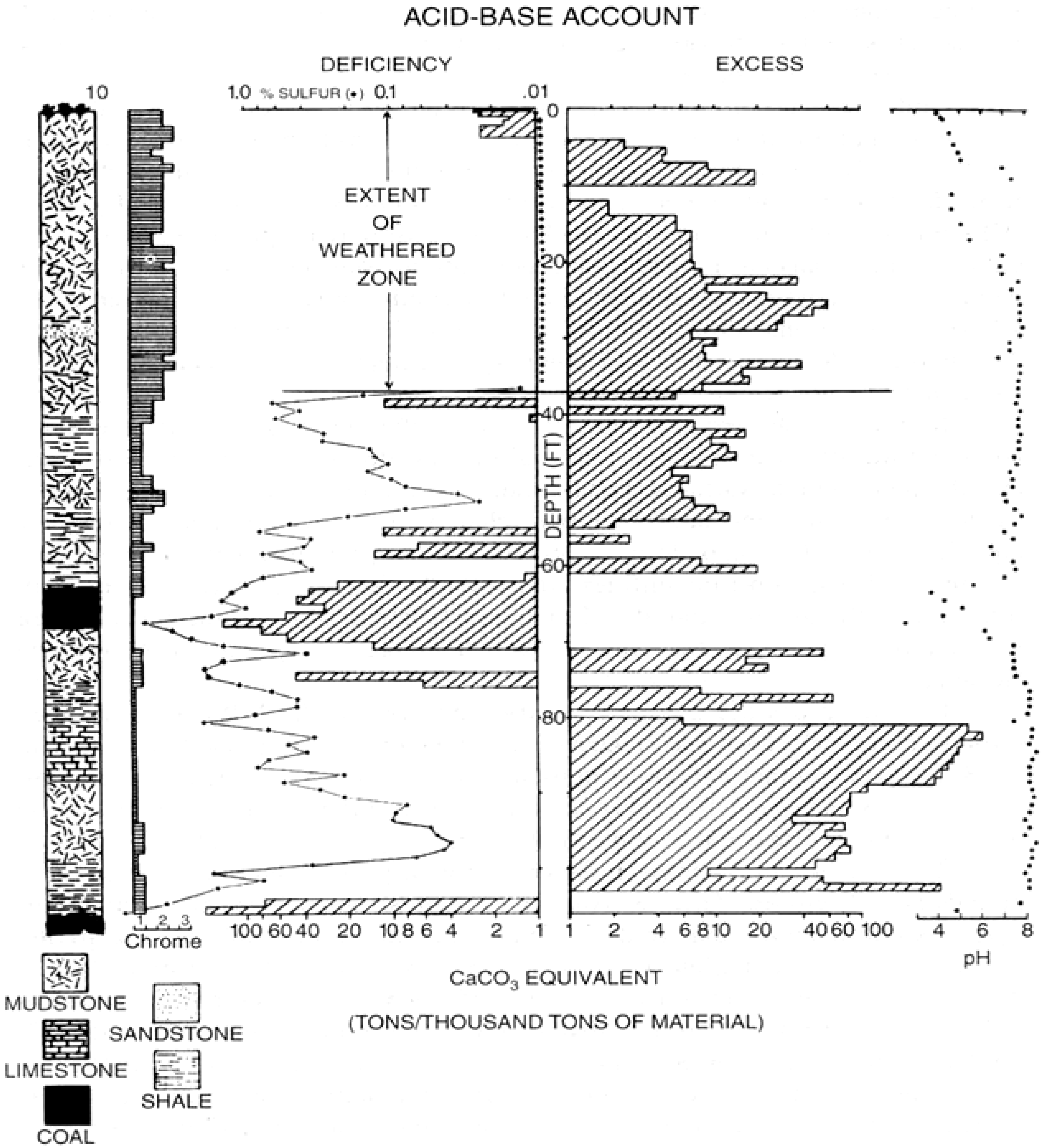
ABA is the most commonly used technique worldwide to estimate the tendency of a given material to generate acid soil conditions and associated drainage. The resultant estimate is termed "*Potential Acidity*", and hopefully gives a conservative estimate of how much lime demand a given strata or waste will require to fully mitigate or neutralize over extended periods.

Parallel and follow-up work by Carrucio & Geidel (USC), Evangelou (UK), and *Skousen et al. (2002; NP/MPA ratio)* and others reinforced the importance and applicability of overall ABA when applied to both small-scale AMD prediction and full scale active mining operations.

By 1985, We Collectively Knew the Four Major Limitations for Reclamation & Revegetation Success!

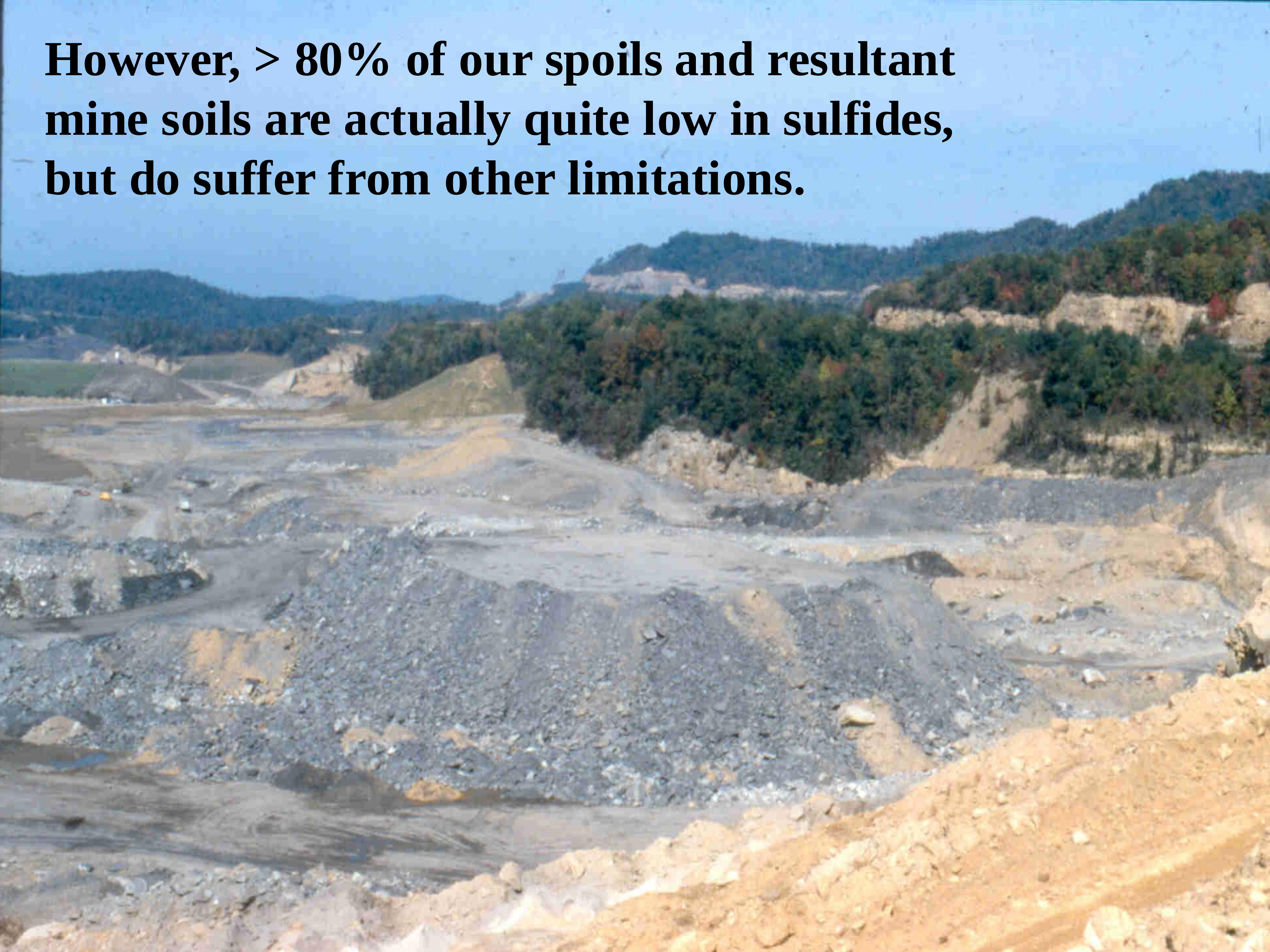
1. **Sulfidic/Pyritic acid forming materials must be avoided or neutralized for any successful stabilization project. There is no doubt that acid-sulfate weathering processes are the major risk to environmental quality from any drastic land disturbance.**

Oxidized, pH 5.5 overburden over reduced carbonate (2%) containing overburden at depth.



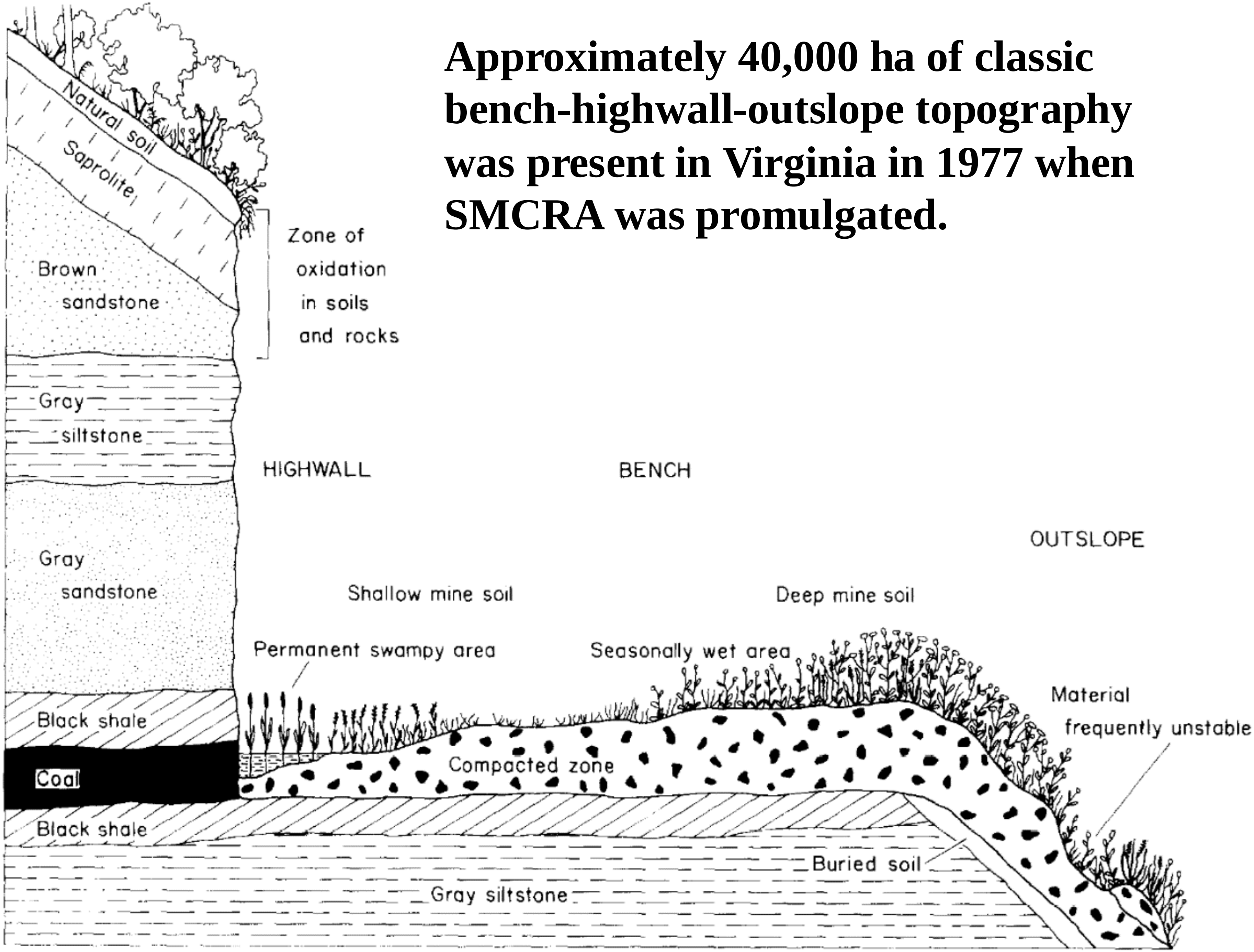
ACID-BASE ACCOUNT
DEFICIENCY
EXCESS
10
1.0 % SULFUR (•) 0.1
.01
EXTENT
OF
WEATHERED
ZONE
0
20
40
60
80
DEPTH (FT)
1 2 3
Chrome
100 60 40 20 10 8 6 4 2 1
1 2 4 6 8 10 20 40 60 100
4 6 8
pH
CaCO3 EQUIVALENT
(TONS/THOUSAND TONS OF MATERIAL)
MUDSTONE
SANDSTONE
LIMESTONE
SHALE
COAL

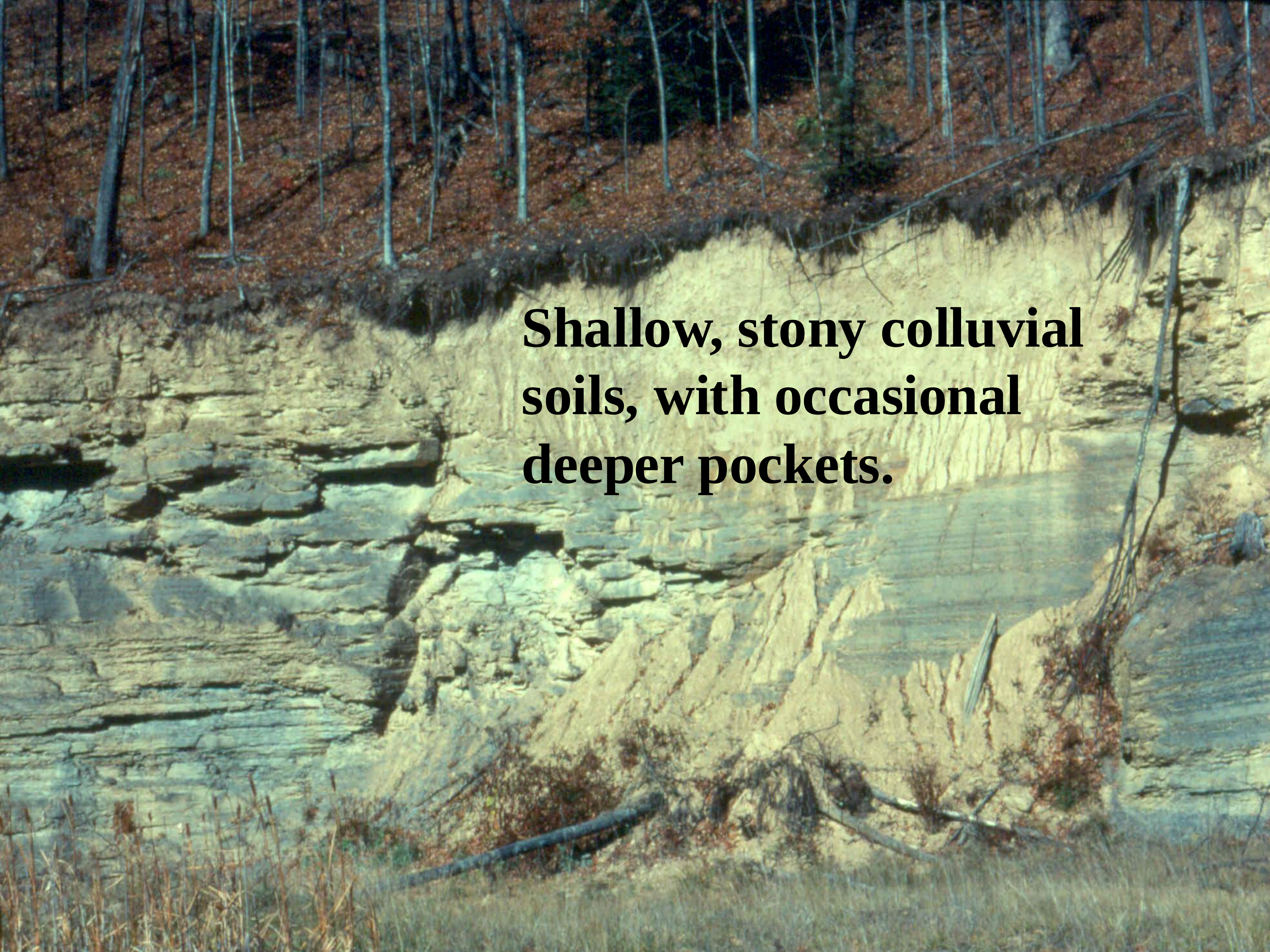
However, > 80% of our spoils and resultant mine soils are actually quite low in sulfides, but do suffer from other limitations.

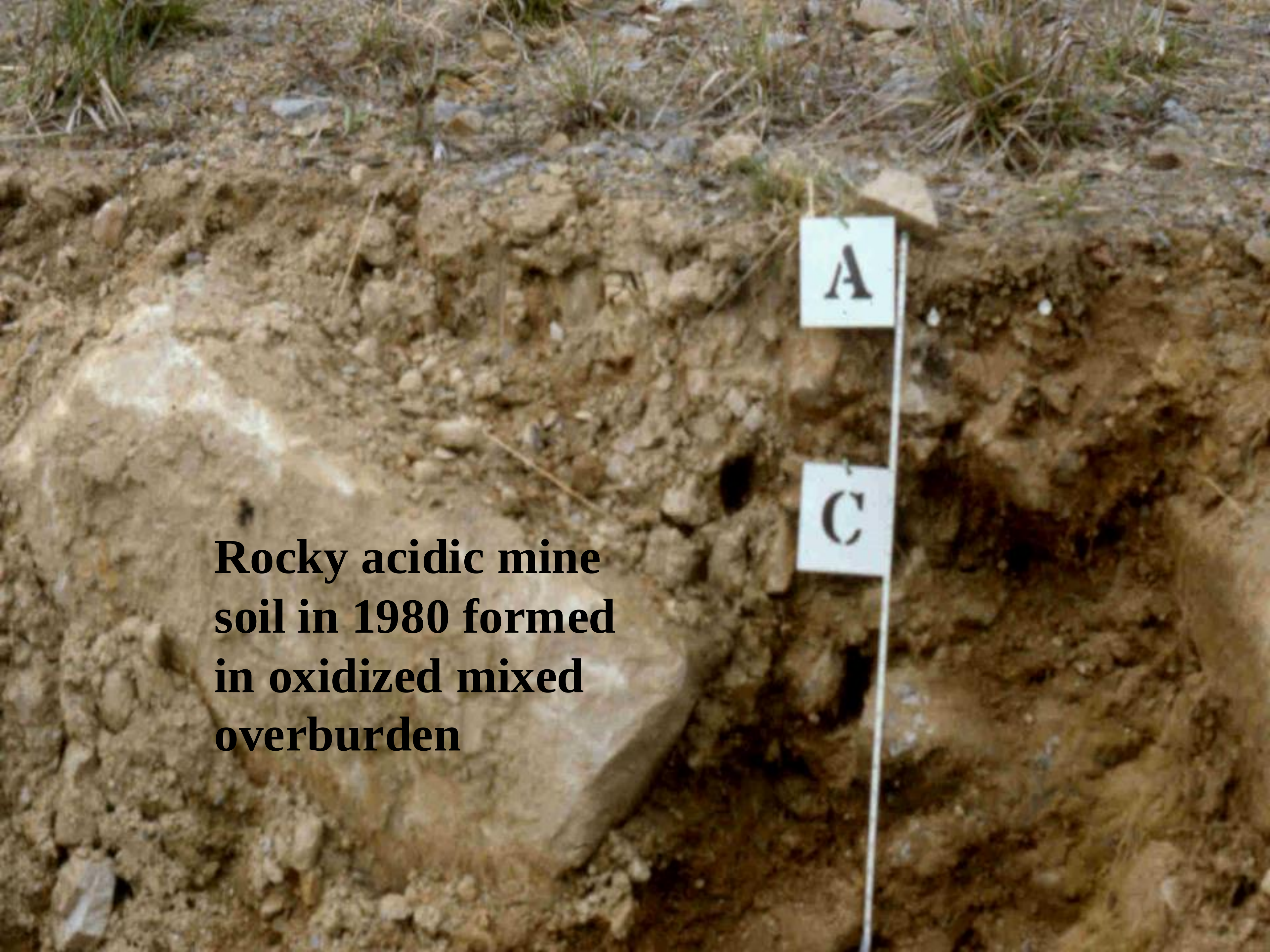


Powell River Project area highwall-bench landscape in 1980. What did the pre-SMCRA landforms and mines soils look like and what were their limitations?

Approximately 40,000 ha of classic bench-highwall-outslope topography was present in Virginia in 1977 when SMCRA was promulgated.

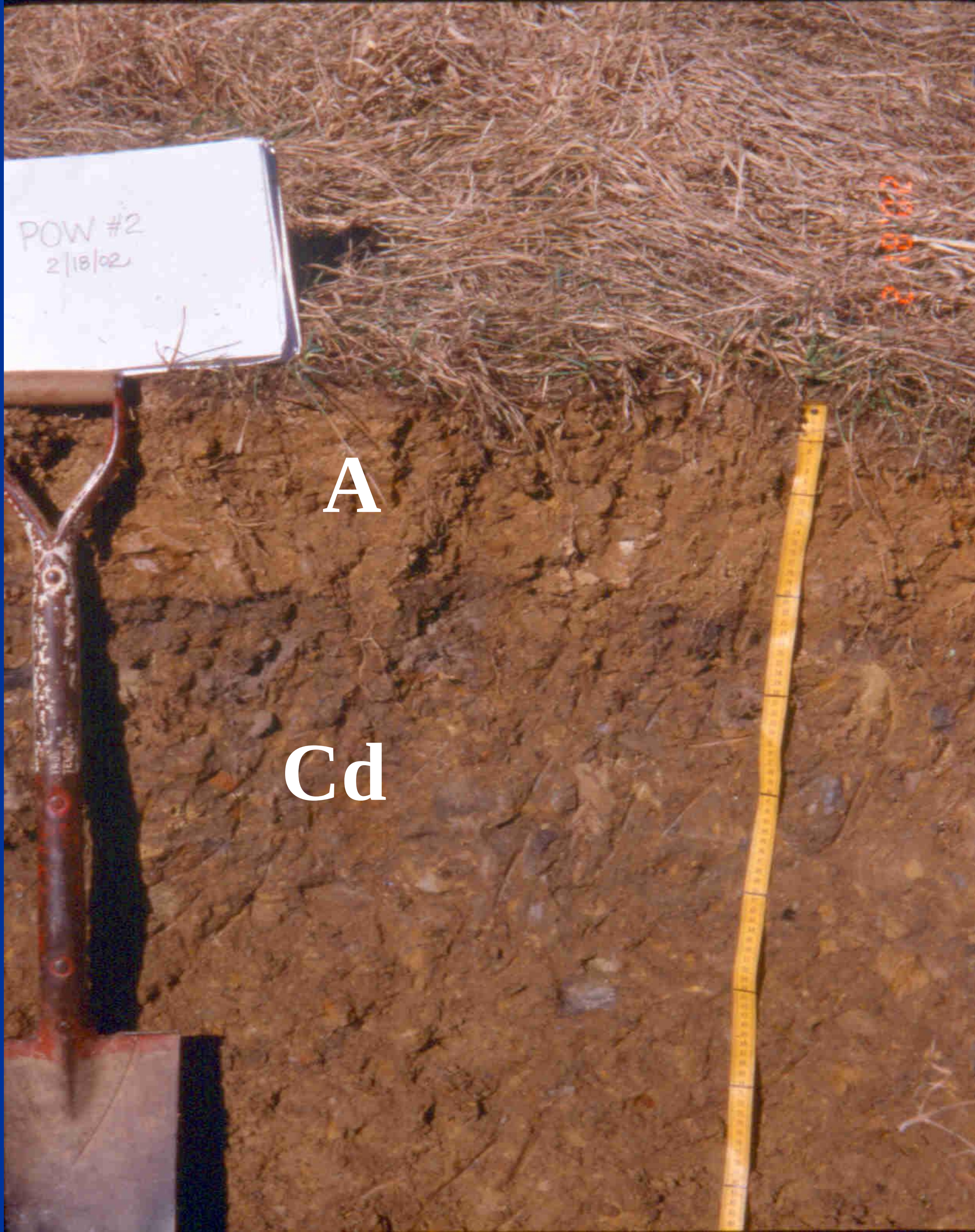



Shallow, stony colluvial
soils, with occasional
deeper pockets.

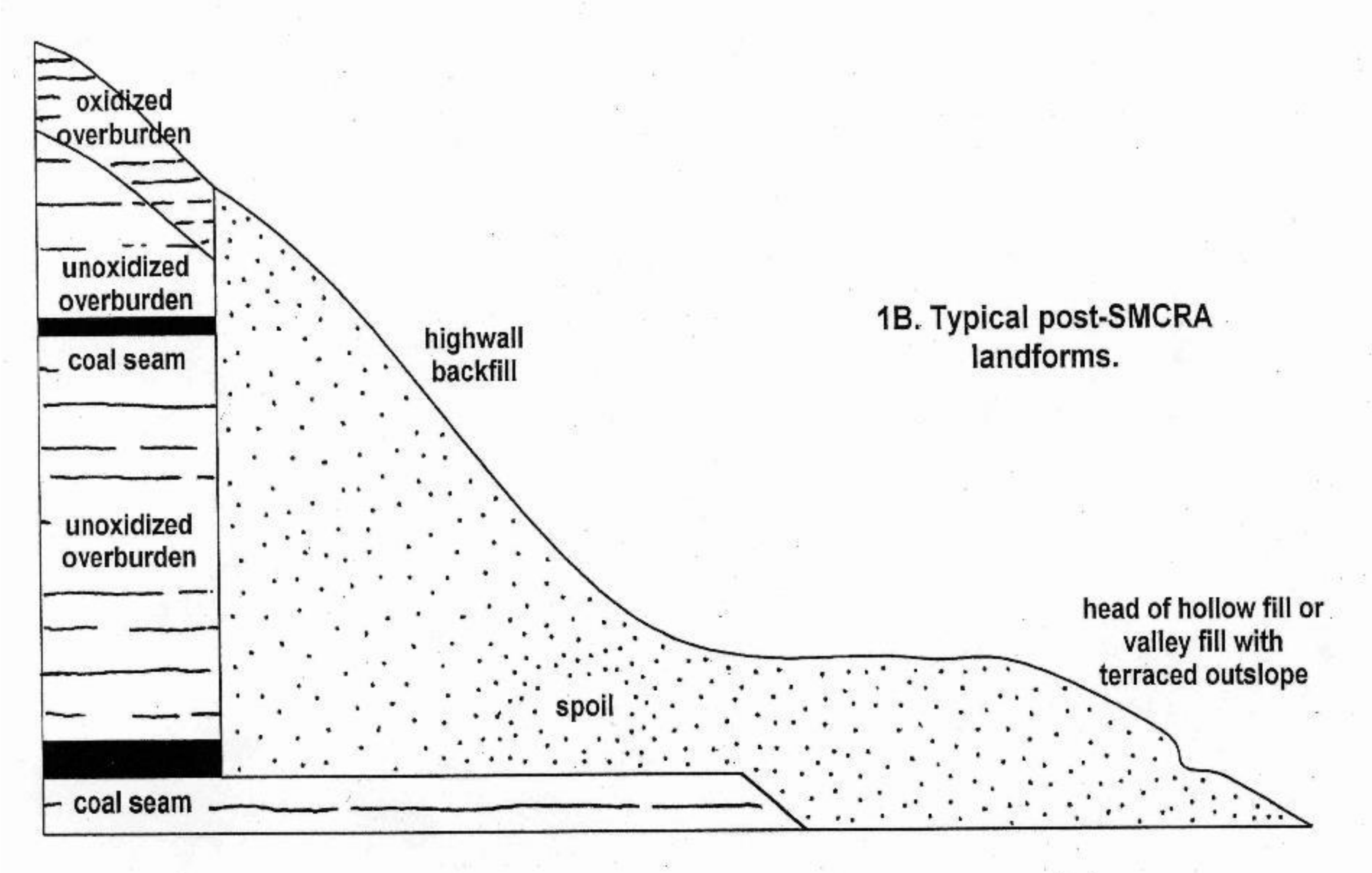

A
C
Rocky acidic mine
soil in 1980 formed
in oxidized mixed
overburden

Very shallow (<50 cm) mine soil formed in mixed oxidized and acidic (pH 5.0) mine spoil over intact siltstone bedrock. Approximately 1/3 of the 1980 soils were shallow.

Older mine soil (20 yrs old) described in 2002 that had been re-graded in 1989 and capped with a lift of local "topsoil". This soil was very acidic (pH 4.0) at depth, but had been surface limed to pH 6.0 for pasture production.



Post- vs. pre-SMCRA landforms. Excess spoil "swell" of up to 30% was contained in stable head-of-hollow fills, directly over headwater drainages.



Cross-section of typical post-SMCRA highwall backfilled, return to AOC mine invoked by mid-1980's after slope failure era.

Steep return to approximate original contour (AOC) backfill. Many failed in the early 1980’s.

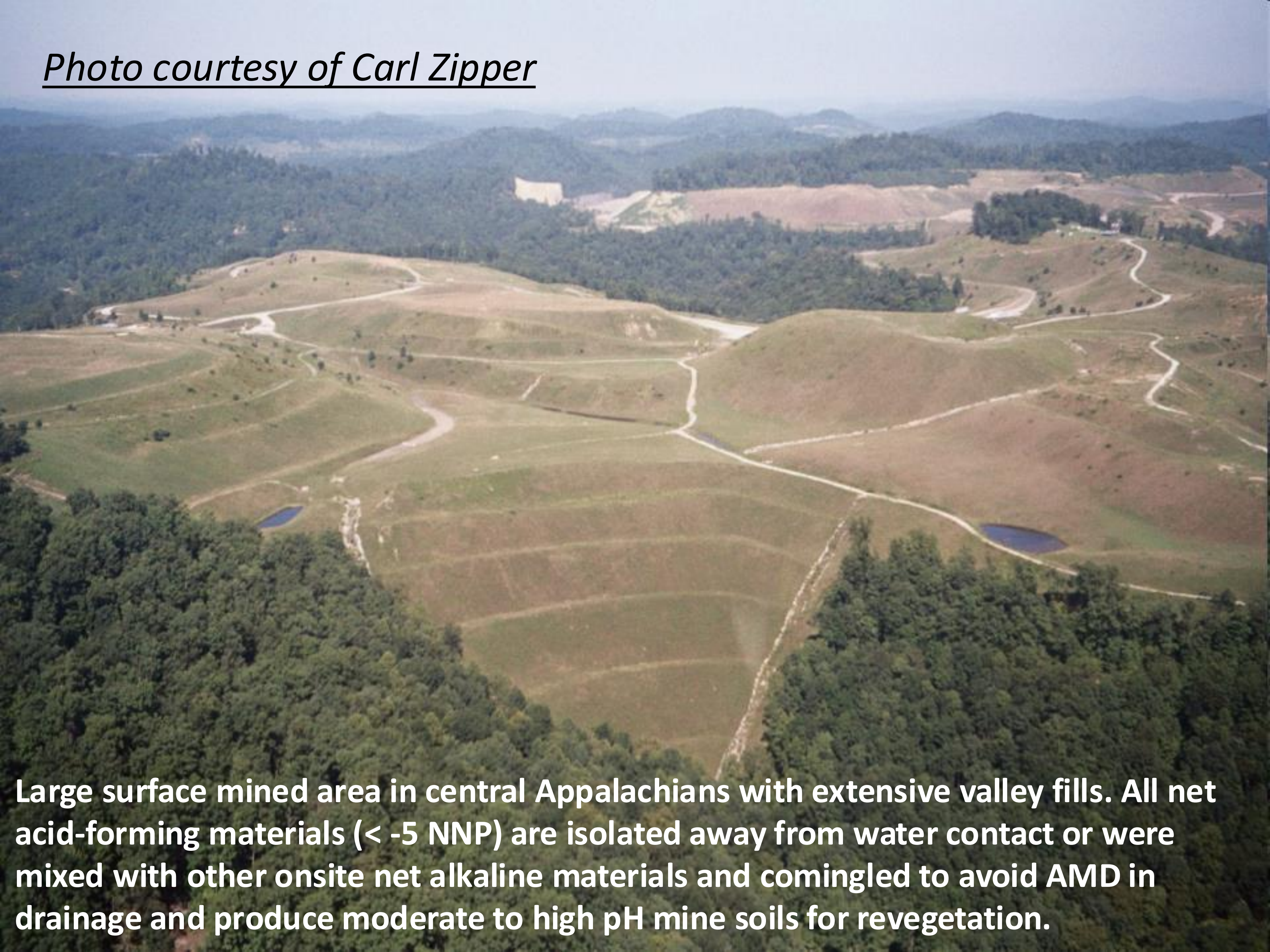


Photo courtesy of Carl Zipper

Large surface mined area in central Appalachians with extensive valley fills. All net acid-forming materials (< -5 NNP) are isolated away from water contact or were mixed with other onsite net alkaline materials and comingled to avoid AMD in drainage and produce moderate to high pH mine soils for revegetation.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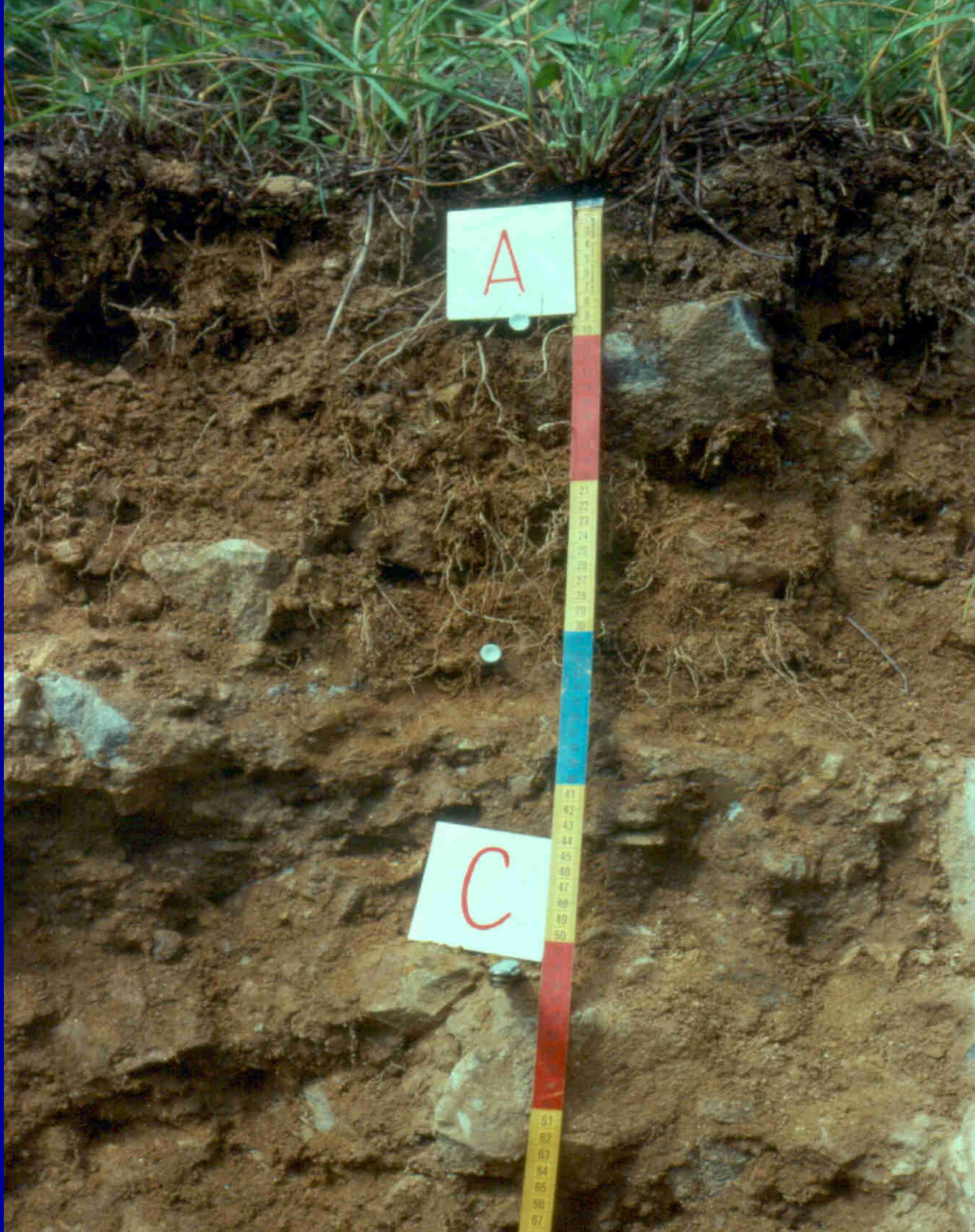
Four Things That Control Reclamation Success!

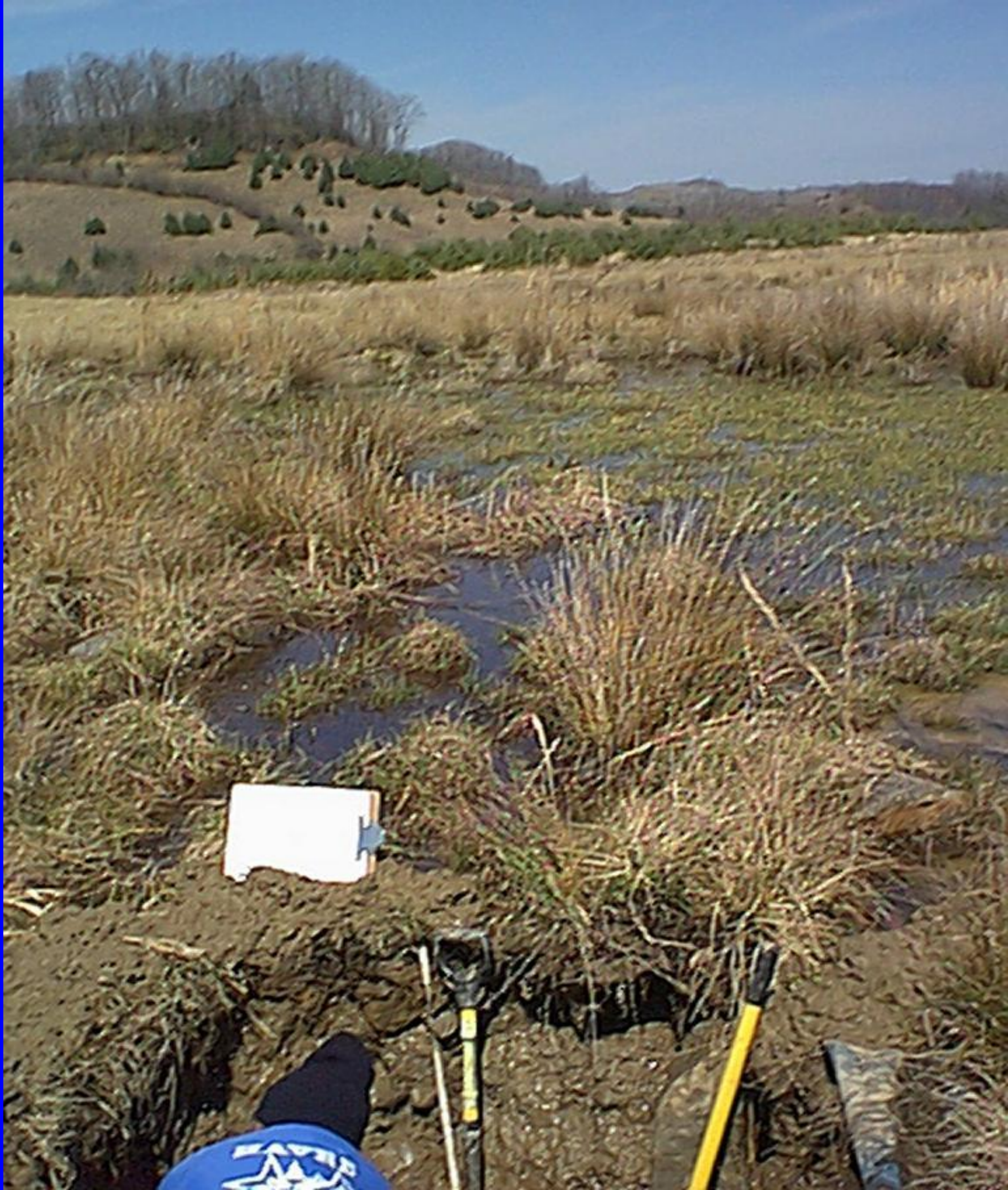
2. **Compaction is the most common limiting factor in coal mined lands (and in most disturbed lands).** Many mine soils with otherwise suitable chemical and physical properties are of very low quality due to severe compaction.

3. **Very coarse textures (sands) or high rock contents (coal spoils)** limit the water holding and effective rooting volume of many disturbed soils.

Regardless of their overall acidity and fertility status, the number one limitation to plant growth in mine soils worldwide is ***severe compaction*.**



Hydric soil in depressional wetland at Powell River in 2002. This wetland was approximately 0.5 ha in size and dominated by *Scirpus* and *Carex* sp. We need to work on wetland species too!

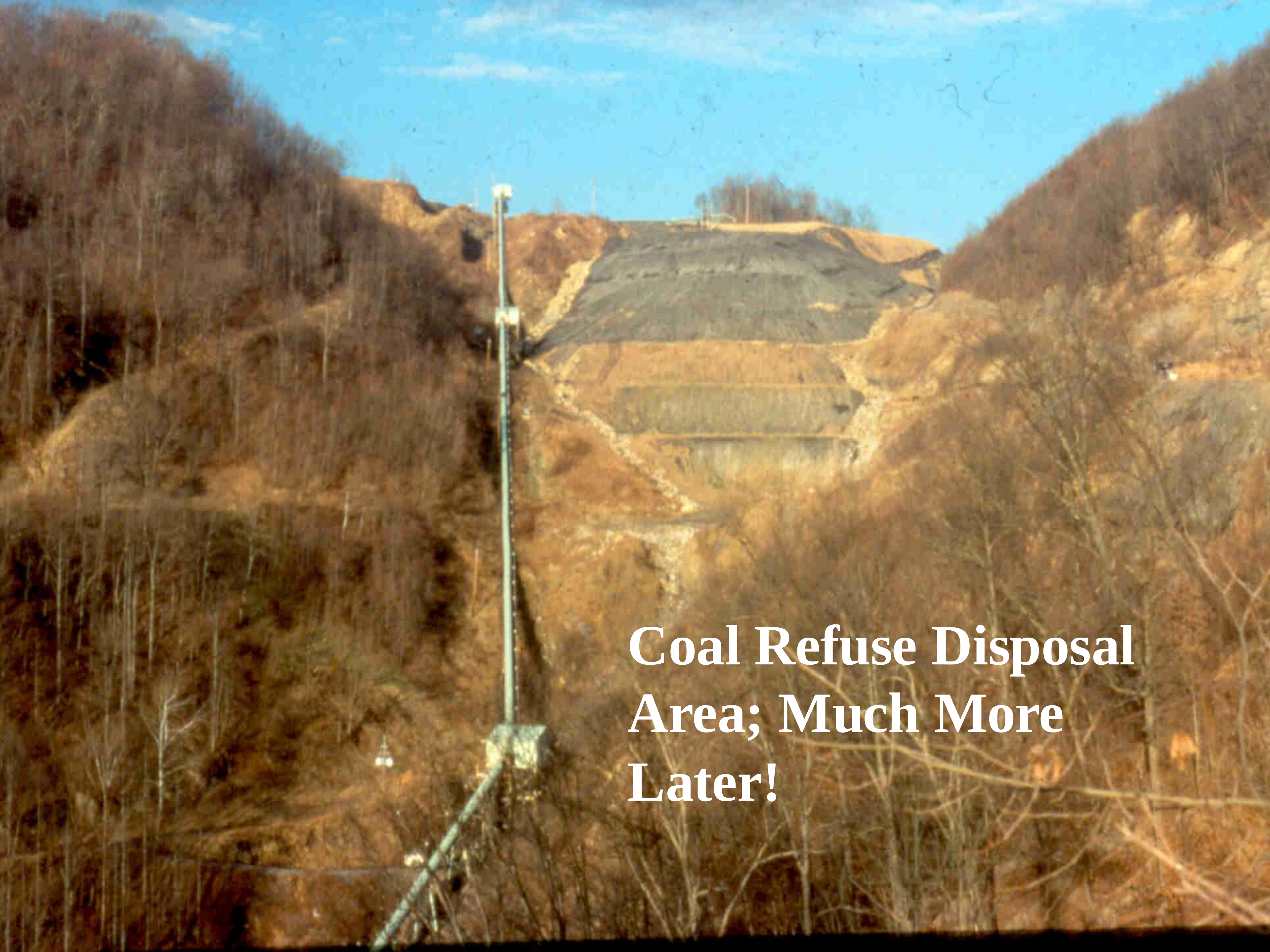



Mixed Topsoil + Weathered
Overburden (A+B+C+R)
Rocky (15% fines),
High pH (7.5)
Sandstone Spoil

Four Things That Control Reclamation Success!

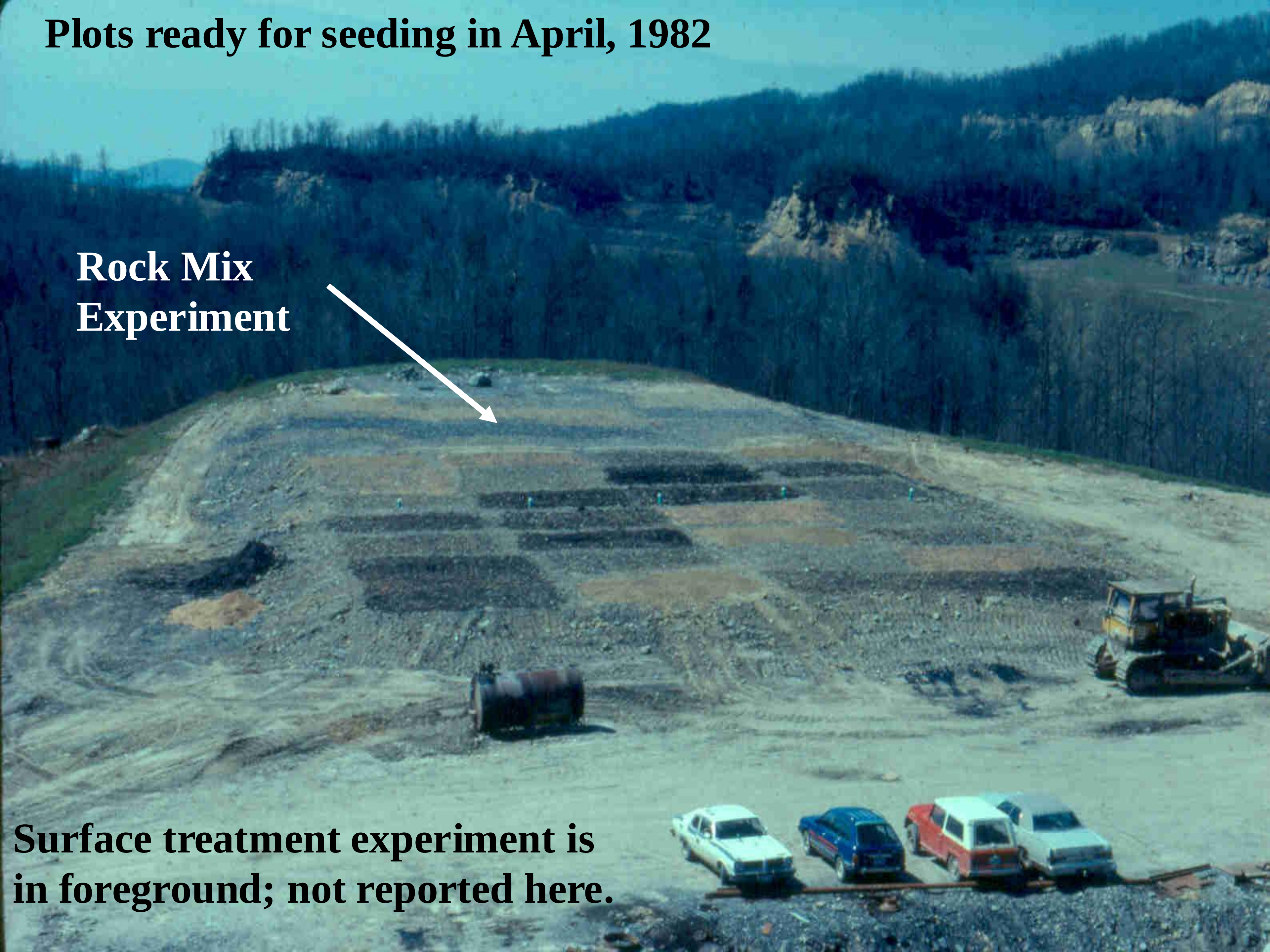
4. Assuming you've avoided acid forming materials, compaction, and excessively sandy/rocky materials, the last thing you really have to be concerned about is slope/aspect/albedo effects. For example, black coal waste on a 35% south-facing slope is going to be very, very difficult to stabilize without significant soil amendments due to heat loads and drought stress.

Many ACOC reclaimed areas have very steep slopes and pose major erosion loss hazards if not quick revegetated. However, the major loss is short term (assuming any vegetation) as the slopes “armor” with coarse fragments. In the early 1980’s many of these “pregnant backfills” failed in the region due to multiple factors.


Coal Refuse Disposal
Area; Much More
Later!

In our coal mining environment, native topsoils & weathered subsoil/saprolites were typically quite thin and difficult to safely and economically strip before mining. For a variety of reasons, until the early 2000's, many were simply shoved over into adjacent mining pits.

Therefore, the vast majority of reclamation in the Appalachians since 1980 has utilized appropriately selected *mine spoils* as *topsoil substitutes*.


Plots ready for seeding in April, 1982
Rock Mix
Experiment
Surface treatment experiment is
in foreground; not reported here.

Mine Soil Amendments

Once you take care of (or account for) these four basic limitations (Acidity; compaction; rockiness; slope/aspect) you can worry about and fertilization practices. That's the easy part!

However, interpreting conventional soil testing extracts and OM methods for hard rock derived mine soils can be very tricky. In particular, plant-available P and soil OM are likely to be overestimated. You should just assume P is limiting and OM is very, very low.

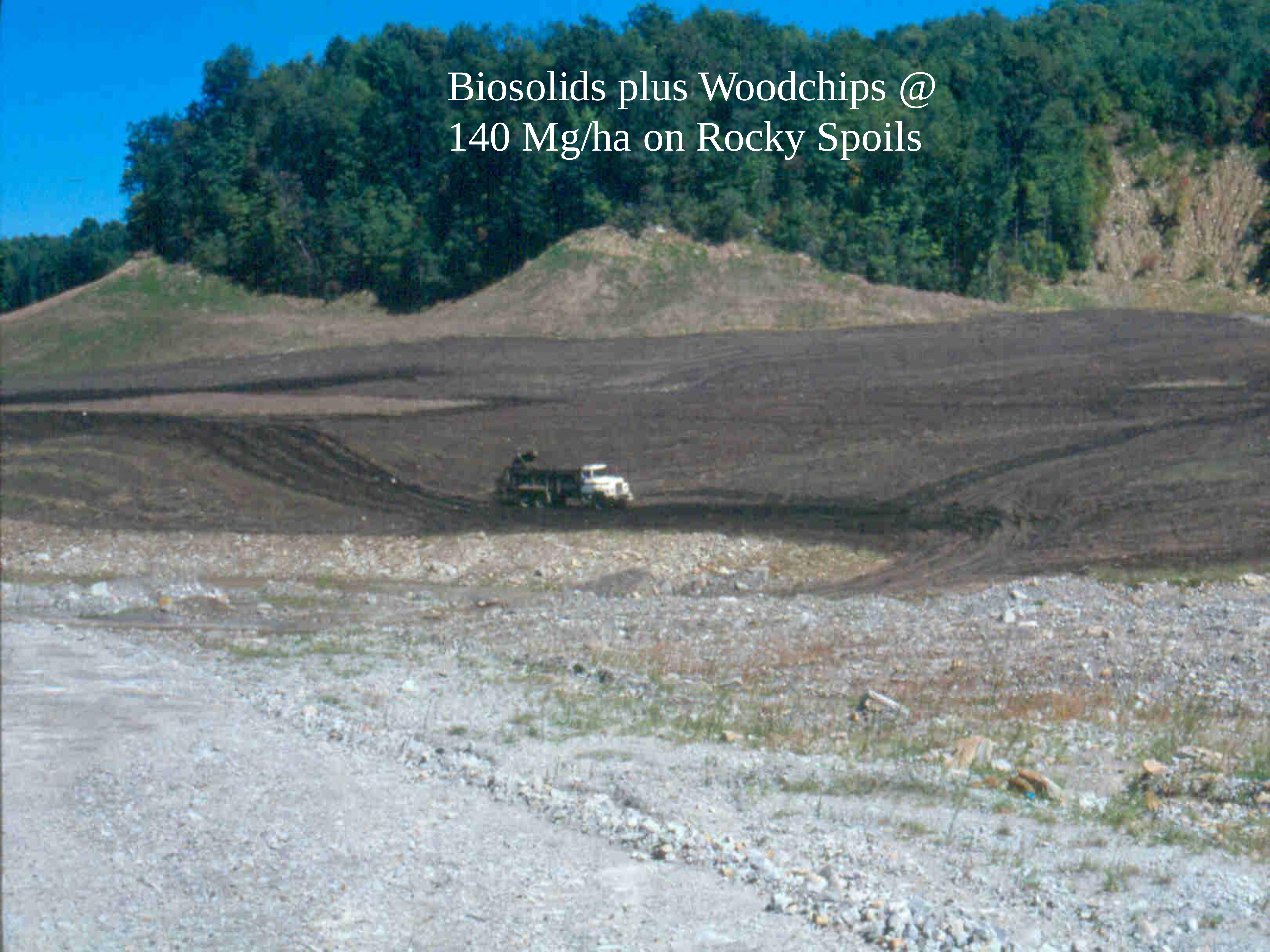
Addition of appropriate soil amendments such as compost, manures, biosolids, waste limes, alkaline CCB's, etc. can also really improve mine soil quality & revegetation success. However, utilization of "out of county waste products" can be highly contentious!

COP in early June, 1982, after seeding and rainfall.

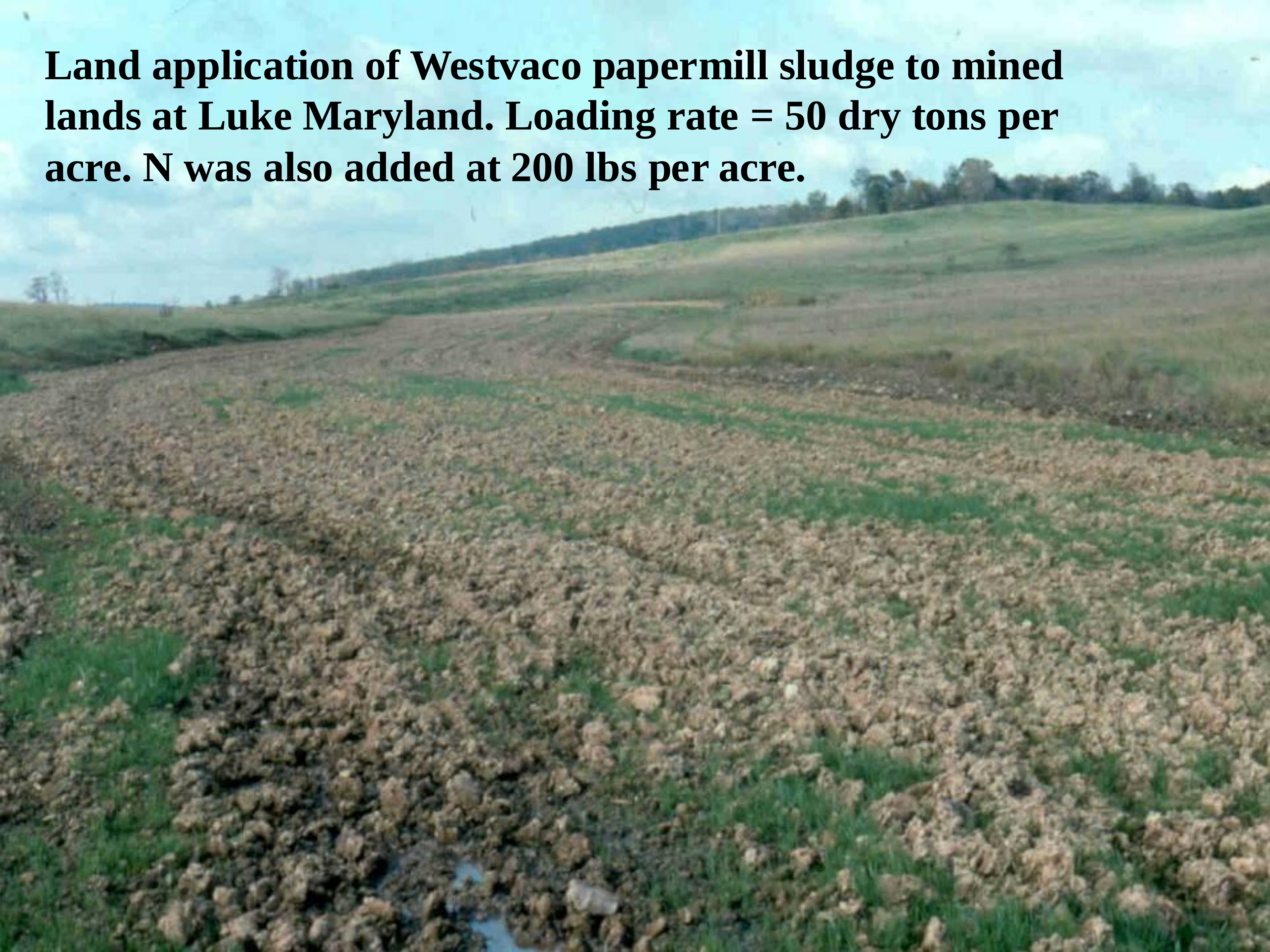
Sandstone Mine Soil

Siltstone Mine Soil

Age 15


Biosolids plus Woodchips @
140 Mg/ha on Rocky Spoils

Powell River Project area 10 years after application with biosolids.



Land application of Westvaco papermill sludge to mined lands at Luke Maryland. Loading rate = 50 dry tons per acre. N was also added at 200 lbs per acre.


Revegetated areas at Luke Maryland with mill sludge.

Herbaceous Revegetation Basics – Skousen, Zipper & many others!

- Reclamation species usually consist of grasses, legumes, shrubs and trees (depending on post-mine designated use).
- Initial efforts usually focus on establishing herbaceous covers; shrubs and trees are often planted by hand later.
- Annual "nurse crops" are frequently used to shelter and help establish perennial species. Vary between spring and fall (e.g. millet vs. rye)
- Species must be matched to site/soil conditions.
- Timing is critical for permanent/perennial stands!

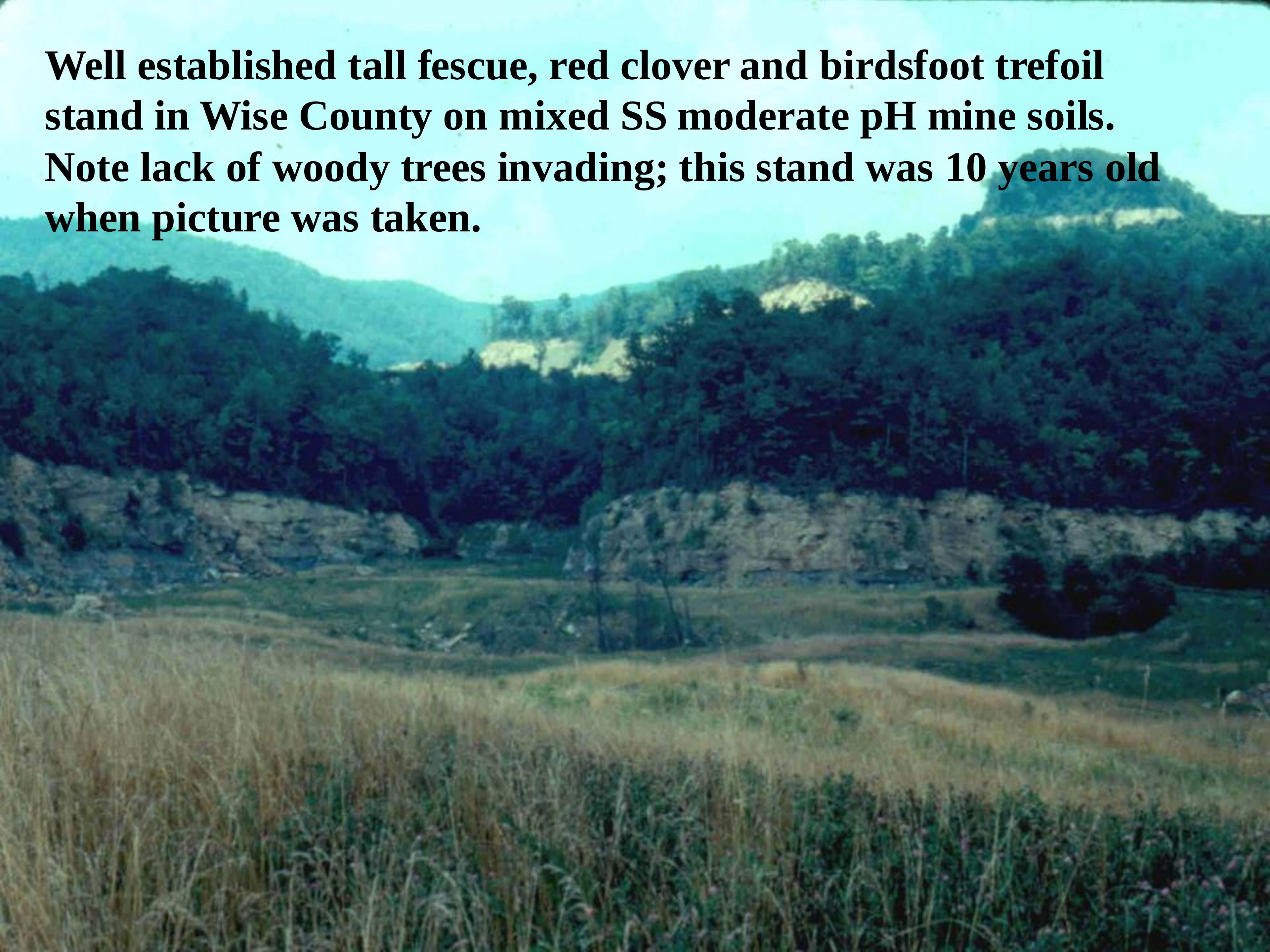
Figure 5. A hydroseeder applying seed in a fertilizer slurry while revegetating a surface coal mine.

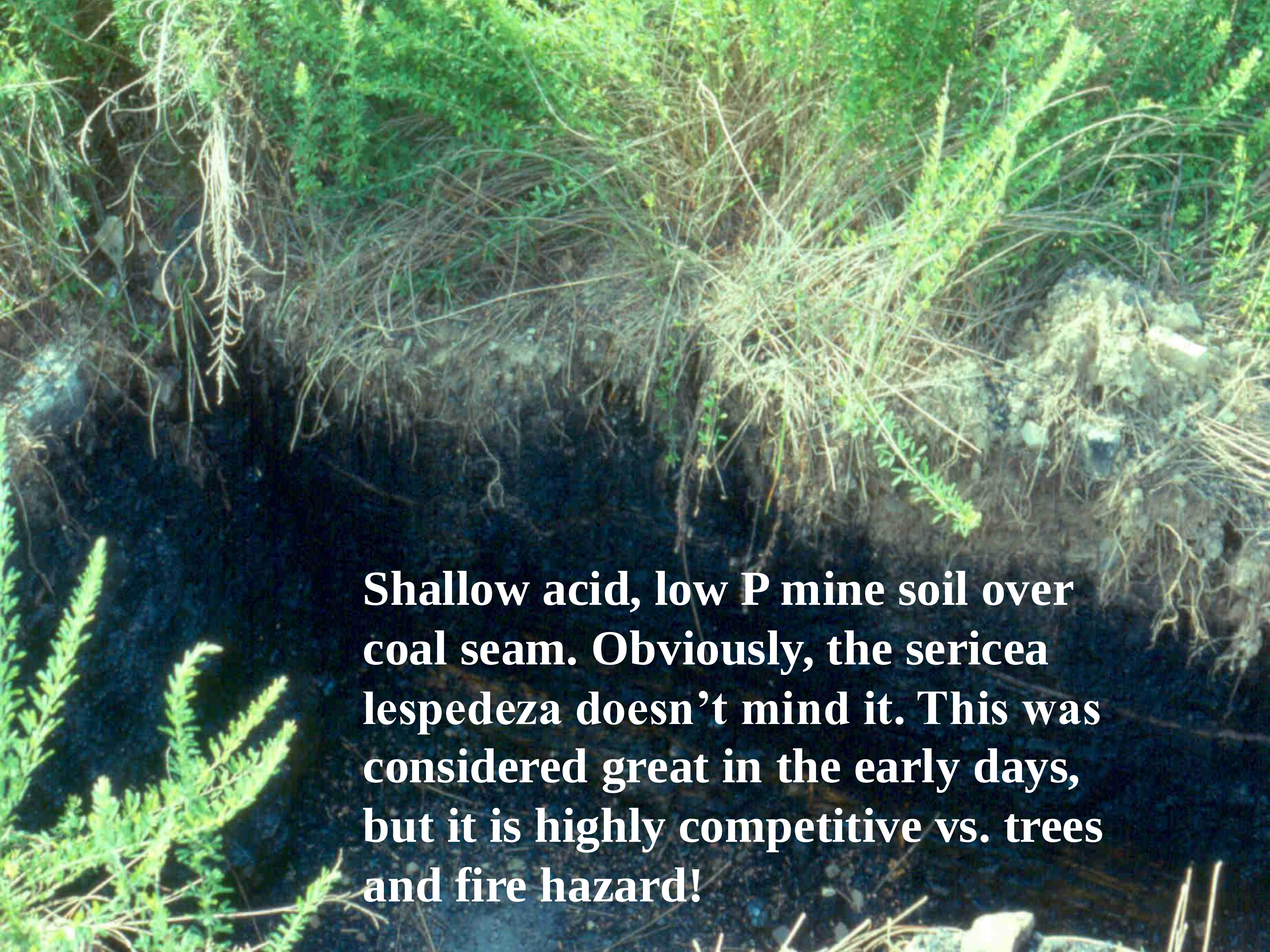
German millet (Setaria italica) is the most common warm season cover used in our region. It will germinate rapidly anytime temperatures remain above 40 F. It will also establish in mid-summer if adequate rainfall occurs and can tolerate heat quite well. Note the tall fescue and legume components that are establishing under the millet canopy.

Revegetation Basics

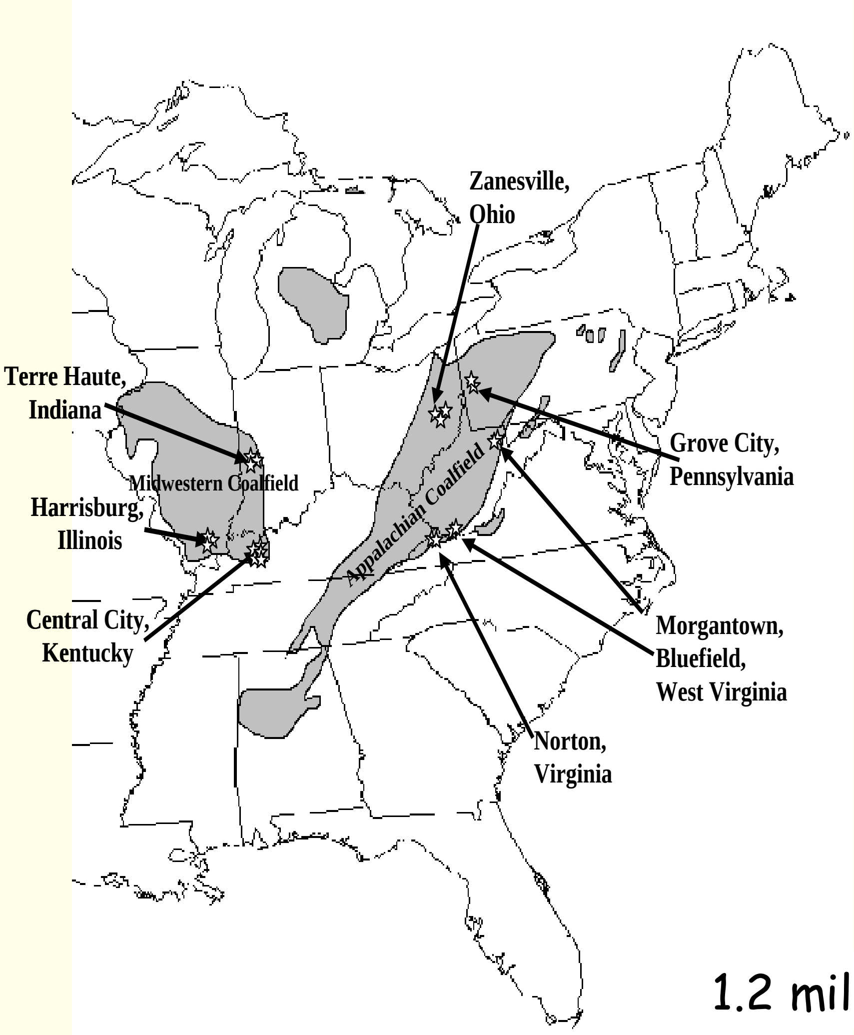
- **Establishing legumes is critical to long term revegetation and soil building.**
- **Long-term N supply is almost entirely from legumes beyond the 2nd year after establishment.**
- **P availability is strongly affected by N.**
- **Legumes must be successfully inoculated with their respective *Rhizobia* symbiont**

Well established tall fescue, red clover and birdsfoot trefoil stand in Wise County on mixed SS moderate pH mine soils. Note lack of woody trees invading; this stand was 10 years old when picture was taken.




Shallow acid, low P mine soil over coal seam. Obviously, the sericea lespedeza doesn’t mind it. This was considered great in the early days, but it is highly competitive vs. trees and fire hazard!

Midwestern and Appalachian Coalfield Regions



Native Hardwood Forest

Surface Mining for Coal

1.2 million acres disturbed by mining in the East

Reforestation and the Forestry Reclamation Approach (FRA)

THE APPALACHIAN REGIONAL REFORESTATION INITIATIVE (ARRI)

FOREST RECLAMATION ADVISORY

Forest Reclamation Advisory No. 2 December 2005

THE FORESTRY RECLAMATION APPROACH

Jim Burger[1], Don Graves[2], Patrick Angel[3], Vic Davis[4], Carl Zipper[5]

The Forestry Reclamation Approach (FRA) is a method for reclaiming coal-mined land to forest under the Surface Mining Control and Reclamation Act (SMCRA). The FRA is based on knowledge gained from both scientific research and experience (Photo 1). The FRA can achieve cost-effective regulatory compliance for coal operators while creating productive forests that generate value for their owners and provide watershed protection, wildlife habitat, and other environmental services.

The purpose of this Advisory is to describe the FRA, which is considered by state mining agencies and US Office of Surface Mining to be an appropriate and desirable method for reclaiming coal-mined land to support forested land uses under SMCRA (Angel and others, 2005). The FRA is also supported by members of the ARRI's academic team, which is drawn from Universities in nine states, and by other groups and agencies.

The FRA's Five Steps

The FRA can be summarized in five steps:

1. Create a suitable rooting medium for good tree growth that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best available material.
2. Loosely grade the topsoil or topsoil substitute established in step one to create a non-compacted growth medium.
3. Use ground covers that are compatible with growing trees.
4. Plant two types of trees–early successional species for wildlife and soil stability, and commercially valuable crop trees.
5. Use proper tree planting techniques.

Step 1. Create a suitable rooting medium: Tree survival and growth can be hindered by highly alkaline or acidic soils. During mining and reclamation, all highly alkaline materials with excessive soluble salts and all highly acidic or toxic material should be covered with a suitable rooting medium that will support trees. The best available

Photo 1. A white oak stand that grew on a pre-SMCRA surface mine in southern Illinois. Observations by reclamation scientists and practitioners of soil and site conditions on reclaimed mines such as this, where reforestation was successful, have contributed to development of the Forestry Reclamation Approach.

growth medium should be placed on the surface to a depth of at least four feet to accommodate the needs of deeply rooted trees.

Growth media with low to moderate levels of soluble salts, equilibrium pH of 5.0 to 7.0, low pyritic sulfur content, and textures conducive to proper drainage are preferred. However, where such materials are not available, an equilibrium pH as low as 4.5 or as high as 7.5 is acceptable if tree species tolerant of those conditions are used.

1

The FRA's Five Steps:

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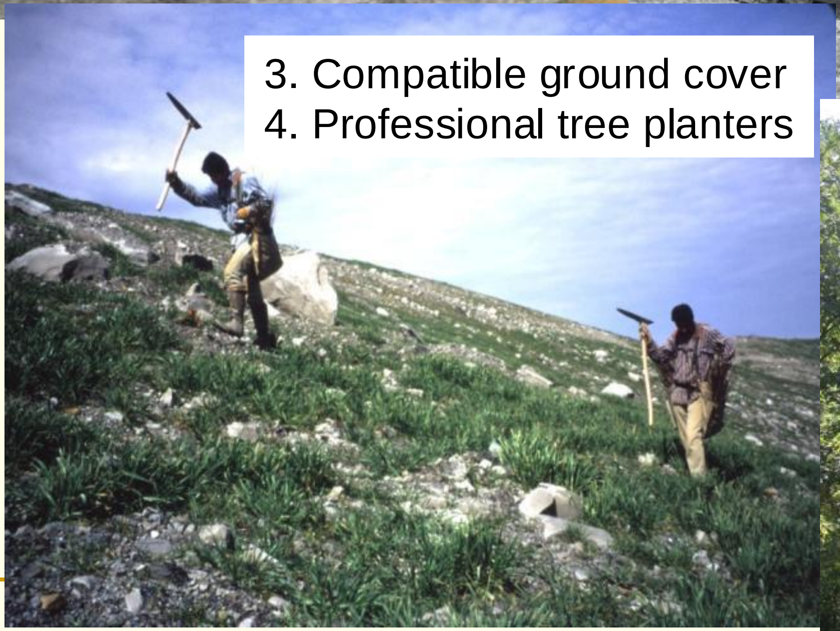
Forestry Reclamation Research

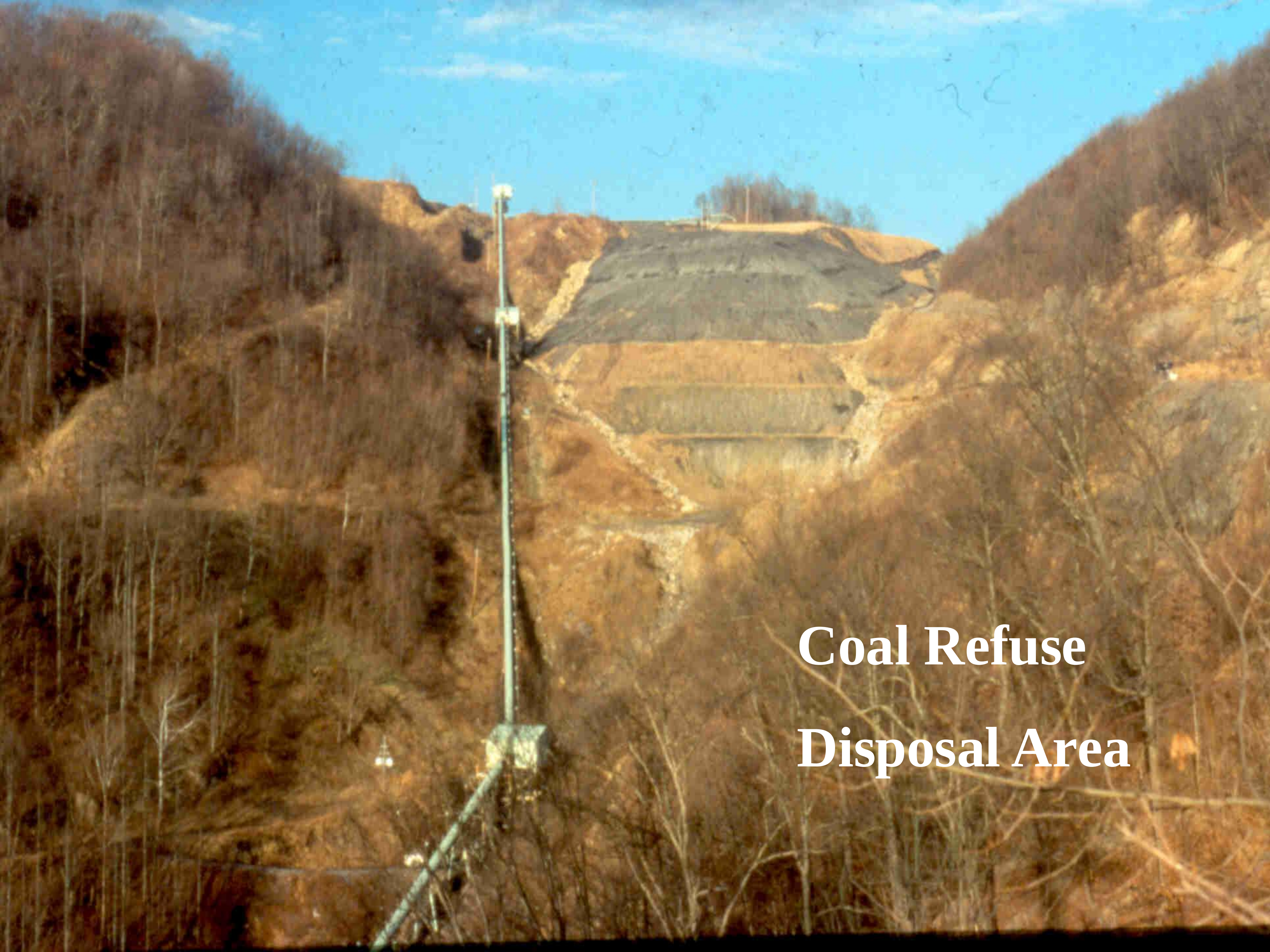
- Goal: Develop and apply methods for restoring productive, native forests on mined land for products and ecosystem services
- Research in 7 Appalachian & Midwestern states
  - 28 years, 32 experimental sites
  - 15 M. S. and Ph. D. Theses
  - 60+ research publications
  - 15 extension pubs
  - Numerous annual field trips
- Outcome:
  Best Management Practices
  " Forestry Reclamation Approach "

VIRGINIA TECH FORESTRY

Forestry Reclamation Approach

Best Management Practices (Burger & Torbert, 1992)



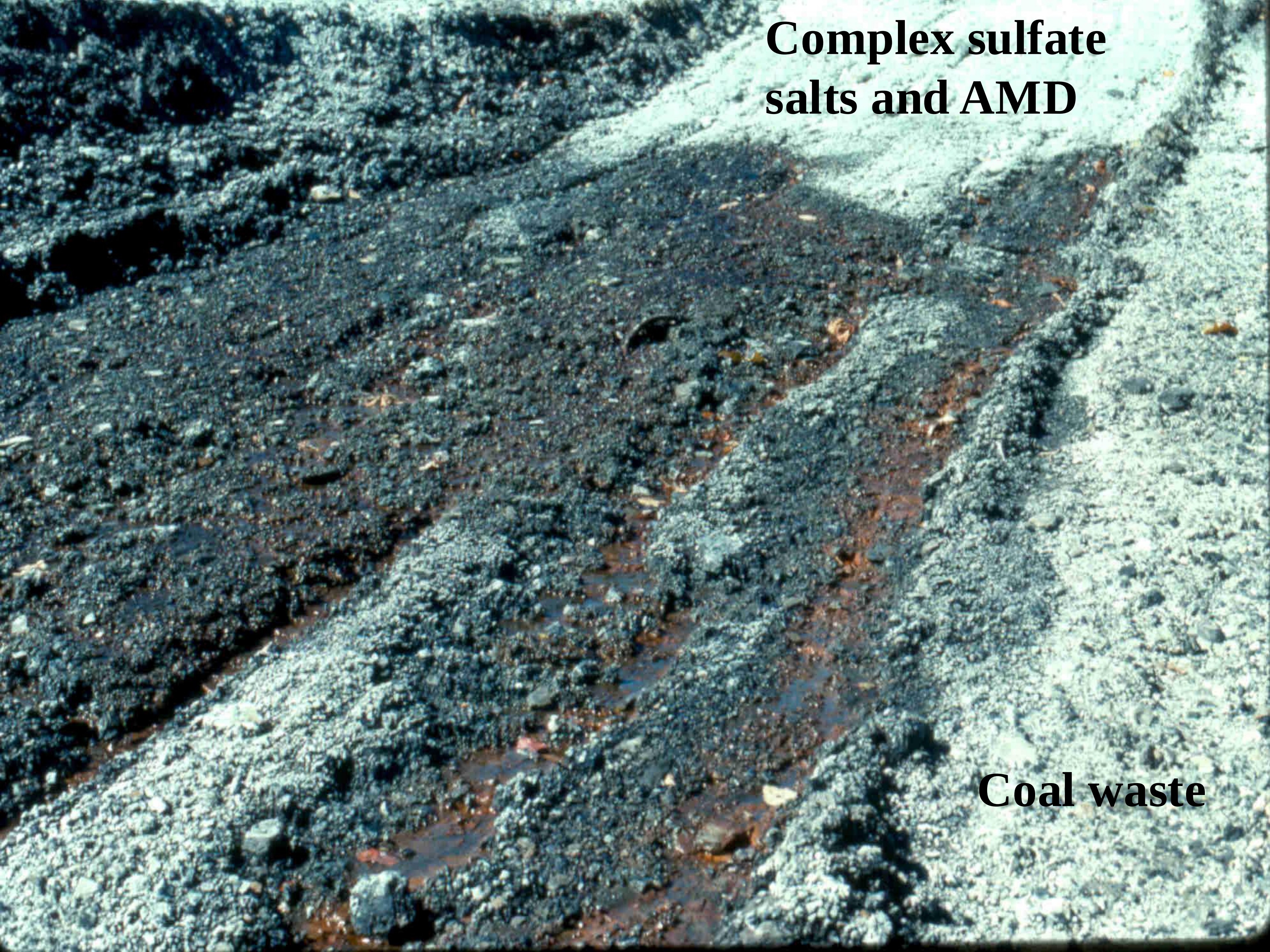

Coal Refuse
Disposal Area

Coal Processing Wastes

- Up to 50% of run-of-mine coal from Appalachian deep mines reports to coal waste disposal piles
- In Virginia alone, we have over 5000 ha of active and abandoned coal refuse piles.
- The vast majority of Appalachian coal refuse is potentially acidic with an average lime requirement of > 10 tons per 1000 (= tons of lime requirement per acre per 6”).

200 ha coarse coal refuse disposal facility near Pound Virginia. No topsoil was set aside for reclamation of this facility.

Fine coal slurry (< 1 mm) from the fine coal cleaning circuit is typically impounded behind a dam of coarse refuse. These cells usually are found high and to the rear of the valley fills to minimize catastrophic effects of dam failures.


Complex sulfate
salts and AMD
Coal waste


The vast majority of coal refuse fills in the Appalachians are net acid forming and generate AMD which is treated with chemicals and passive systems.

Three year-old seeding on acid forming refuse in West Virginia failing due to excess salts, low P and low water holding capacity and rooting depth.

The soil pH here was 4.5, not directly limiting.


Incorporation of 45 Mg/ha lime on sulfidic coal waste materials.

In addition to adequate lime, direct seedings need heavy P to offset fixation losses. We also believe the P limits S oxidation and salt evolution in these moderately acid forming materials.


33% volumetric addition of alkaline fly ash to acidic coal refuse.
36

After two years, trenches were ripped up the limed and non-limed sides of each wedge to observe rooting vs. subsoil properties.

Note very limited growth on bare waste, but rapid increase in cover and vigor with very limited (15 cm) soil covers with lime at soil/refuse contact.

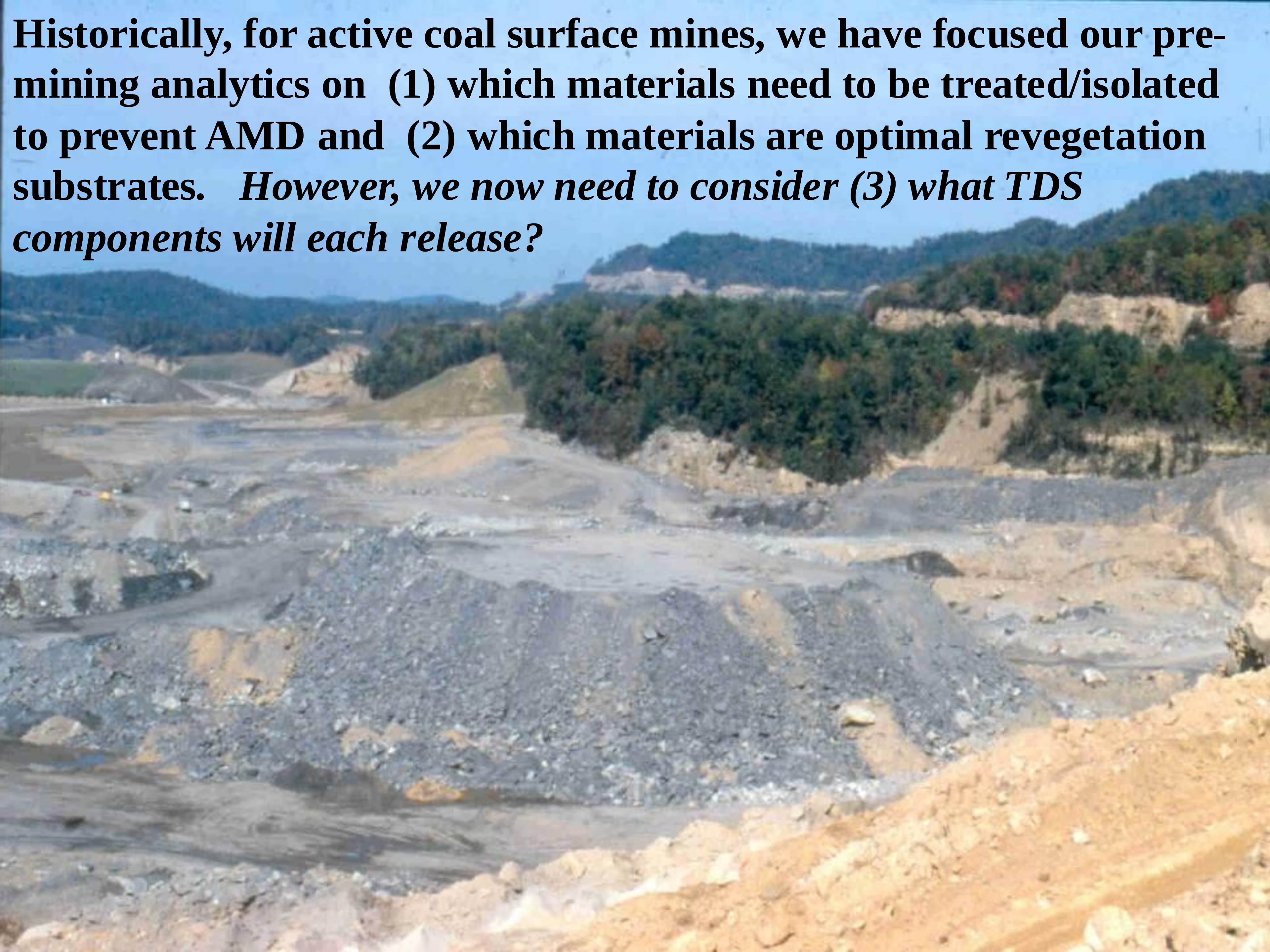
Fall seeding

Species	Latin name	Rate kg ha^{-1}
Redtop	*Agrostis alba*	3
Hard fescue	*Festuca ovina (var. Scaldis)*	20
Tall fescue	*Festuca arundinacea*	20
Annual ryegrass	*Lolium multiflorum*	15
Cereal rye	*Secale cereale*	25
Weeping lovegrass	*Eragrostis curvula*	3
Birdsfoot trefoil	*Lotus corniculatus*	5
Yellow sweet clover	*Melilotus officinalis*	2
Ladino clover	*Trifolium repens*	2
Kobe lespedeza	*Lespedeza striata*	10

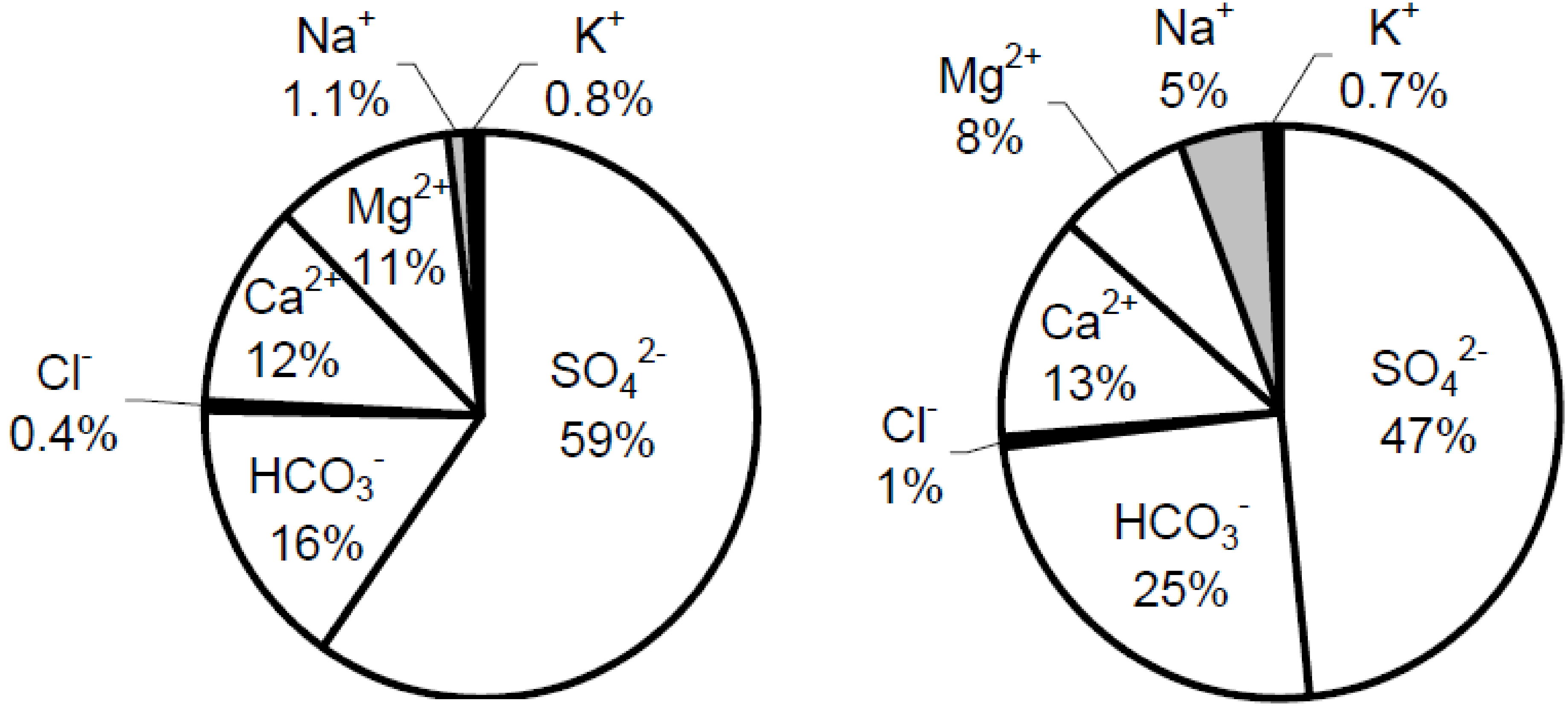
Direct seeding results after 3 years with lime, high P and 80 Mg/ha biosolids and acid/salt tolerant seed mix. The tall plants are native annual invading into the plots.

Unfortunately, surface revegetation efforts per se seldom have any lasting effect on the discharge of acidic drainage from pyritic waste piles! Simply limiting O_2 to the bulk pile is not enough!

Historically, for active coal surface mines, we have focused our pre-mining analytics on (1) which materials need to be treated/isolated to prevent AMD and (2) which materials are optimal revegetation substrates. ***However, we now need to consider (3) what TDS components will each release?***



Large "excess spoil" valley fills are common in the central Appalachian coal mining region and are largely comprised of net non-acidic materials that produce moderate pH (6.0 to 8.5) discharge.



Pond et al. 2008   Timpano 2011

Dominant constituents of total dissolved solids (TDS) in circumneutral water released by coal mine valley fills in the central Appalachian USA coalfields.

TDS/EC Discharge Standards?

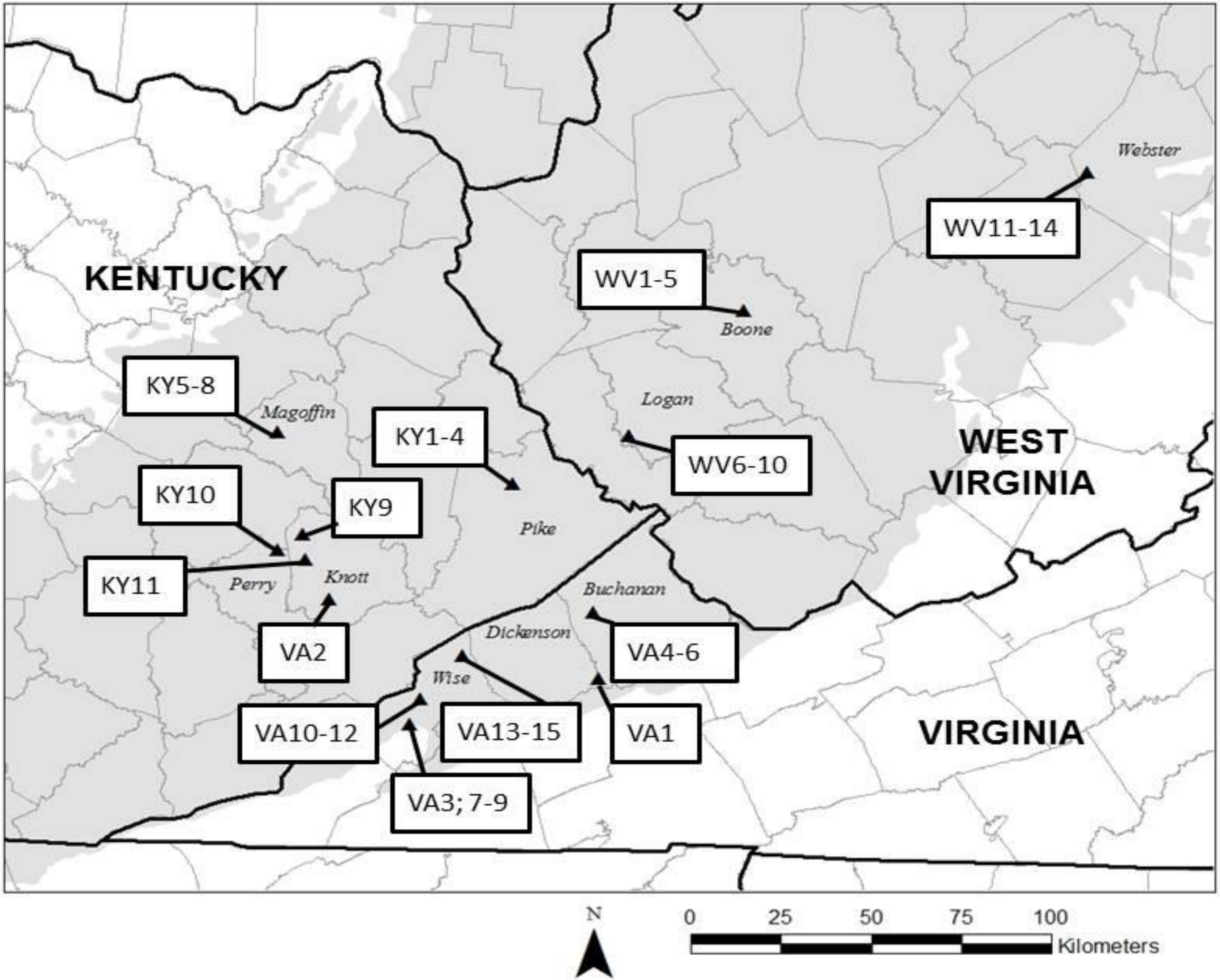
Several widely cited study (e.g. Pond et al., 2008), found that streams with high conductivity -- above 500 µs/cm -- were biologically impaired. Impacts are primarily to sensitive macroinvertebrates (mayflies etc.)

On April 1, 2010, USEPA issued new "guidance" requiring measures to mitigate discharges above 300 µs/cm, and a reduction in mine size or cancellation of active or future fills if above 500 µs/cm.

While this guidance was overturned in DC federal court in 2012, TDS remains a dominant state & federal regulatory concern.

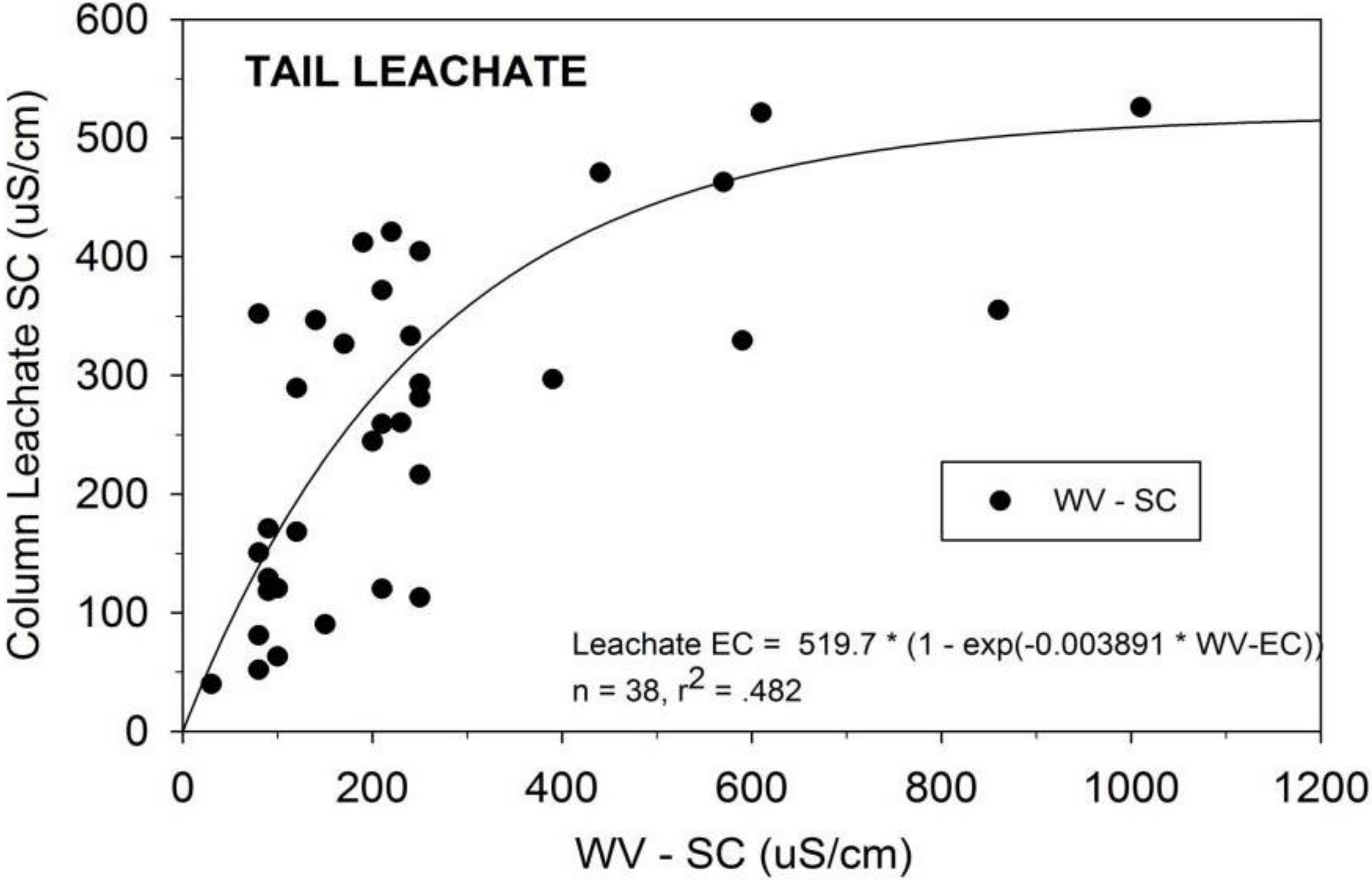
Where's it come from?

- **Acid-base reactions**; sulfide oxidation and carbonate neutralization reactions.
- Background **carbonation reactions** in non-sulfidic materials.
- **Hydrolysis** of primary mineral grains.
- **Entrained Cl and SO_4** in rocks (minor).
- Other minor weathering reactions like K release from micas, etc.



KENTUCKY
WEST VIRGINIA
VIRGINIA
Webster
WV11-14
WV1-5
Boone
Logan
WV6-10
KY5-8
Magoffin
KY1-4
KY10
KY9
Pike
KY11
Perry
Knott
Buchanan
VA2
Dickenson
VA4-6
Wise
VA10-12
VA13-15
VA1
VA3; 7-9
N
0
25
50
75
100
Kilometers

- Over 70 regional spoils have been run in triplicate under unsaturated conditions (3 columns per sample) with simulated rain.
- Whole spoil crushed & screened to < 1.25 cm.
- Typically run for minimum of 20 weeks (40 cycles) with 2 x 2.5 cm of simulated rain (pH 4.6) per week (1 cycle = 2.5 cm)

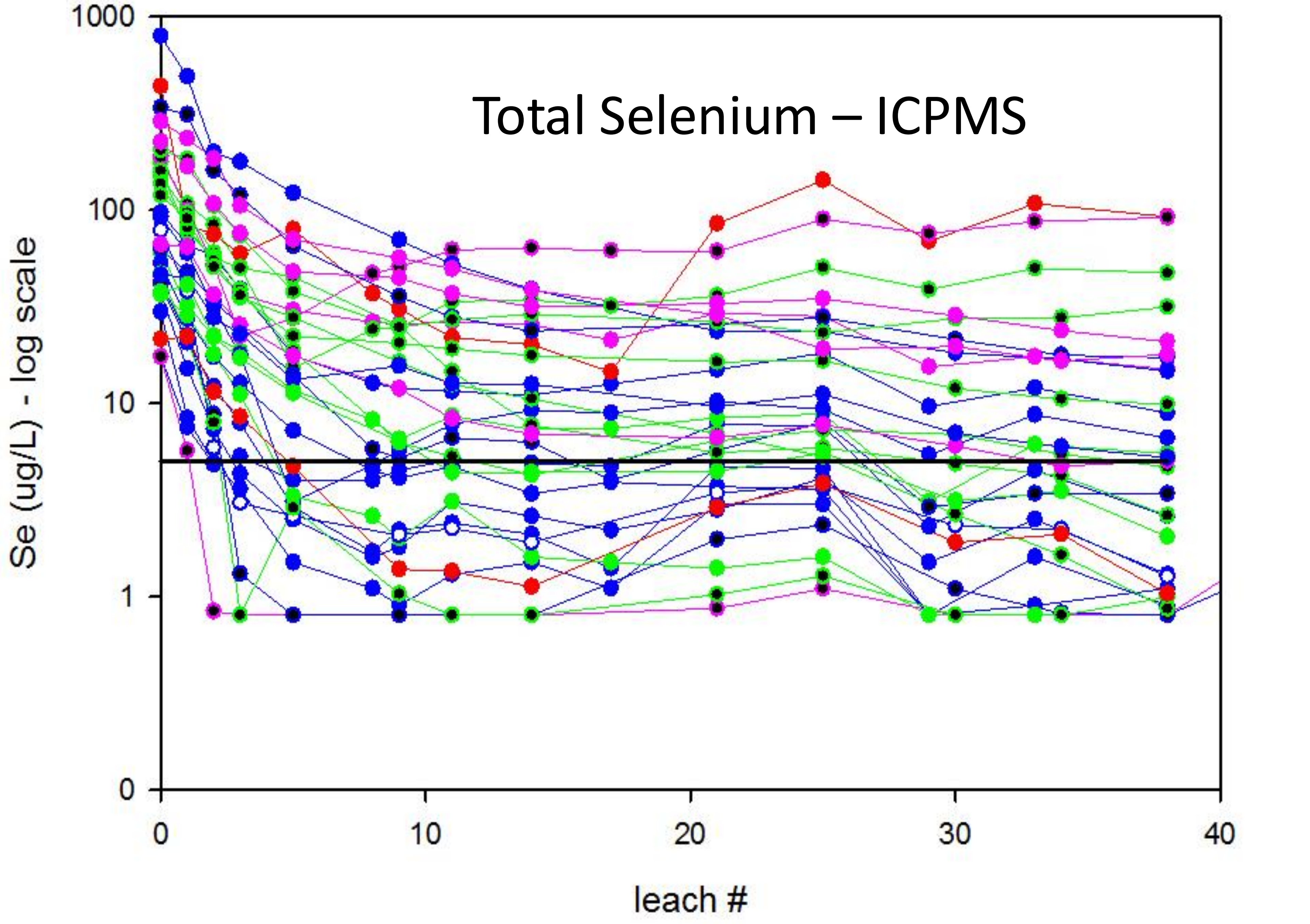

TAIL LEACHATE
Column Leachate SC (uS/cm)
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
WV - SC (uS/cm)
WV - SC
Leachate EC = 519.7 * (1 - exp(-0.003891 * WV-EC))
n = 38, r2 = .482

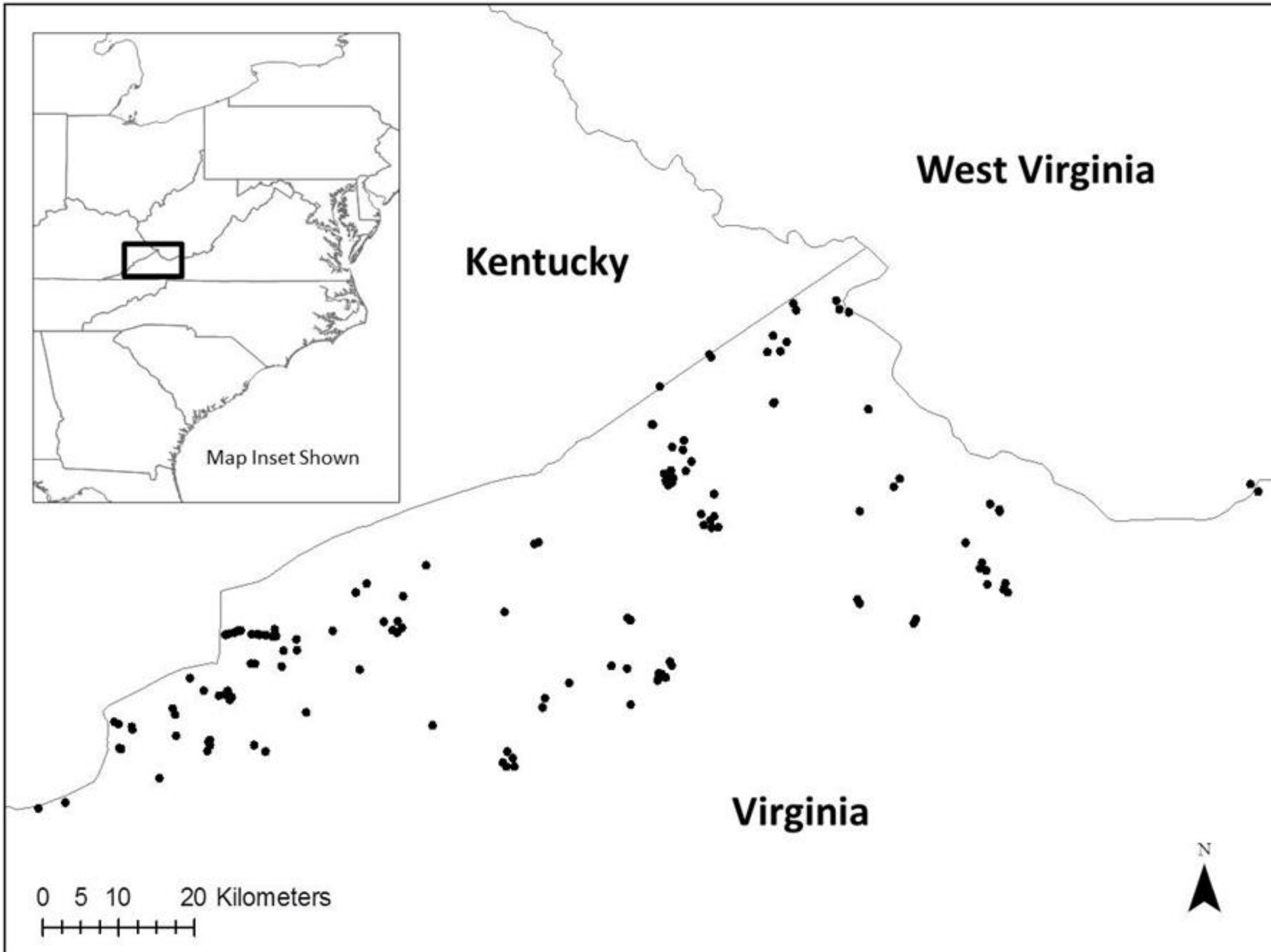
Spoil Handling and Placement

- Identify "hot TDS" materials and isolate them in similar fashion to acid forming strata.

- Current durable rock fills where hard/gray unoxidized rocks (with even moderate TDS potential) are placed via bulk end-dumping are essentially "*TDS sources by design*".

- Consider alternative fill designs where surface lifts are compacted to minimize infiltration.


Total Selenium – ICPMS
Se (ug/L) - log scale
1000
100
10
1
0
0
10
20
30
40
leach #


Map Inset Shown
West Virginia
Kentucky
Virginia
0 5 10 20 Kilometers
N

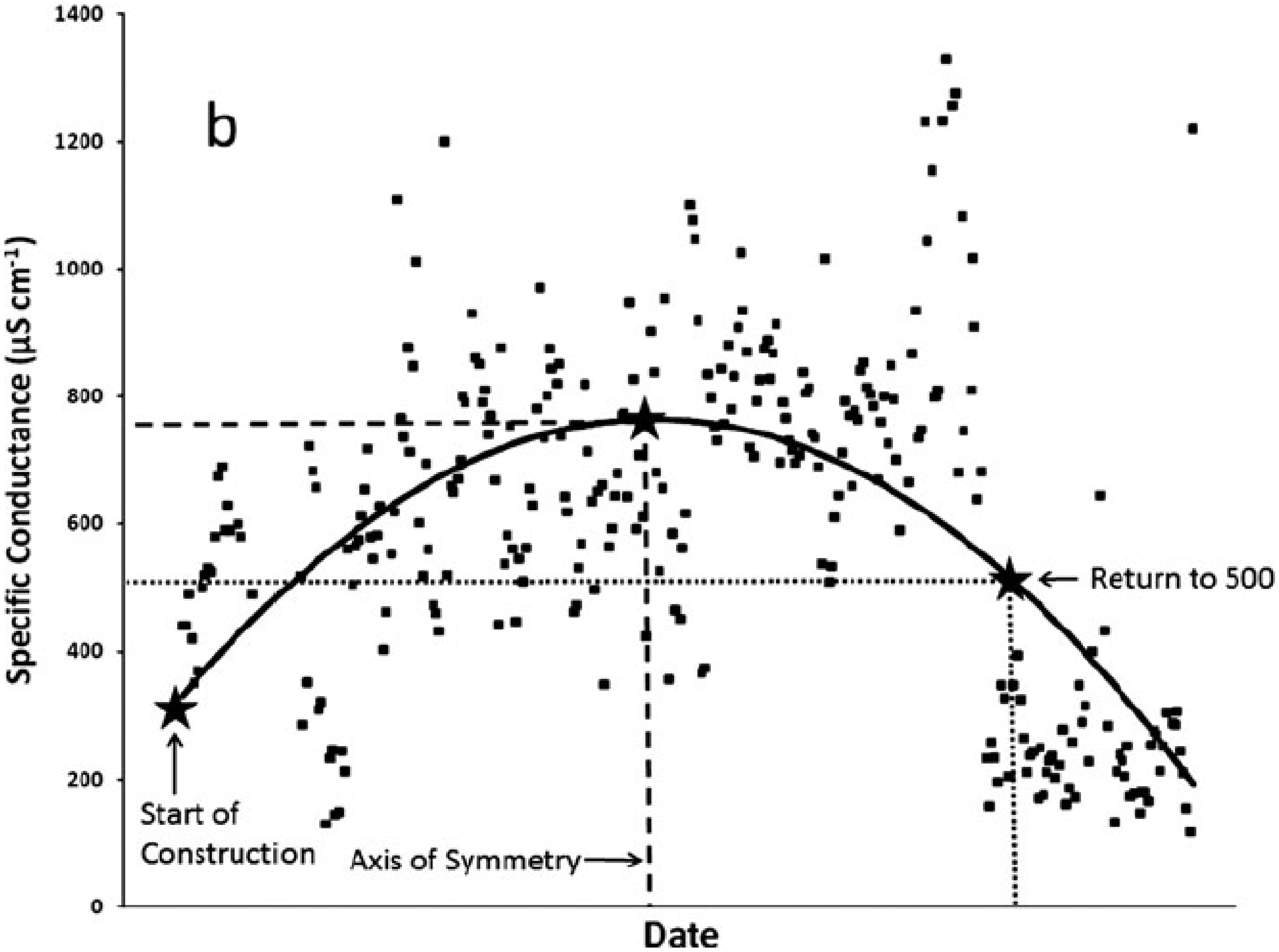
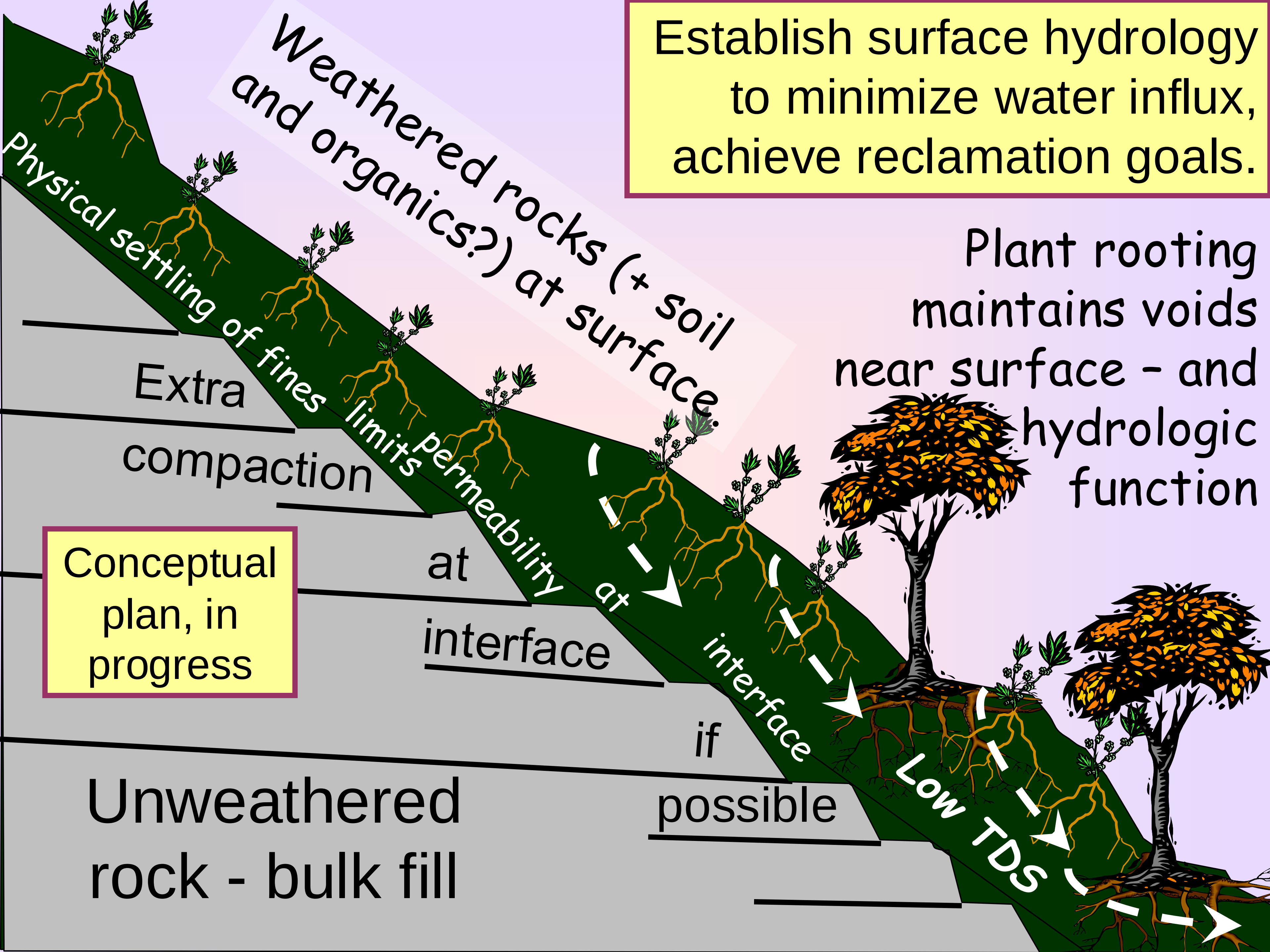


FIGURE 3. Example of Specific Conductance (SC) Data at a Valley Fill with (a) Disturbance Phases Delineated, and (b) a Quadratic Model Fit to Data (solid line), with Axis of Symmetry and the Method for Estimating the Time Required for SC to Return to 500 µS/cm Illustrated.

Field SC data for 137 valley fill discharge points in SW Virginia from Evans et al. 2014 (JAWRA).

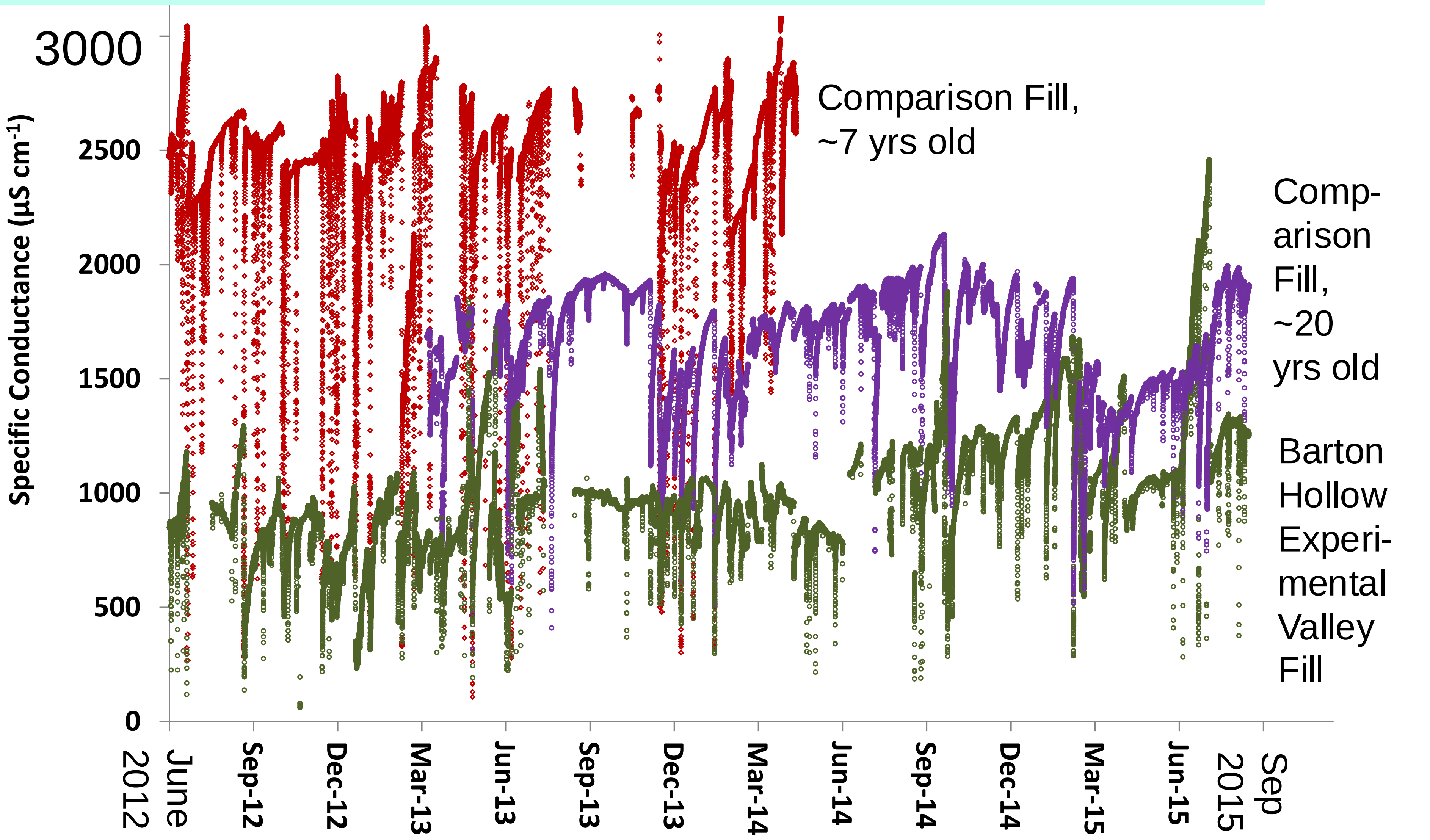
Note (a) range of commonly observed values and (b) long term trend of decline for many locations over time.

How much time? 15 to 20 years in the field via the model, but longer for a number of locations. Why?


Establish surface hydrology to minimize water influx, achieve reclamation goals.
Weathered rocks (+ soil and organics?) at surface.
Plant rooting maintains voids near surface - and hydrologic function
Physical settling of fines limits permeability at interface
Low TDS
Extra compaction at interface if possible
Conceptual plan, in progress
Unweathered rock - bulk fill


Barton Hollow Experimental Valley Fill
23 July 2015
Top lift, still under construction, is not visible.

Specific Conductance at Barton Hollow Experimental Valley Fill and two comparison fills over a 3-year monitoring period.



Where are we going to do with all these mined lands?

Large surface mined area in central Appalachians with extensive valley fills.

Legacy Issues and Opportunities

- **Virginia DMLR is now called the Division of Mined Land *Repurposing*! Similar focus in KY and WV.**

- **Reforestation/afforestation of major interest, but challenged by markets/logistics, invasives, autumn olive, sericea, etc.**

- **Solar is of local interest, but grid connection is limiting? Settling/stability/slopes vs. racking systems also an issue.**

- **Former prep plants/refuse piles being considered for landfill, small nuclear plants, etc.**

- **Long-term TDS from valley fills and particularly refuse piles will challenge the combined industry/regulatory structure as surface production continues to decline.**

Carl E. Zipper
Jeff Skousen *Editors*

Appalachia's Coal-Mined Landscapes

Resources and Communities in a New Energy Era

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6 Coal's Legacy

As mining declined in the Appalachian coalfield, the legacy of the region's coal-mining history remains. Although the Appalachian forest remains among the most biodiverse in the non-tropical world, major areas of forest have been lost (Drummond and Loveland 2010). Approximately 2.5 million acres (10,000 km^2, as compiled from federal government data by Zipper 2020), about 6.5% of the >150,000 km^2 Appalachian coalfield area, have been disturbed by surface coal mining since the late 1970s, in addition to prior disturbances. In central Appalachia, 5900 km^2 of surface-mine disturbances, approximately 7% of an 83,000 km^2 study area were evident from analysis of satellite data (Pericak et al. 2018). Many of those forests have been replaced by plant communities dominated by exotic invasive species (Sena

Simple Summary

- **Avoid acid-forming materials at all costs, but realize that background acid-base reactions are going to get you at discharge points regardless.**
- **Compaction, compaction, compaction is your worst enemy for all revegetation alternatives, period.**
- **Native weathered soil and oxidized underlying strata are your friends in most instances. They are finer in texture and less rocky and contribute important biological activity.**
- **The majority of our coal mined landscapes in the region are relatively easy to stabilize and revegetate; refuse piles will continue to be the major challenge for decades to come.**

A short history of changes in reclamation of Central Appalachian coal mined lands over the last 45 years.

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