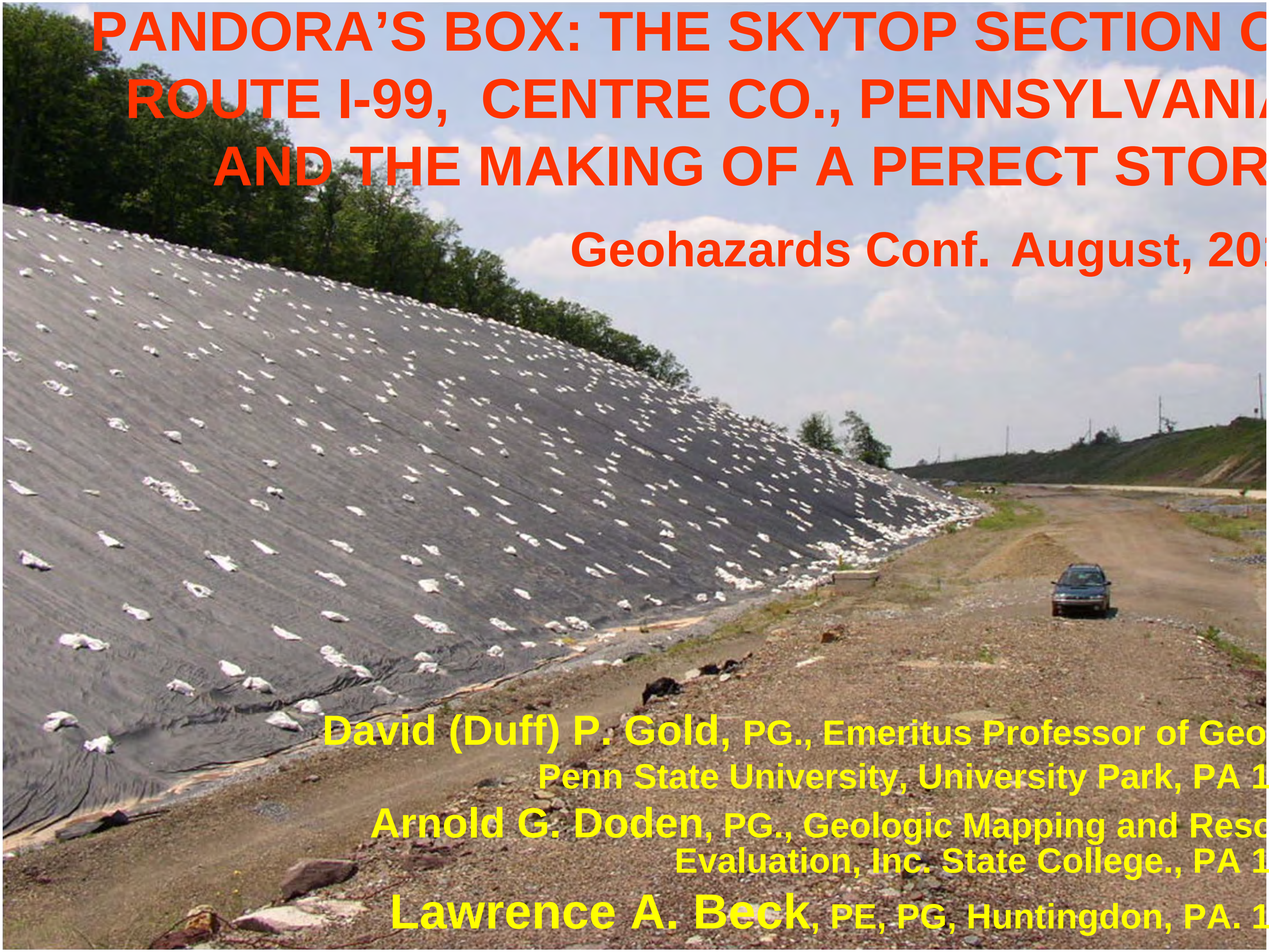
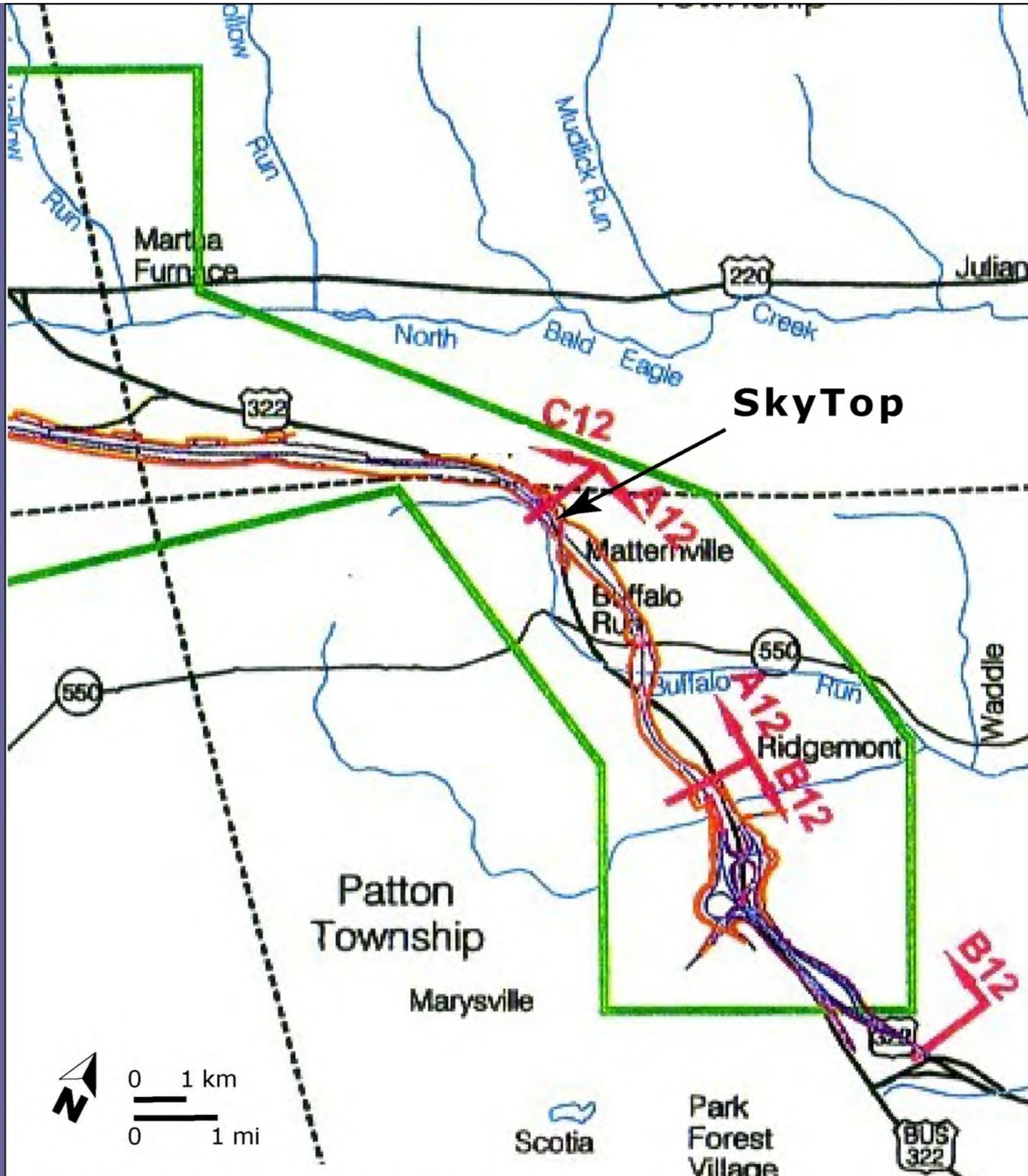

PANDORA’S BOX: THE SKYTOP SECTION O
ROUTE I-99, CENTRE CO., PENNSYLVANI
AND THE MAKING OF A PERECT STOR
Geohazards Conf. August, 20
David (Duff) P. Gold, PG., Emeritus Professor of Geo
Penn State University, University Park, PA 1
Arnold G. Doden, PG., Geologic Mapping and Reso
Evaluation, Inc. State College., PA 1
Lawrence A. Beck, PE, PG, Huntingdon, PA. 1

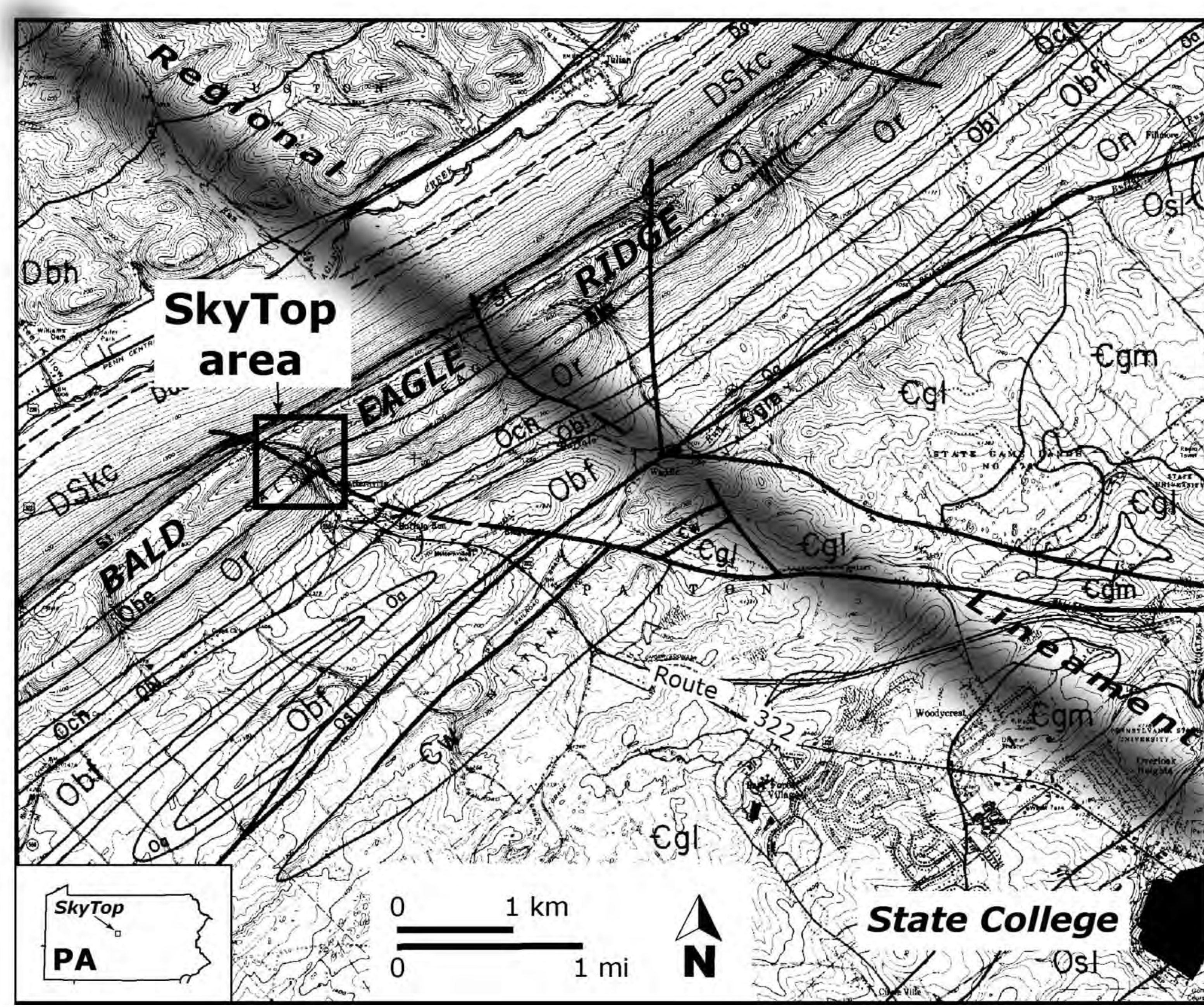
Route Selection

- Plans for ridge-side connector between I-80 and 176 initiate late 1950's – strategic access between Altoona (railway work-shops and Lock Haven (light aircraft factory).
- Resurrected with dam projects (Raystown).
- Revitalized late 1970's with socio-economic drive to cross ridge into Nittany Valley.
- Final footprint a rollercoaster between valley floor and ridge crest alignments (late 1990's) to cross Bald Eagle Ridge at Skytop.



Modified from a PennDOT base map

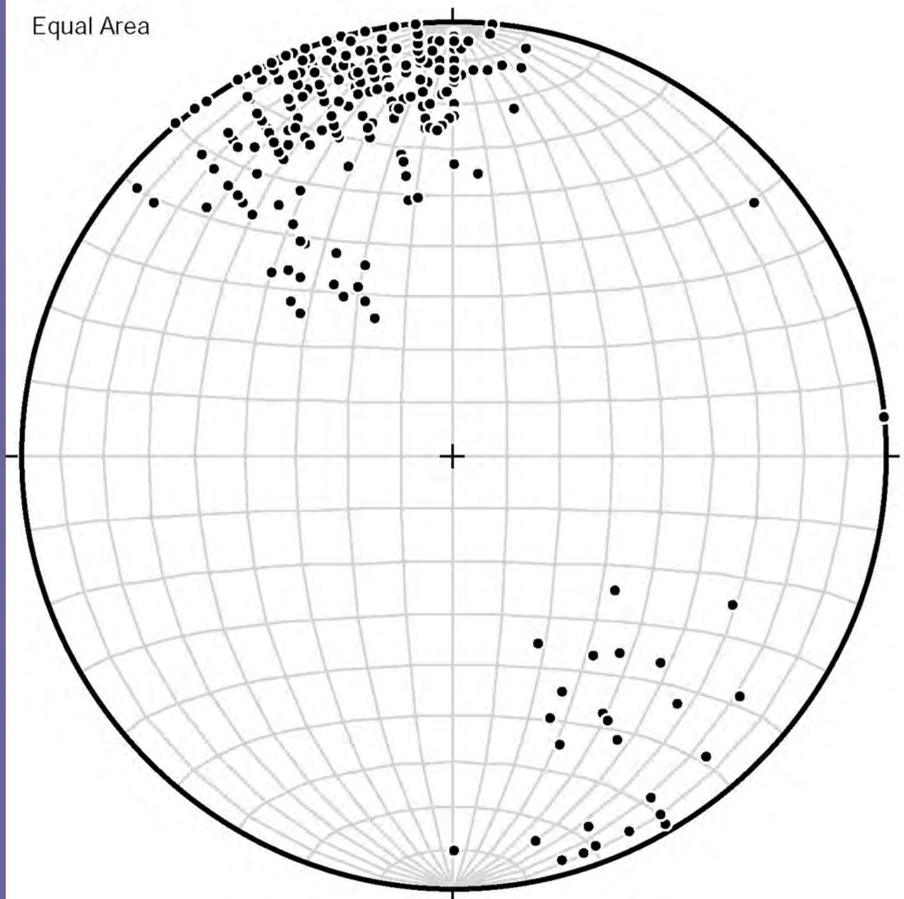
Skytop from Southwest

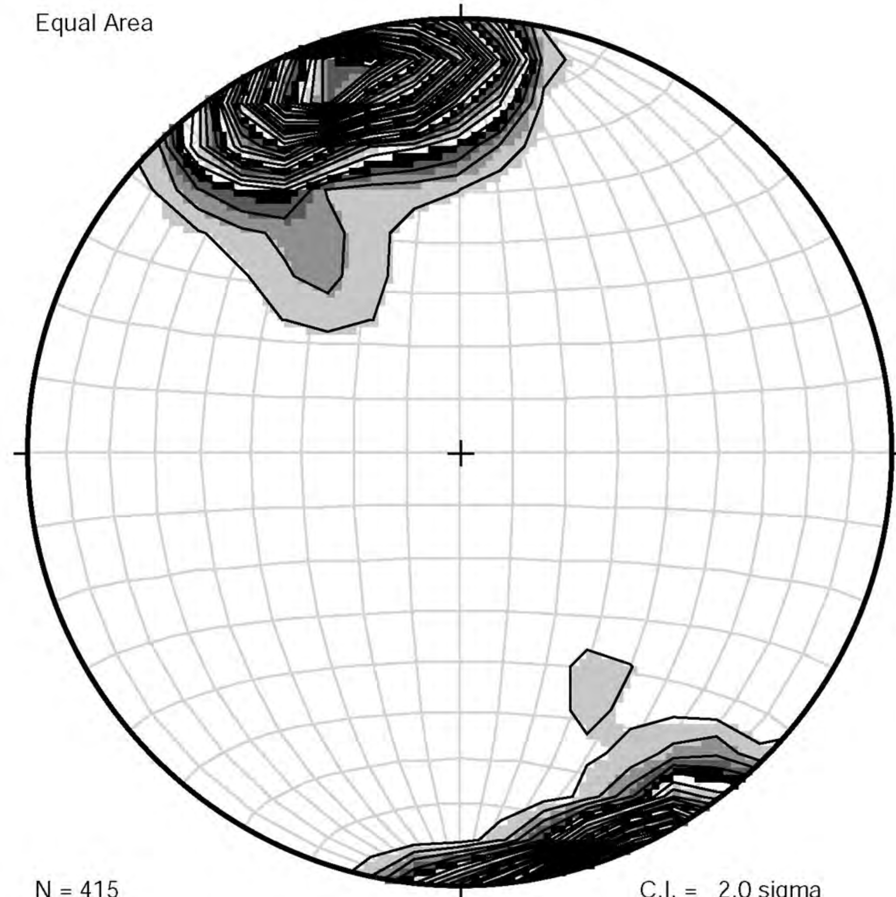

Regional
Lineament
SkyTop
area
EAGLE
RIDGE
BALD
Route
322
DSkc
Dbh
Or
Obf
Obl
Oon
Osl
Och
Obe
Oa
Ɛgm
Ɛgl
Ɛw
SkyTop
PA
0
1 km
0
1 mi
N
State College

Skytop area stratigraphic section

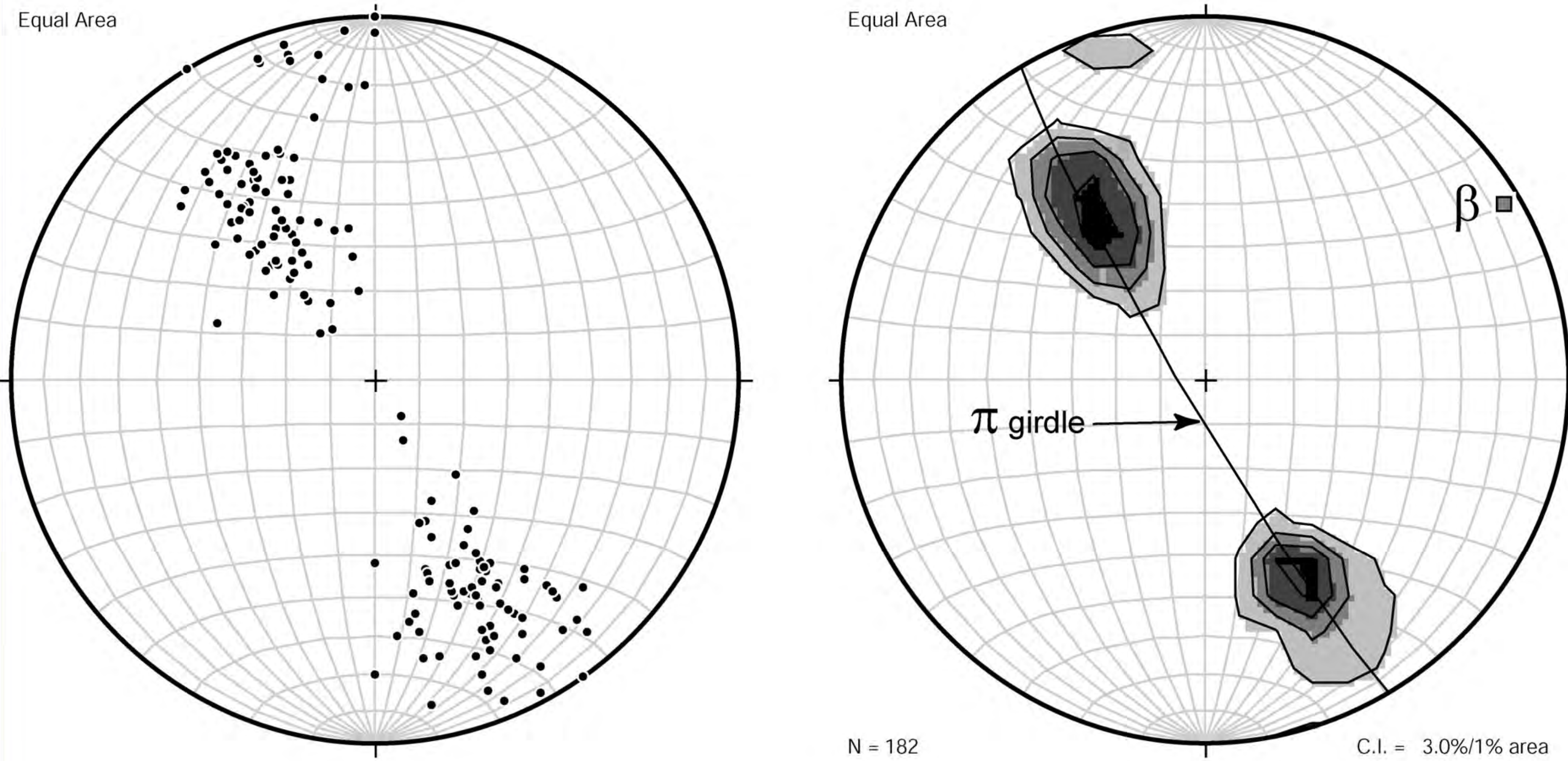
		Group or Formational Names	Thickness (ft) Regional	Local
Devonian		Hamilton Gp. (Marcellus & Mahantango)	970	
		Onondaga limestone and shale	30	
		Old Port limestone, shale, sandstone, chert	220	
		Keyser limestone	100	
Silurian		Tonoloway limestone & dolostone	400-820	
		Wills Creek calcareous shale & dolostone	445	
		Bloomsburg red shale, siltstone, & sandstone	85-360	
		Mifflintown (McKenzie & Rochester) shale & limestone	625	
		Rose Hill shale & Keefer sandstone	600-950	
		Tuscarora quartzite	400-500	**400**
Ordovician	Upper	**Juniata red shales, sst, ss**	700-1400	**600**
		Bald Eagle green graywackes	600-800	**700**
		Reedsville shale	700-1000	**~ 650**
	Middle	Trenton limestones	475	
		Black River limestones	500	
	Lower	Bellefonte dolostone	1000	
		Axemann limestone and dolostone	0-360	
		Nittany dolostone	1000-1200	
		Stonehenge limestone and dolostone	630	
Camb.		Gatesburg and Mines dolostone & sandstone	1800+	
		Warrior limestone	600+	

A-12 Section Bedding





C-12 Section Bedding



π Diagram for C-12 Section of I-99
(π girdle 150/85: β = 05/060)

UNEXPECTED GEOLOGY

1. Chevron folds in Tuscarora quartzite and shale.
2. Cross-strike epigene sulfide veins, mainly in Bald Eagle Sandstone.
3. Transgressive, low angle, oblique-slip faults in Reedsville Shale.

Components to Pandora's Box

1. Ridge crest excavations through wind gap exposing 3rd order *Chevron* folds in overturned beds of Tuscarora Quartzite.
2. Transgressive epithermal sulfide veins in the underlying Bald Eagle Sandstone. Long delay between excavation (~ 1 mcy, or 1.7 m tons) of 5% pyritic rock and the realization it was toxic.
3. In addition to steeply dipping strike-slip faults underlying the wind gap, some low angle reverse faults were day-lighted in the 350 ft deep canyon excavation

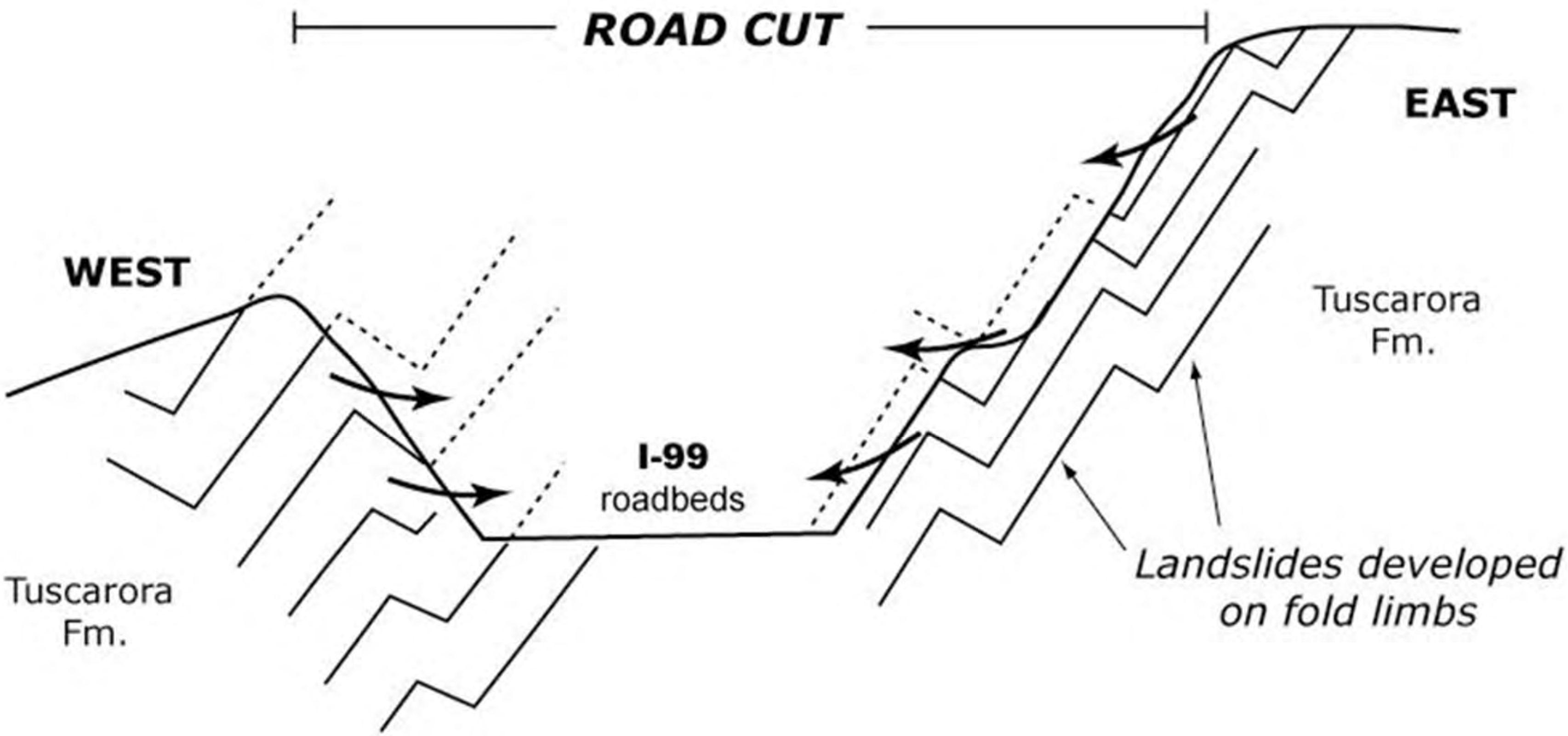
Anthropogenic (opening the lid)

1. Sampling protocol suited for syngenetic (bedded) sulfide deposits rather than veins.
2. Dump and/or fill sites not prepared for generation of acid rock drainage (ARD).
3. Layer-cake mixing of pyritic rock waste with limestone dust or bag-house lime.
4. Unawareness of sulfuricization process in the fill areas, or efflorescent mineral “blooms” in the cut faces, as well as
5. The reactiveness of epigene “whisker” pyrite.

What makes the perfect storm?

- Road bed excavated along the trough axis of a syncline – double “wammy” landslides.
- Change in road-bed grade and slope angle of cuts to stabilize slopes, and “load the toe” areas with buttresses.
- Use excavated pyritic rock for required “fill”.
- Distribute “toxic” rock to 5 major fill/dump sites, and 114 minor sites along a 20 mile stretch of roadways.

Chevron folds and landslides at Skytop



Reverse drag fold in Juniata Fm

(crest of Bald Eagle Ridge- 200

Chevron fold in Tuscarora Quartzites

C-12 section of I-99 excavation in Bald Eagle Valley

(fold limbs are perpendicular to each leg)

Northwest limb of Chevron fold in Tuscarora Quartzite

(Crest of Bald Eagle Ridge)

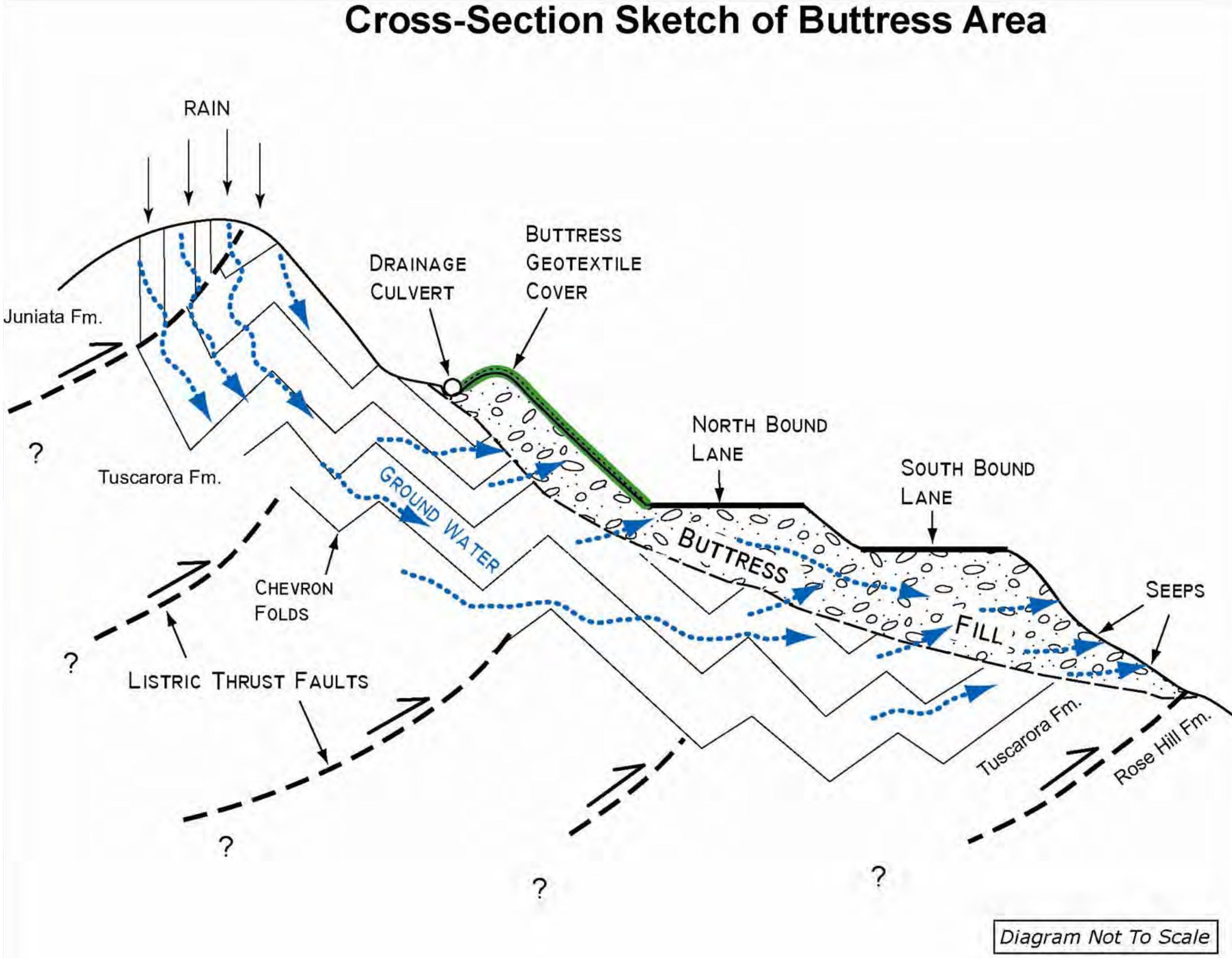

153.037mm
1:3000
SR 0220-C12
2-61

Scarps from slow rock slides above Section C-12

Headwall cracks on crest of Bald Eagle Ridge

Graben (syn and antithetic rotational faults)

Bald Eagle Ridge:C-12 section land slide headwall



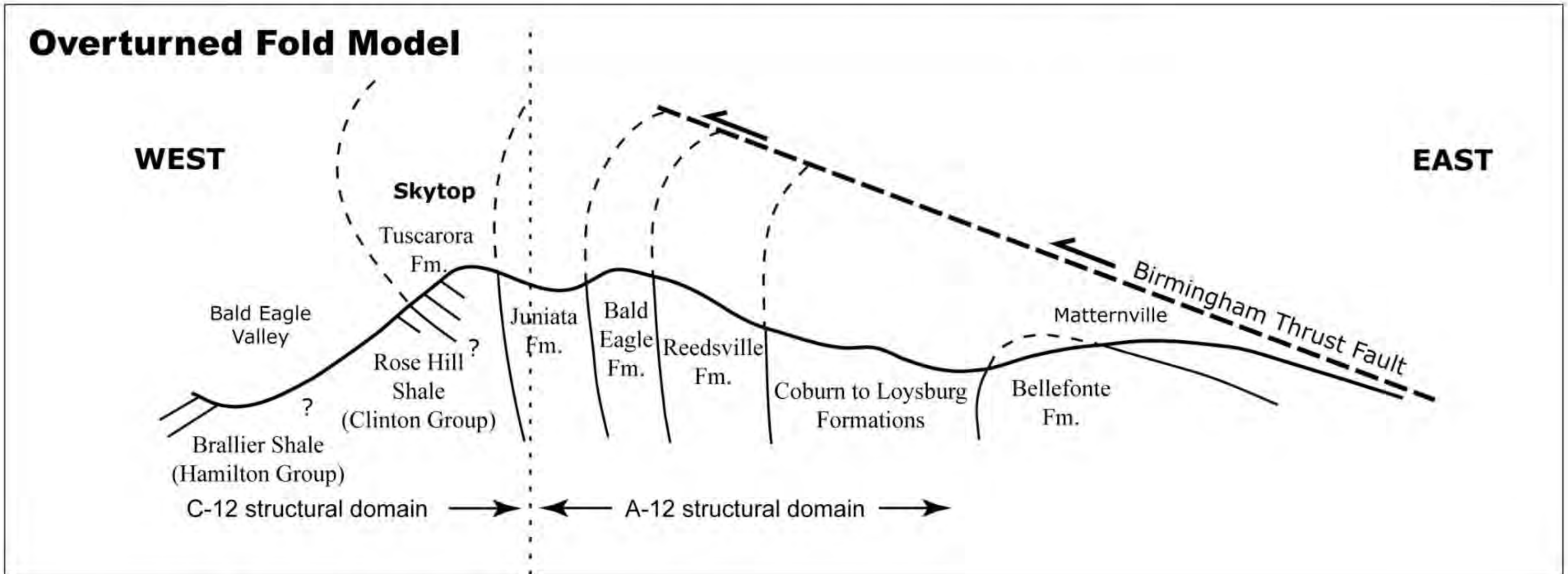
- Recharge area between Stations 816+00 and 843+80 = 1,460,000 sq. ft.
- 17.9 gallons of ground water/day/linear foot at base of buttress
- Rain fall ~ 40 inches/year → Infiltration rate = 20 ± 3 inches/year

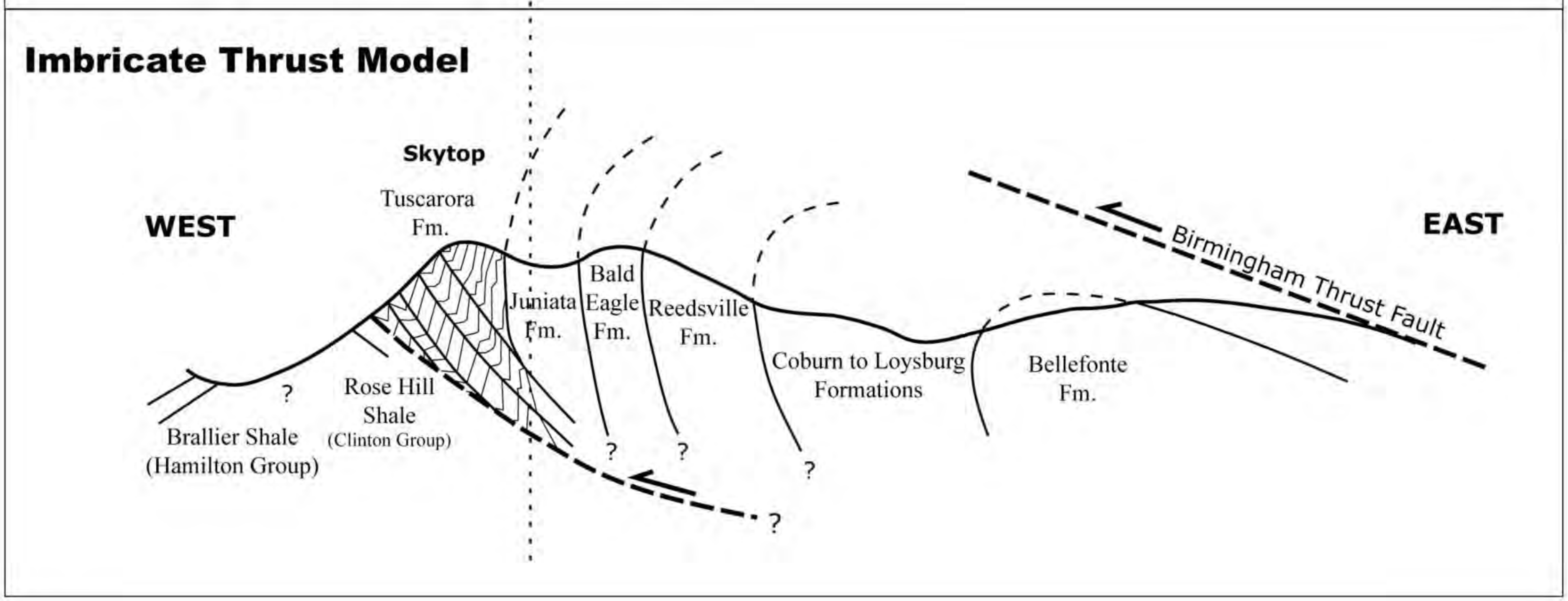
C-12 Section

Note grade change in N-bound lane by 17 ft for approx 1 mile.

"Fill is pyritic rock

Structural models for Skytop



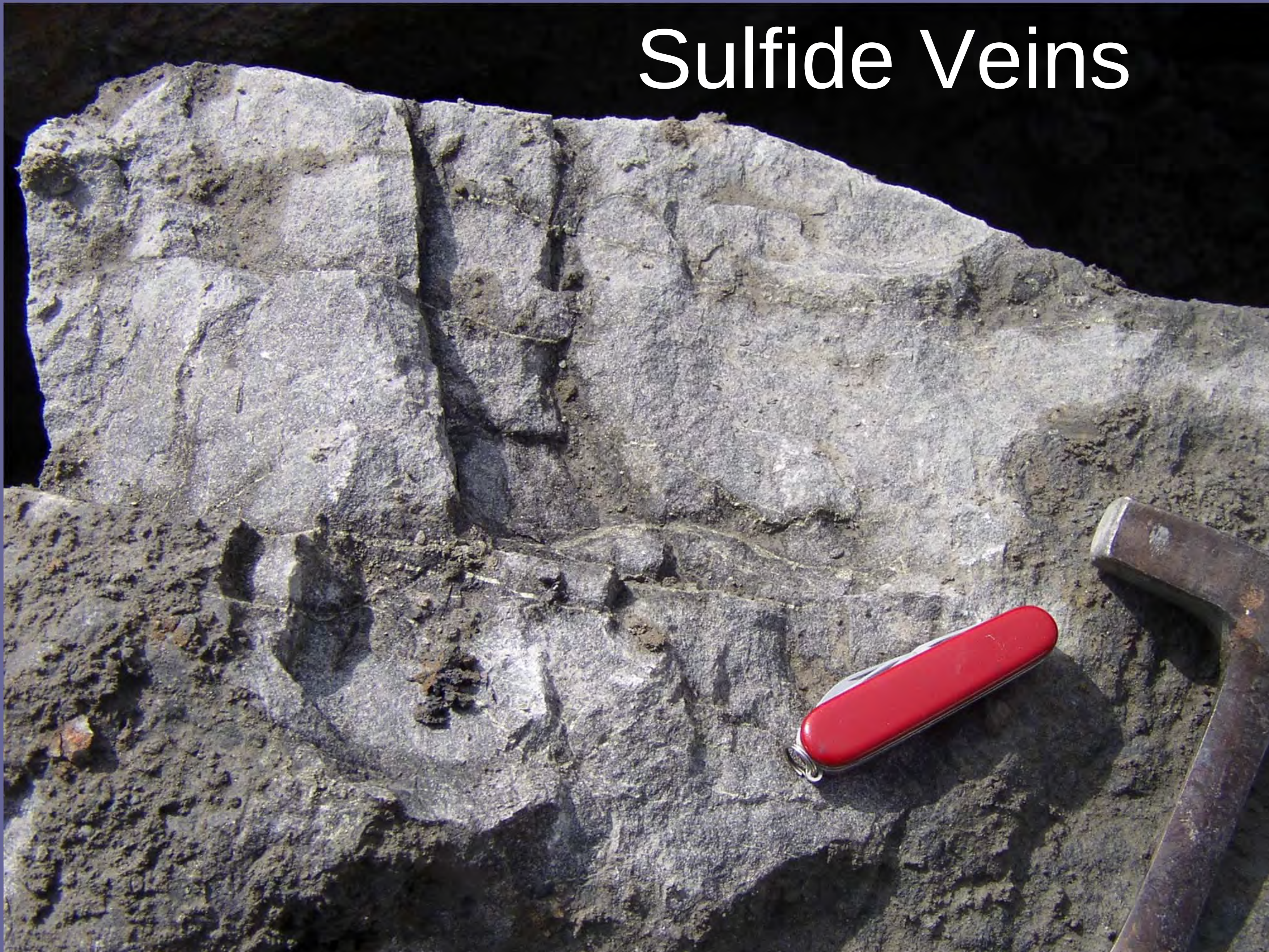


NATURE OF SULFUR-BEARING DEPOSITS

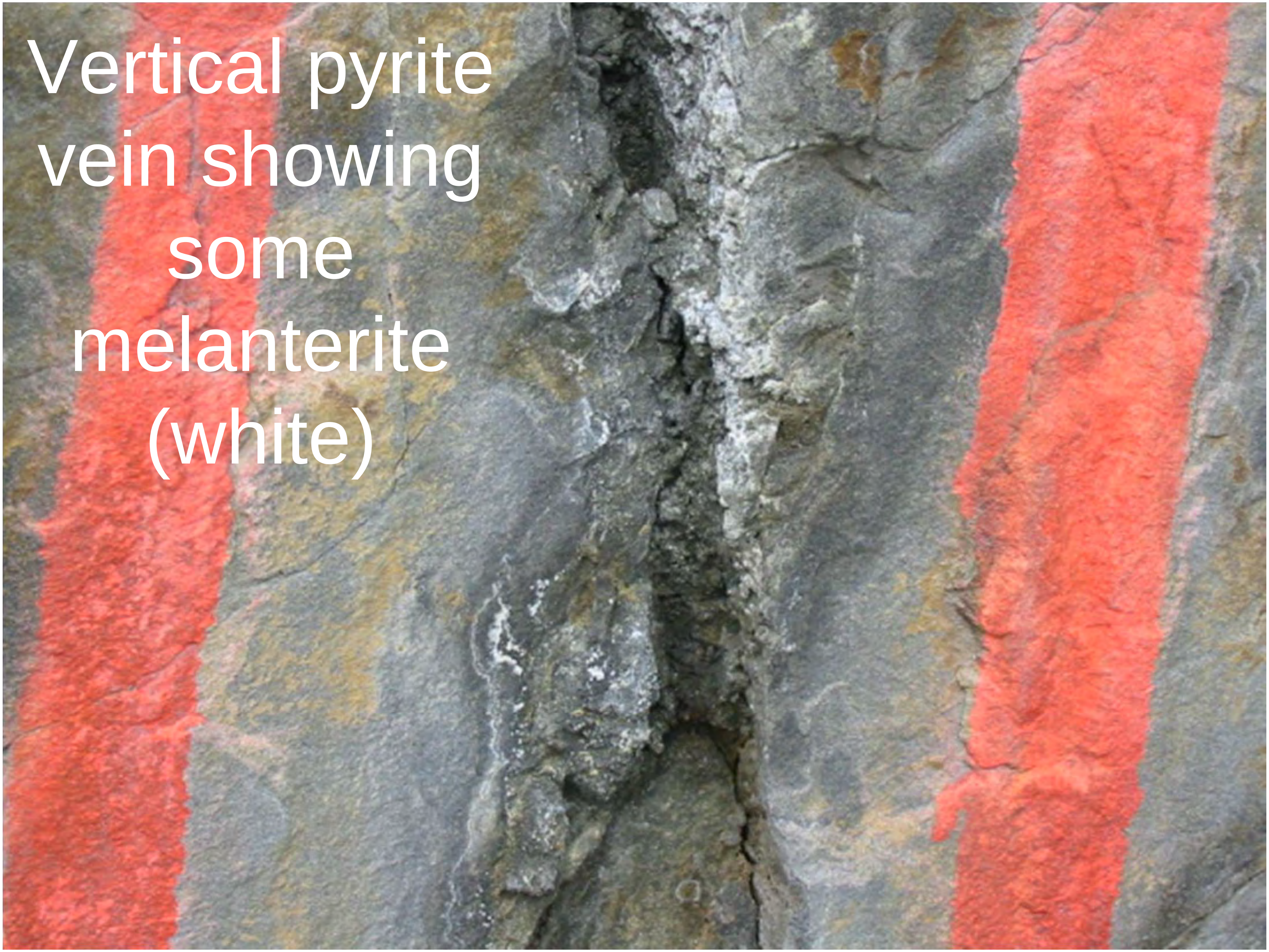
- Forms of sulfur (native, sulfides, sulfates, thio-sulfur organic compounds, and sulfosalts).
- Approx 200 common minerals with sulfur.
- Types: epigene, syngene and supergene.
- Weathering and alteration (supergene processes):
  - *REDOX (Eh and pH dependent)*
  - *Gossan and Oxidized Cap Rock (OCR) from leaching above ground water table*
  - *Evaporation (Efflorescent Minerals, Acid Sulfate Soils and Sulfuricization)*
  - *Expansion due to alteration*


Oxidized Cap Rock
Sulfide veins in "reduced"
Bald Eagle Sst
Juniata
Redbeds
Bald Eagle Red Sst

Sulfide Veins

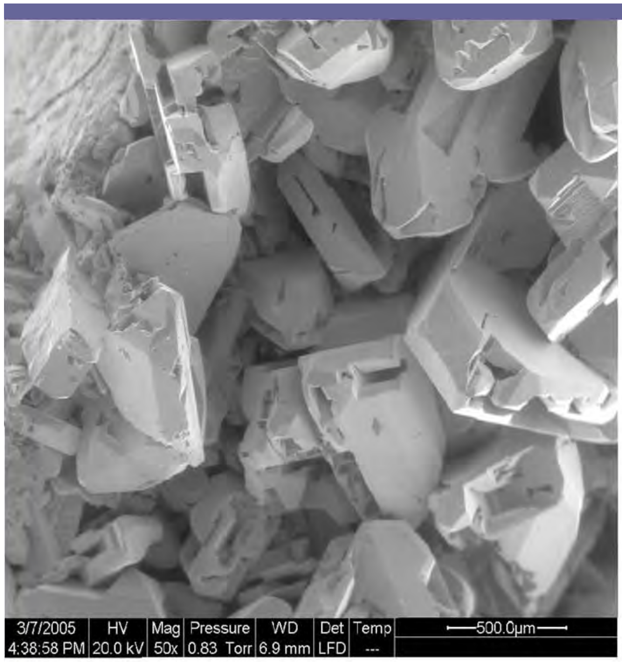



Pyrite vein in Bald Eagle Sandstone

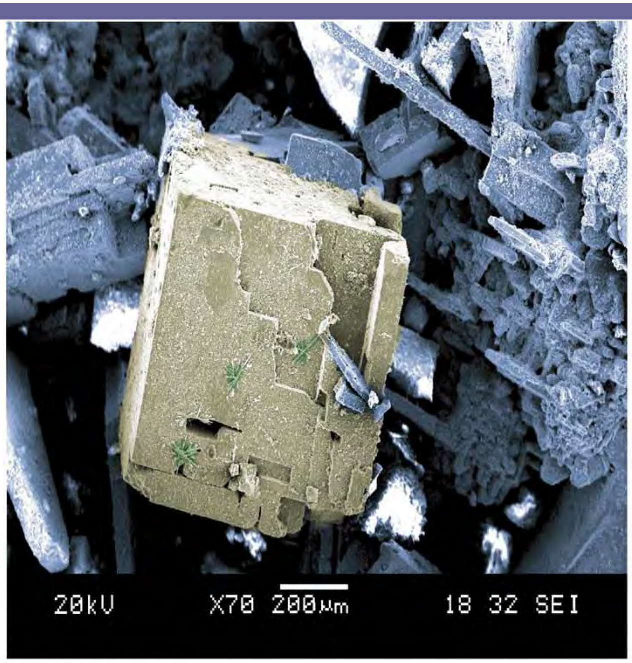

Vertical pyrite vein showing some melanterite (white)

Fault in massive sulfide vein

poles aligned with two directions of slickenlines



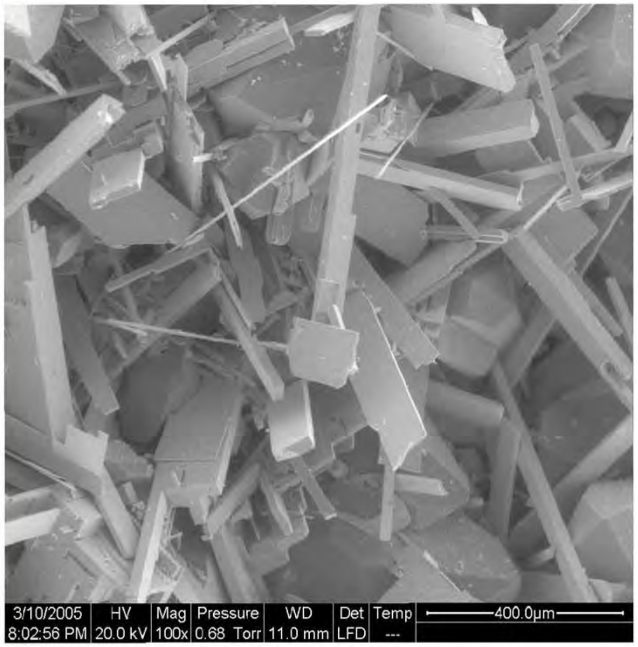
Skytop-1205a_001 (Sicree)



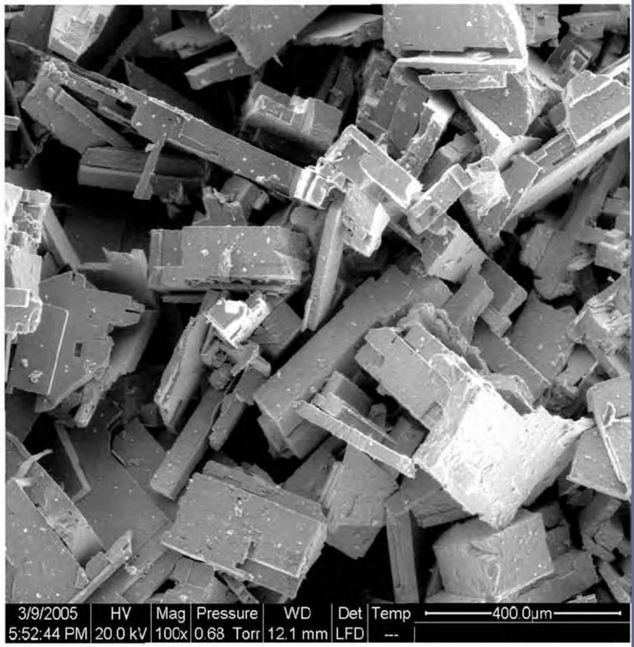
formag (Mathur)

SEM Images Skytop pyrite.

Note blade and needle habit of “whisker” pyrite



Skytop-1200-a_009 (Sicree)



Skytop 1206a_005 (Sicree)

Tentative List of Skytop Minerals

Sulfides:

Pyrite	FeS_2		cubic
Marcasite	FeS_2		ortho
Pyrrhotite –4C	$Fe_{1-x}S$	(typically Fe_7S_8)	momo
Pyrrhotite –7C	β-$Fe_{1-x}S_8$		hex
Chalcopyrite	Cu FeS_2		tetr
Tennantite?	$(Cu,Fe)_{12}As_4S_{13}$		cubic
Sphalerite	ZnS		cubic
Wurtzite?	β-ZnS		hex
Greenockite?	CdS		hex
Galena	PbS		cubic

Phosphates:

Wavellite	$Al_3(PO_4)_2(OH,F)_3 \cdot 5H_2O$	ortho
Variscite	$AlPO_4 \cdot 2H_2O$	ortho
Woodhouseite	$CaAl_3(PO_4)(SO_4)(OH)_6$	trig

Oxides and oxy-hydroxides

Quartz	SiO2	hex
Hematite	Fe_2O_3	trig
Limonite/Goethite	FeOOH	ortho
Lepidocrocite?	γ-FeOOH	ortho
Akaganeite	β- FeOOH	tetr
Jarosite	$KFe_3(SO_4)_2(OH)_6$	hex

Efflorescent minerals:

Copaipite	$Fe^{2+}Fe^{3+}_4(SO_4)_6(OH)_2 \cdot 20H_2O$	tric
Halotrichite	$Fe^{2+}Al_2(SO_4)_4 \cdot 22H_2O$	mono
Gypsum	$CaSO_4 \cdot 2H_2O$	mono
Melanterite	$FeSO_4 \cdot 7H_2O$	mono

Other suspected phases:

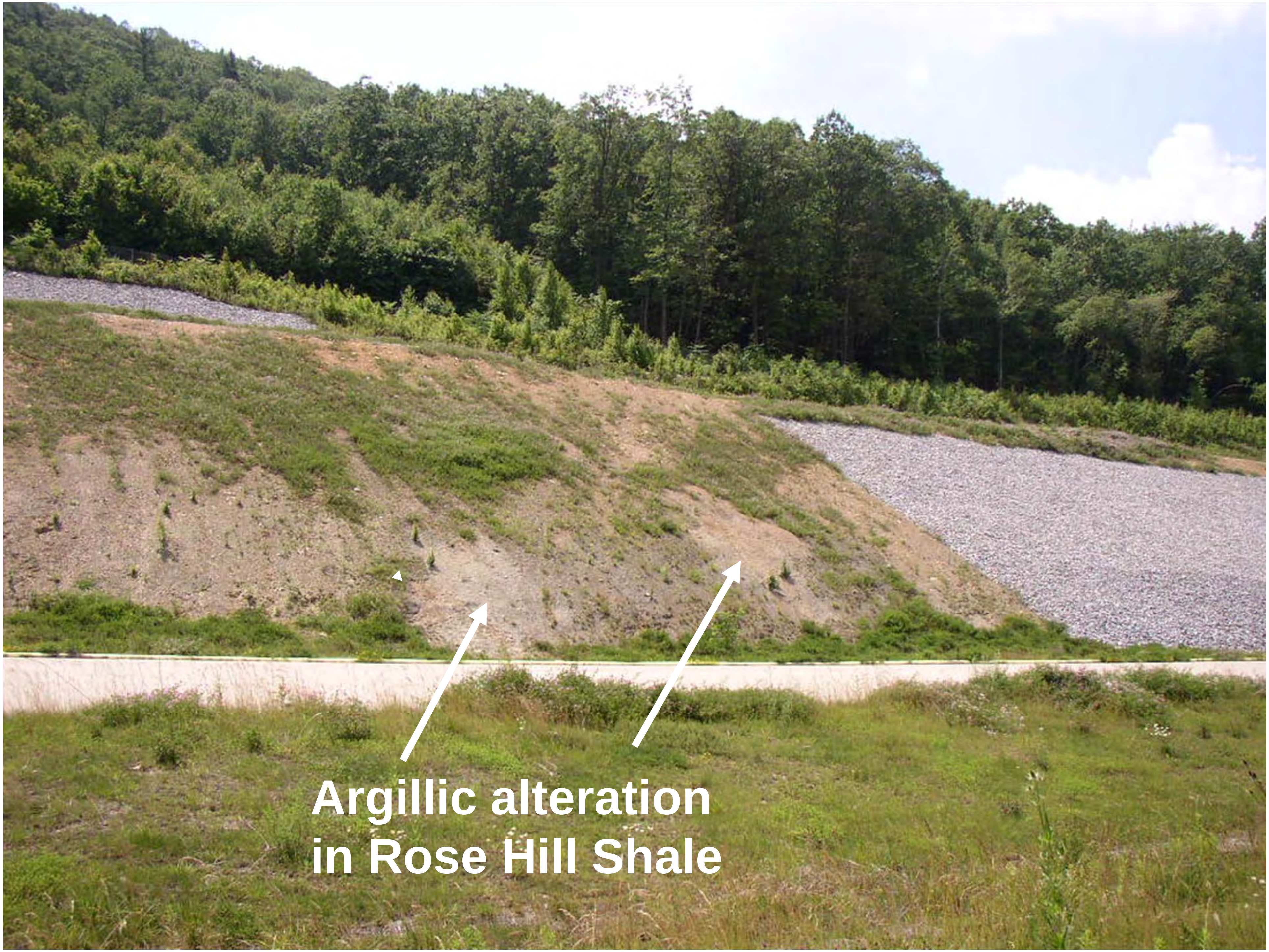
Barite	Ba SO_4	ortho

Other trace elements:

Cd, As, Sb, Au, Ag, Hg,	probably epigenetic in pyrite
Zr	probably detrital (syngenetic) zircon in sandstone
Y	probably detrital (syngenetic) xenotime in sandstone

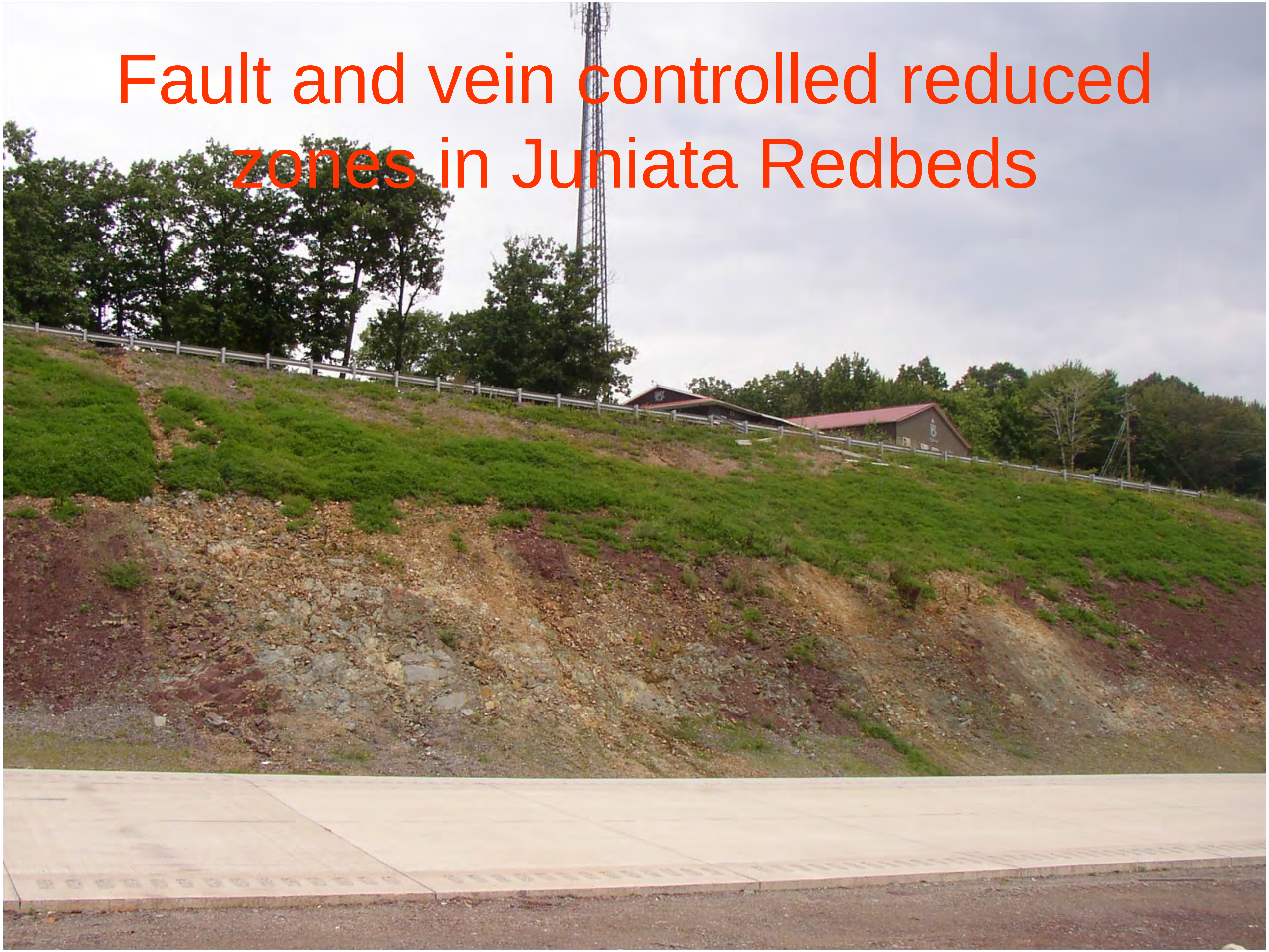
HYDROTHERMAL VEINS
Reducing Sulfide-bearing fluids

- Main veins are transgressive 140-170˚/vertical
- Close relationship to J2 joints
- Metasomatism (add S, Fe++, Cu, Pb, Zn, Cd, As, Ga, Ge, and Sb; lose Si, Al, K, Ti, V, Th, Y, La, Ce, RE mainly by dilution). Barite, Phosphate-minerals and quartz in exterior veins
- Quartz fluid inclusion temps 150 to 380˚ C
- Reduction halos in Redbeds
- Argillic alteration in shales
- Gossan above water table in Oxidized Cap Rock


Argillic alteration
in Rose Hill Shale

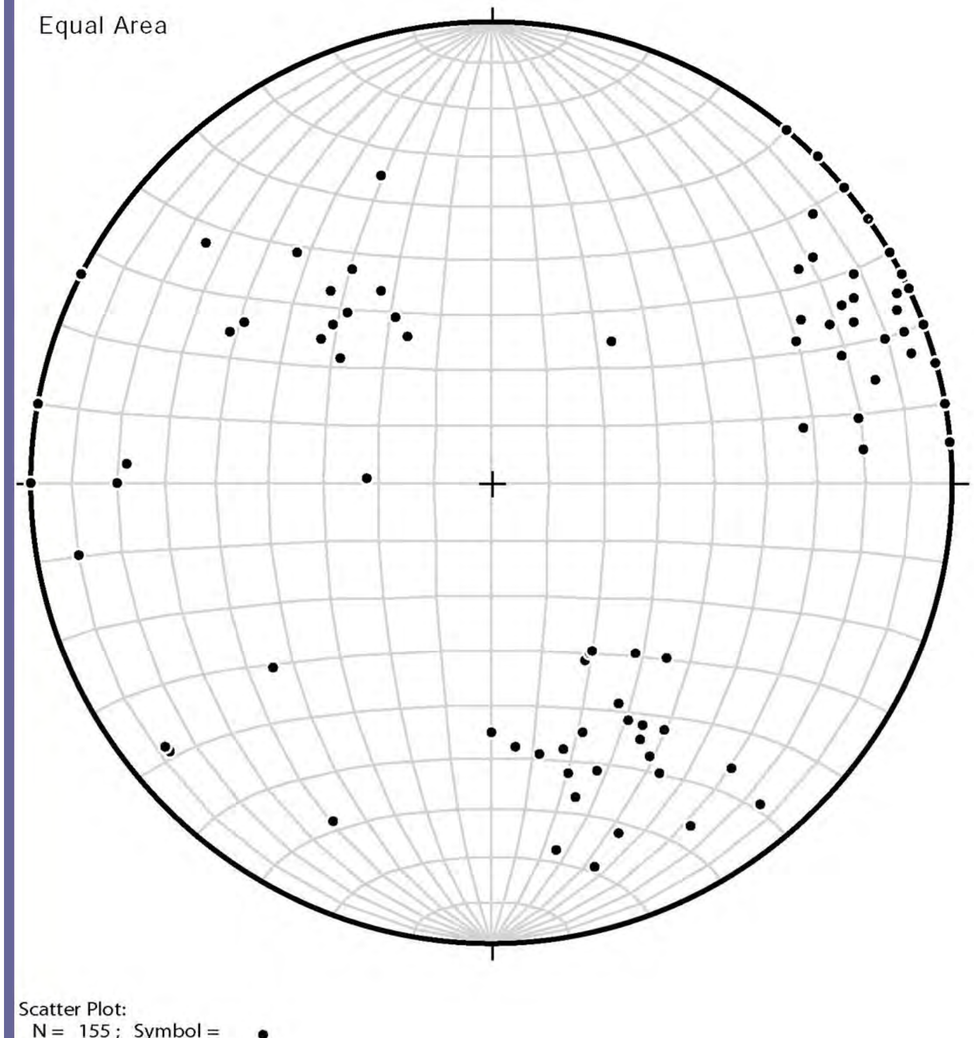

Reduction halo from vein in Juniata Redbed

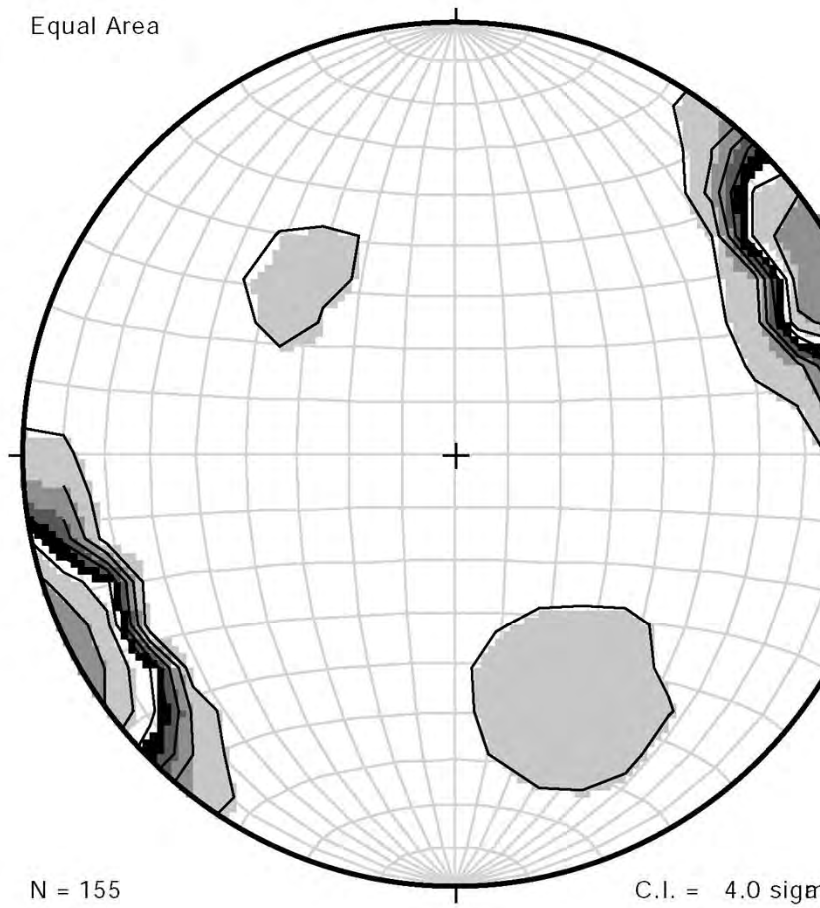
Fault and vein controlled reduced zones in Juniata Redbeds



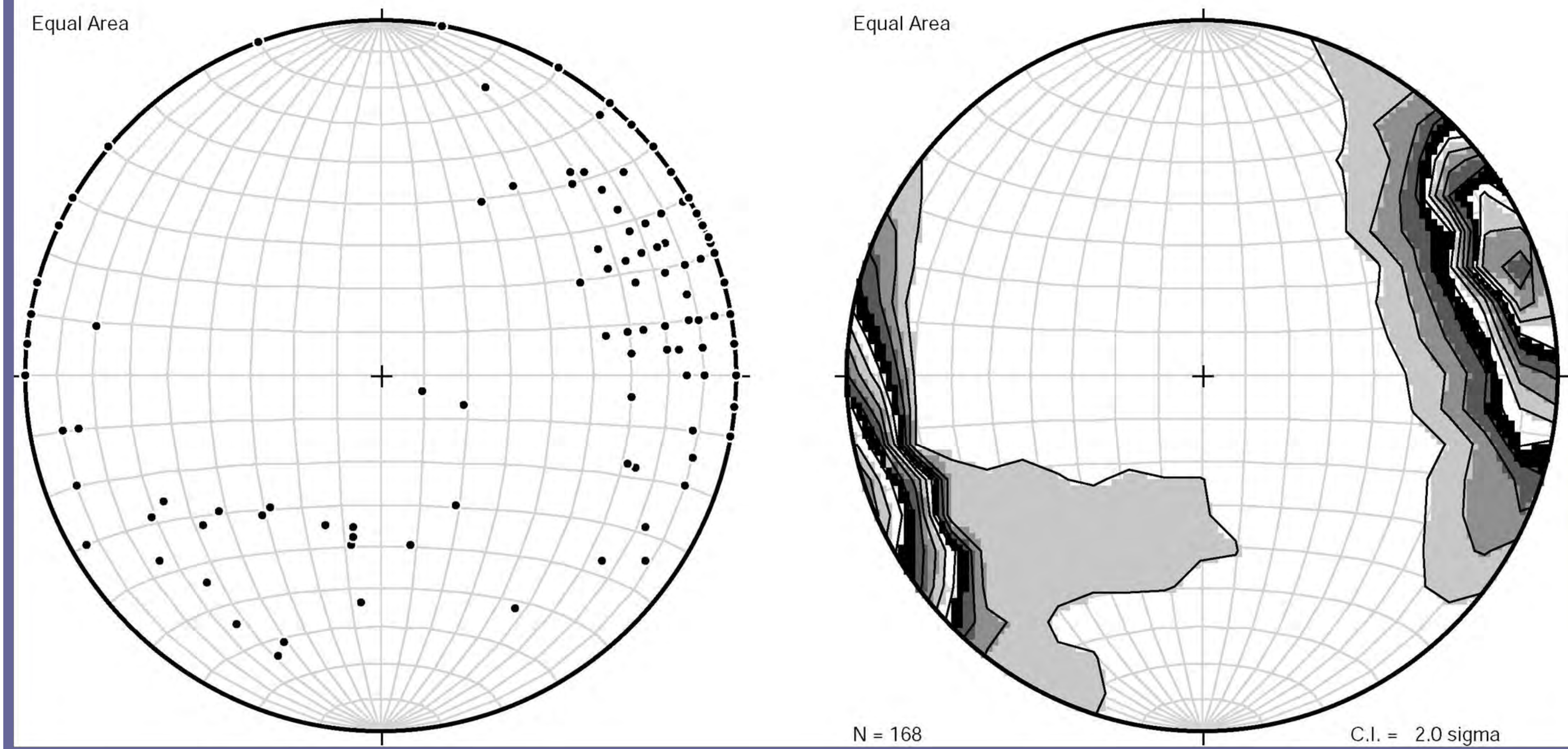
Contact of REDOX zone in Juniata Redbeds, beneath OCR

C-12 Section Joints





A-12 Pyrite-bearing Veins



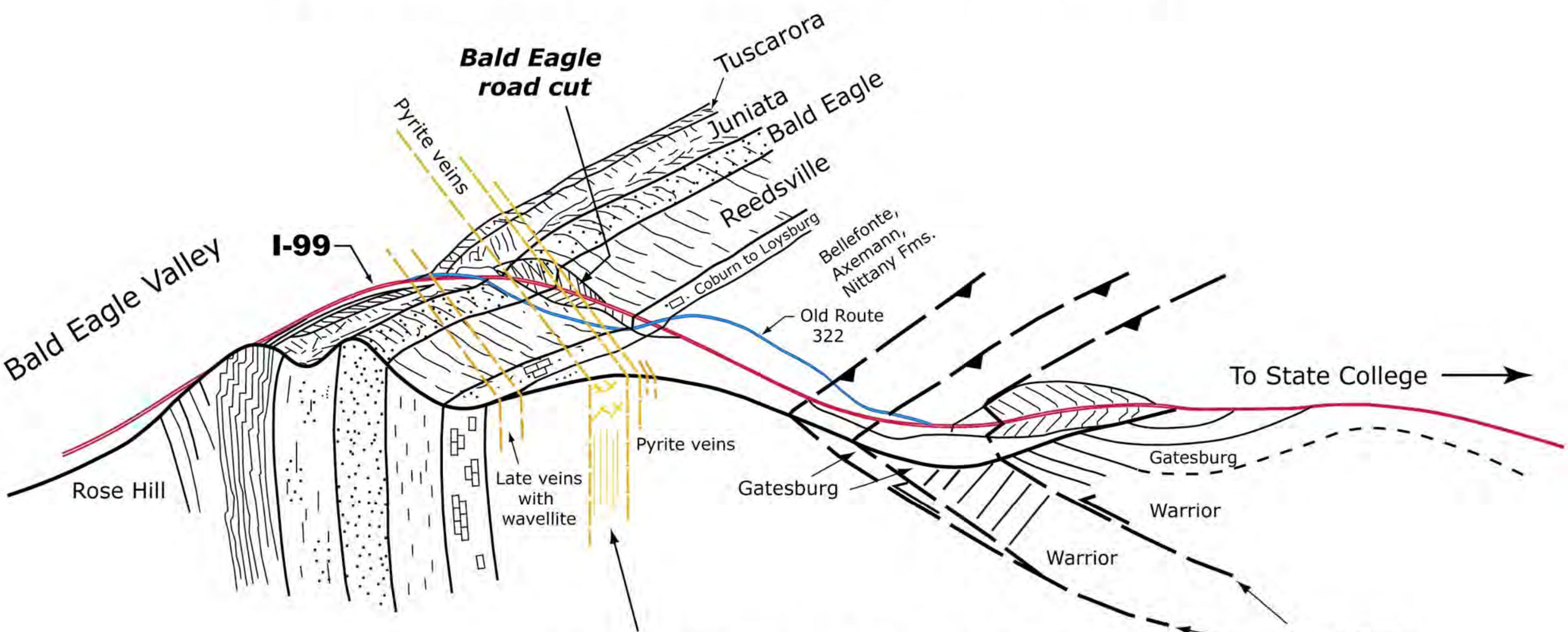
Evidence for hydrothermal activity

- Mineralogy: sulfides (pyrite and pyrrhotite), sulfates (barite), phosphates (wavellite).
- Habit: veins and stockworks.
- REDOX (reduction haloes and fronts).
- High fluid inclusion temperatures in associated quartz (150 to 360˚C)

Summary: Epigenetic Vein Deposits

- Best preserved in brittle rocks (i.e. ridges).
- Most likely in wind and/or water gaps.
- Locations difficult to predict (lineaments?).
- Different level of geologic expertise needed.
- Sampling strategy needs to be adjusted for steeply dipping veins.
- More unwanted trace elements and more reactive than bedded pyrite deposits.
- Weathering imposed zones from leached rock at the surface, to oxides on the water table, downward to sulfides.

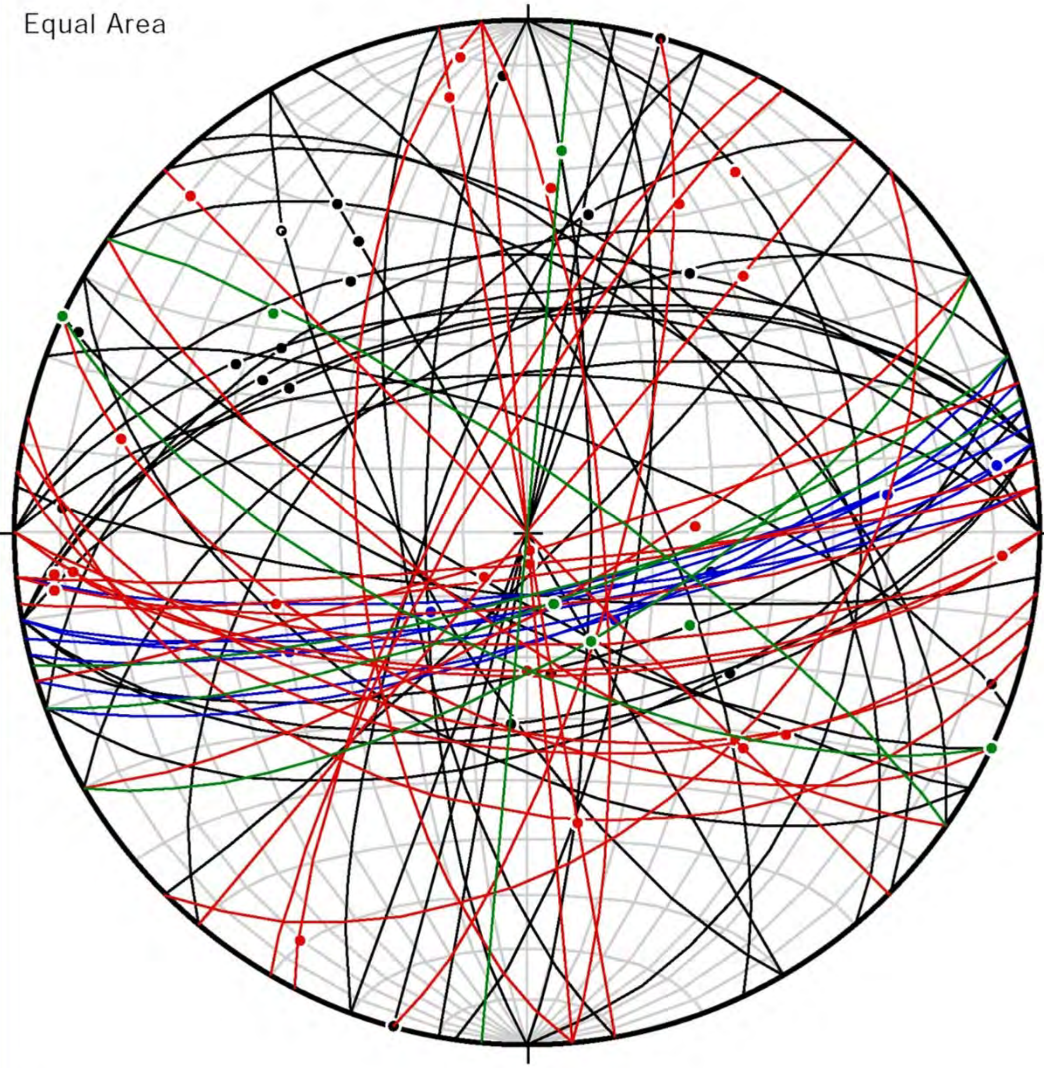
Sketch showing cross-strike nature of the late sulfide veins at Skytop



Pyrite veins deposited in fractures (joint set J2) that formed after the folding event (Alleghenian Orogeny, ~ 250 m.y. ago)

by D.P. Gold
June 1, 2004

A-12 Section Faults



Great Circle:
N = 1 ; first plane = 1 ; last plane = 1
Pattern = solid

SOME CONSEQUENCES OF OXIDIZING PYRITE

1. Production of Sulfuric Acid

2. Volumetric expansion with alteration of pyrite to Fe- sulfates

3. Reaction of sulfuric acid with and added carbonate “neutralizers” to form potentially lethal carbon dioxide gas

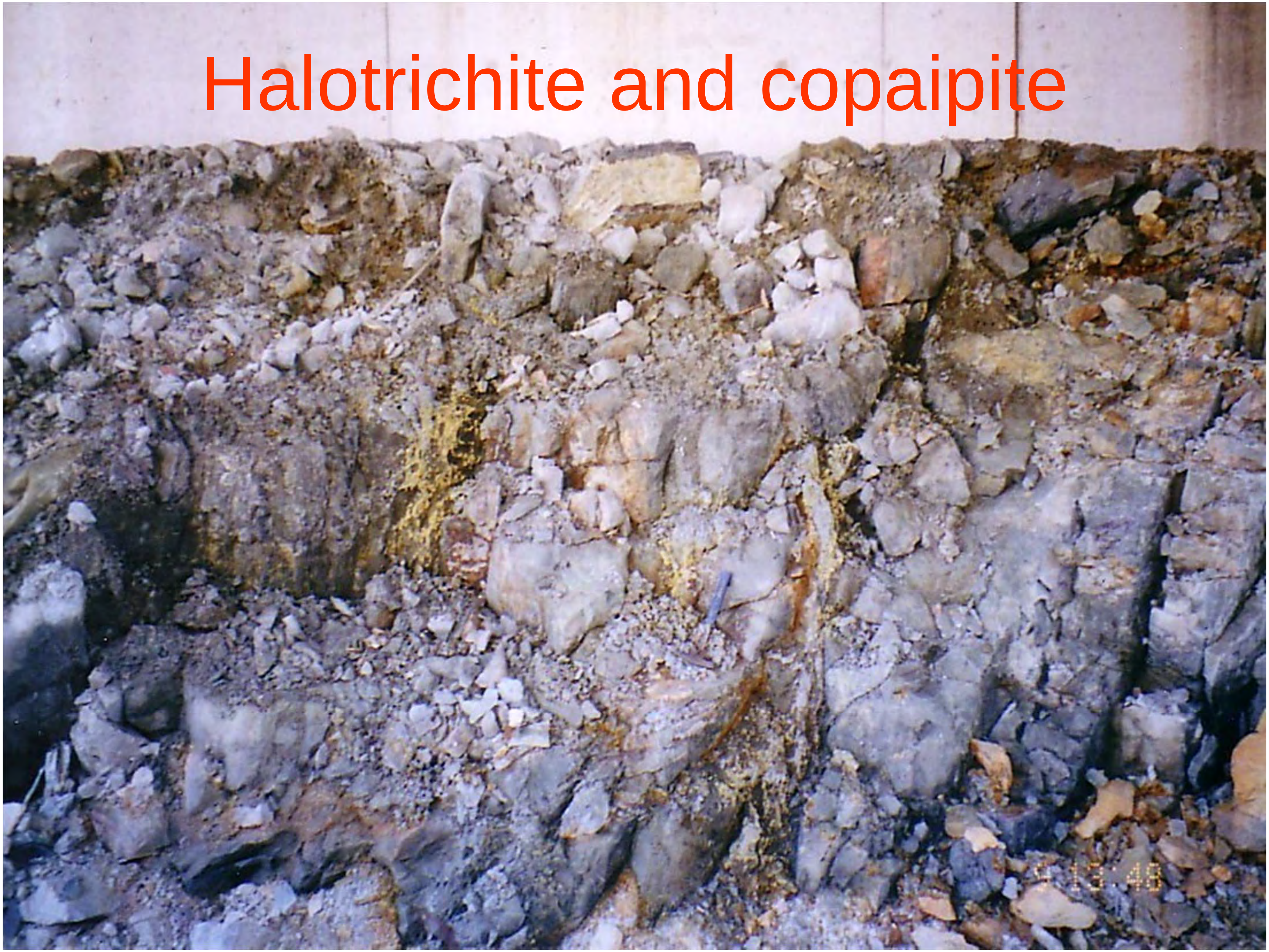
Evidence for sulfuricization activity

- Leached zone (Gossan) & “Oxidized Cap Rock” (OCR) (rainbow rock).
- Drop in pH in ground water and streams (increase in sulfates and iron).
- Drop in pH in acid weeps and seeps.
- Transient *Efflorescent* mineral “blooms” in vadose zone exposures (seeps and weeps).
- Efflorescent minerals on fresh sulfide exposures.
- Efflorescent minerals adjacent to “toxic” fill.
- Stressed vegetation.

Gossan

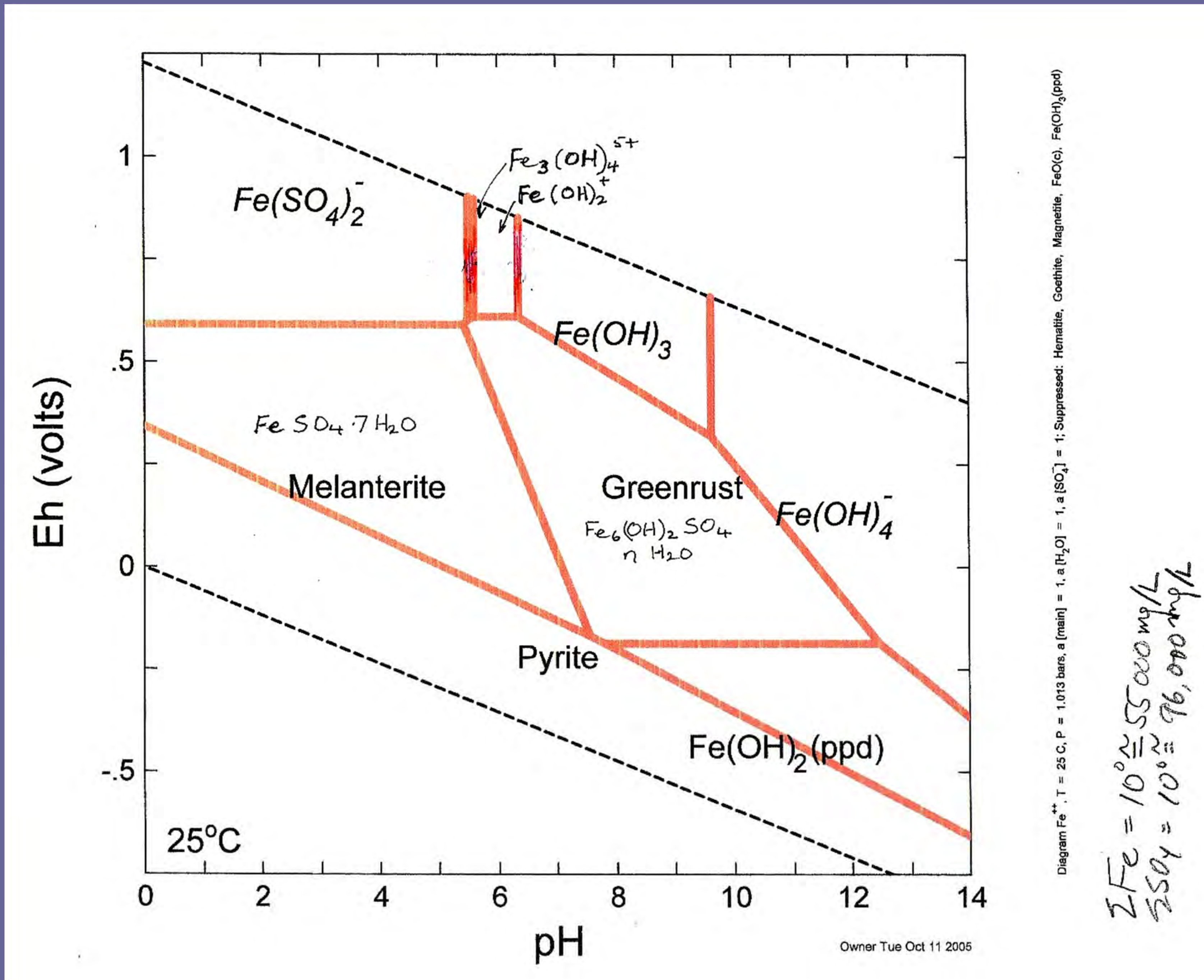
Melanterite ($FeSO_4 \cdot 7H_2O$) on pyrite veins

Halotrichite and copaipite

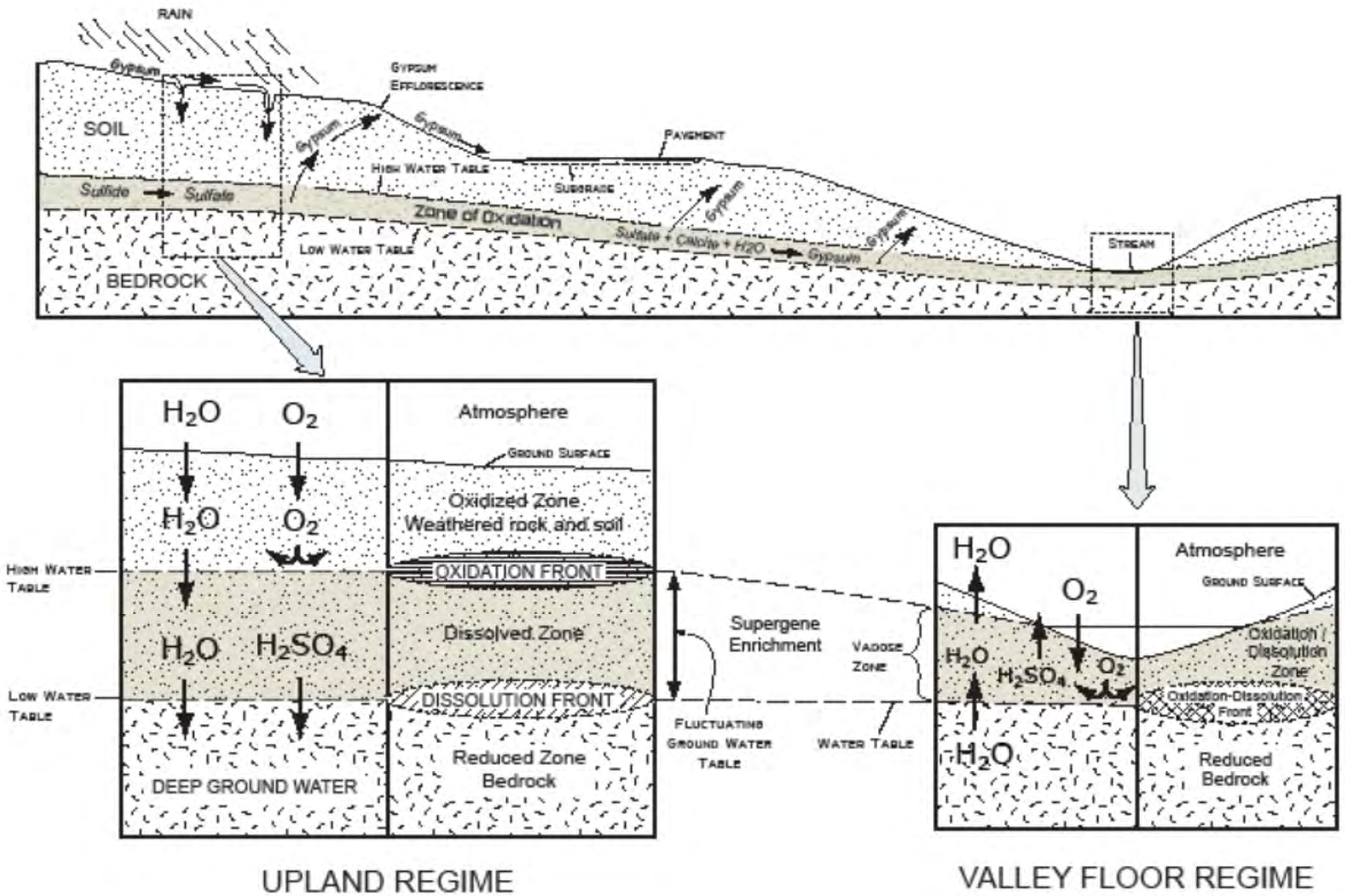


Melanterite and rozenite

REDOX Interface, with efflorescent copaipite


Eh (volts)
pH
1
.5
0
-.5
0
2
4
6
8
10
12
14
Fe(SO4)2-
Fe3(OH)4 5+
Fe(OH)2+
Fe(OH)3
Fe SO4·7H2O
Melanterite
Greenrust
Fe6(OH)2 SO4 n H2O
Fe(OH)4-
Pyrite
Fe(OH)2 (ppd)
25°C
Owner Tue Oct 11 2005
Diagram Fe++, T = 25 C, P = 1.013 bars, a [main] = 1, a [H2O] = 1, a [SO4--] = 1; Suppressed: Hematite, Goethite, Magnetite, FeO(c), Fe(OH)3(ppd)
ΣFe = 10^0 ≅ 55 000 mg/L
SO4 = 10^0 ≅ 96,000 mg/L

Conceptual Model of Supergene Sulfuricization



Model after Burkart et al. (1999), Chigma and Oyama (1999), and Fanning et al. (2002).

Remediation Material

- Must have neutralizing as well as buffering properties.
- Mass balance versus sequestration.
- Mass balance works only if:
  - mixing is rigorous,
  - similar grain size with particle to particle contact between reactants.
- Channelizing and gypsum armoring.
- *When Bag House Lime, containing* - Calcite ($CaCO_3$), Portlandite ($Ca(OH)_2$), Lime (CaO)

  Is saturated with water it forms highly alkaline slaked lime , with a pH > 12, that dissolves Al and precipitates alumina gel if pH is reduced

  (also dissolved zinc-coated drainage pipes).

Alumina gel – 3.59% Zn

Epsomite and calcite on bauxsol

Acid leach – 5024 Fill

REMEDIATION PLAN
IMMOVABLE PYRITIC ROCK

- Cover 2 bedrock cut faces with carbonate neutralizer mixes and geosynthetic textile
- Cover pyritic rock fill deemed "immovabe"
  - in elevated road bed (1 mile bifurcation zone)
  - and buttresses (to load toe of landslide in landslide prone area)

Estimated cost of $14 million

NB: Temporary PVC cover very effective

Buttress: BHL subcover

Buttress with dressed subcover

Little Cut Face Covered With Geotextile and GeoWeb, filled with #57 aggregate

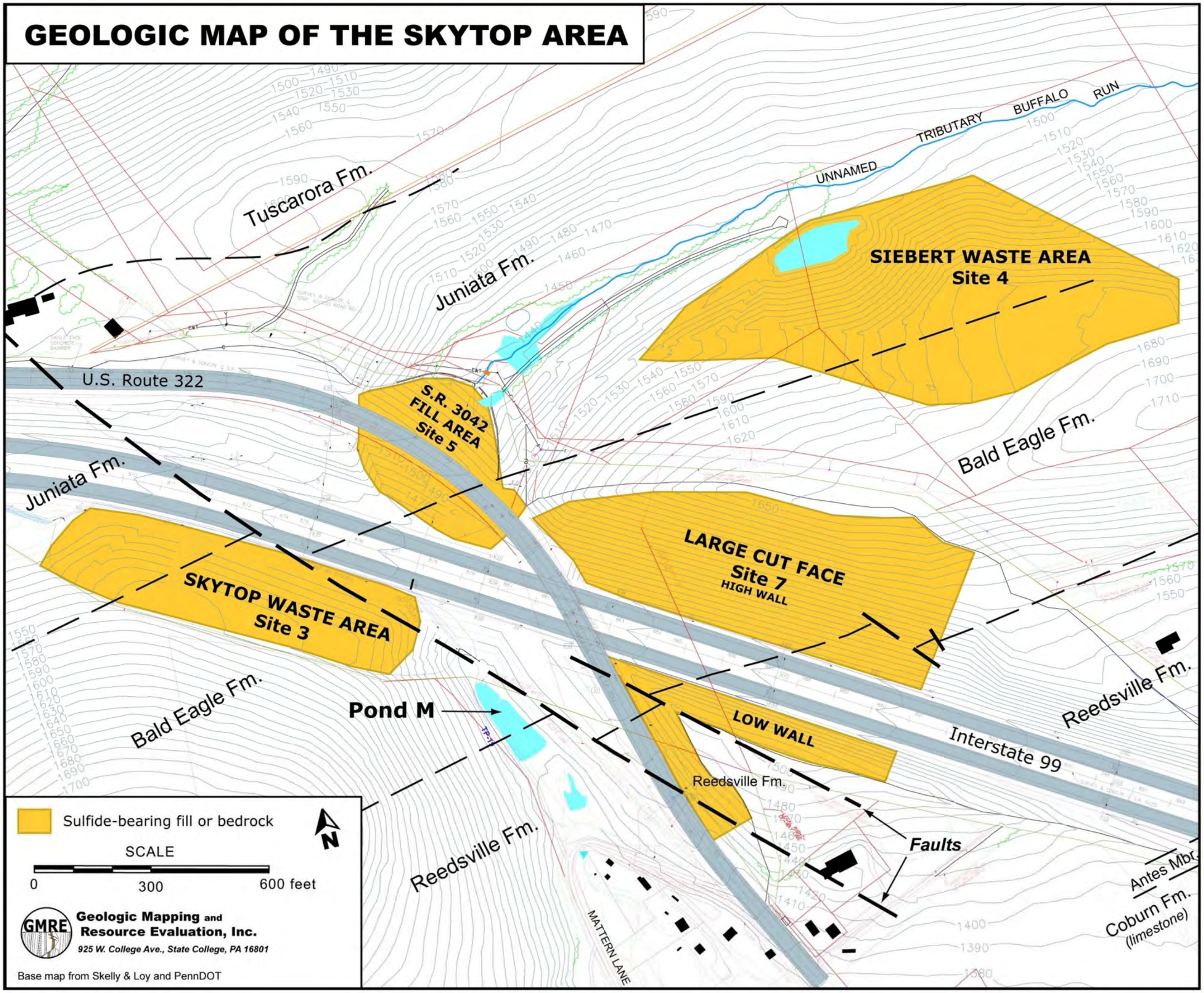
Geoweb, containing # 57 aggregate on dressed slope

Experimental Slurry on Redox zone in Tuscarora Quartzite and Shale

Little Cut-face covered with geoweb and aggregate July, 2011

REMEDIATION PLANS
MOVEABLE PYRITIC ROCK

- Legal imperative to move the pyritic waste dumps out of Buffalo Run drainage basin
- Develop an *Engineered Rock Placement Area (ERPA)* for approx 1 million tons of pyritic rock plus admixed Bag House Lime to 40 acre site near Port Matilda (*Dry tomb* concept with 23 acre footprint)
- Estimated cost of $26 million


GEOLOGIC MAP OF THE SKYTOP AREA
UNNAMED TRIBUTARY BUFFALO RUN
Tuscarora Fm.
Juniata Fm.
SIEBERT WASTE AREA
Site 4
U.S. Route 322
S.R. 3042
FILL AREA
Site 5
Juniata Fm.
Bald Eagle Fm.
LARGE CUT FACE
Site 7
HIGH WALL
SKYTOP WASTE AREA
Site 3
Pond M
LOW WALL
Interstate 99
Reedsville Fm.
Bald Eagle Fm.
Reedsville Fm.
Reedsville Fm.
Faults
Antes Mbr.
Coburn Fm.
(limestone)
MATTERN LANE
Sulfide-bearing fill or bedrock
N
SCALE
0
300
600 feet
GMRE
Geologic Mapping and
Resource Evaluation, Inc.
925 W. College Ave., State College, PA 16801
Base map from Skelly & Loy and PennDOT


Waste dumps
Siebert
3042
Skytop

Volumes of sulfide-bearing rock in fill or waste piles at Skytop

LOCATION	ESTIMATED TOTAL QUANTITIES CUBIC YARDS	ESTIMATED ACID ROCK QUANTITIES CUBIC YARDS
Trumbull Batch Plant	322,426	15,425
Bifurcation/Buttress	794,000	264,063
Skytop waste pile	99,114	93,114
Siebert waste pile	310,000	239,857
S.R. 3042 fill	137,725	62,100
Crushed rock pile in cut	28,187	28,187
Arbogast (pile/material on top)	11,317	11,317
Arbogast waste pile	433,521	27,291
Structure 317 fill	951,000	158,402
Sellers Lane fill	533,000	18,983
Blue Course Drive (off site)	52,528	To be determined
Total	**3,666,818**	**918,739**

27 Acre Footprint of Engineered Rock Placement Area (Dry Tomb)

ERPA near completion 6/11/08 (approx 3.8 m tons)

SEQUENCE OF EVENTS

1. Strike joints (J1) associated with Early Alleghanian folds.
2. Small clusters of pyrite in Bald Eagle Sst due to Late Alleghanian gas drive, (also reducted most of the red sandstone to its current grayish green color.
3. Late to Post Alleghanian cross-strike J2 joints (probably post-Palisadian).
4. Pyrite veins spatially related to J2 joints.
5. Re-Os age of 35 Ma for pyrite in NNE-trending fault zone is an enigma.

Geological Conclusions

- Timing – Post Alleghanian Orogeny: related to cross-strike fractures in lineaments.
- Depth from fluid inclusions – 5-10 km.
- Unroofing from fission track and vitrinite reflectance – 5-8 km.
- Main Veins in J2 joint sets.

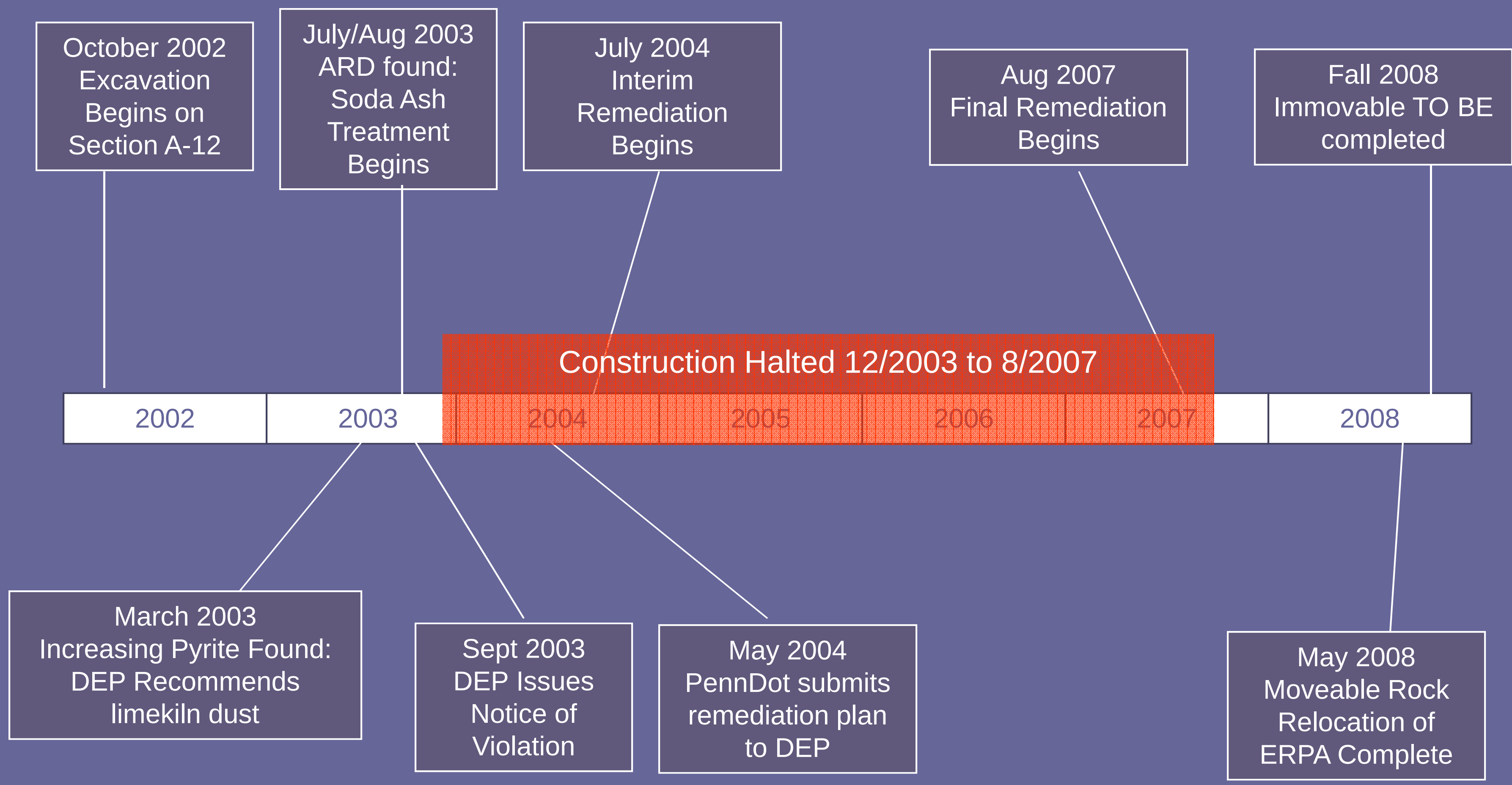
Conclusions

1. Need for inter-disciplinary interactions.
2. Nature and origin of sulfide mineralization must be known and understood.
3. An **Effective Sampling Strategy** is crucial.
4. Most effective remediation is to exclude either oxygen or water (preferably both).
5. Current “neutralizing” materials need re-evaluation (problem with “mixing” and armoring with gypsum and “yellow boy”).

Recommendations

1. Must understand geology prior to const-ruction, especially through wind and water gaps.
2. Avoid costly over-runs by “proper and adequate” characterization of excavated rock (mineralogical, chemical and physical) prior to redistribution.

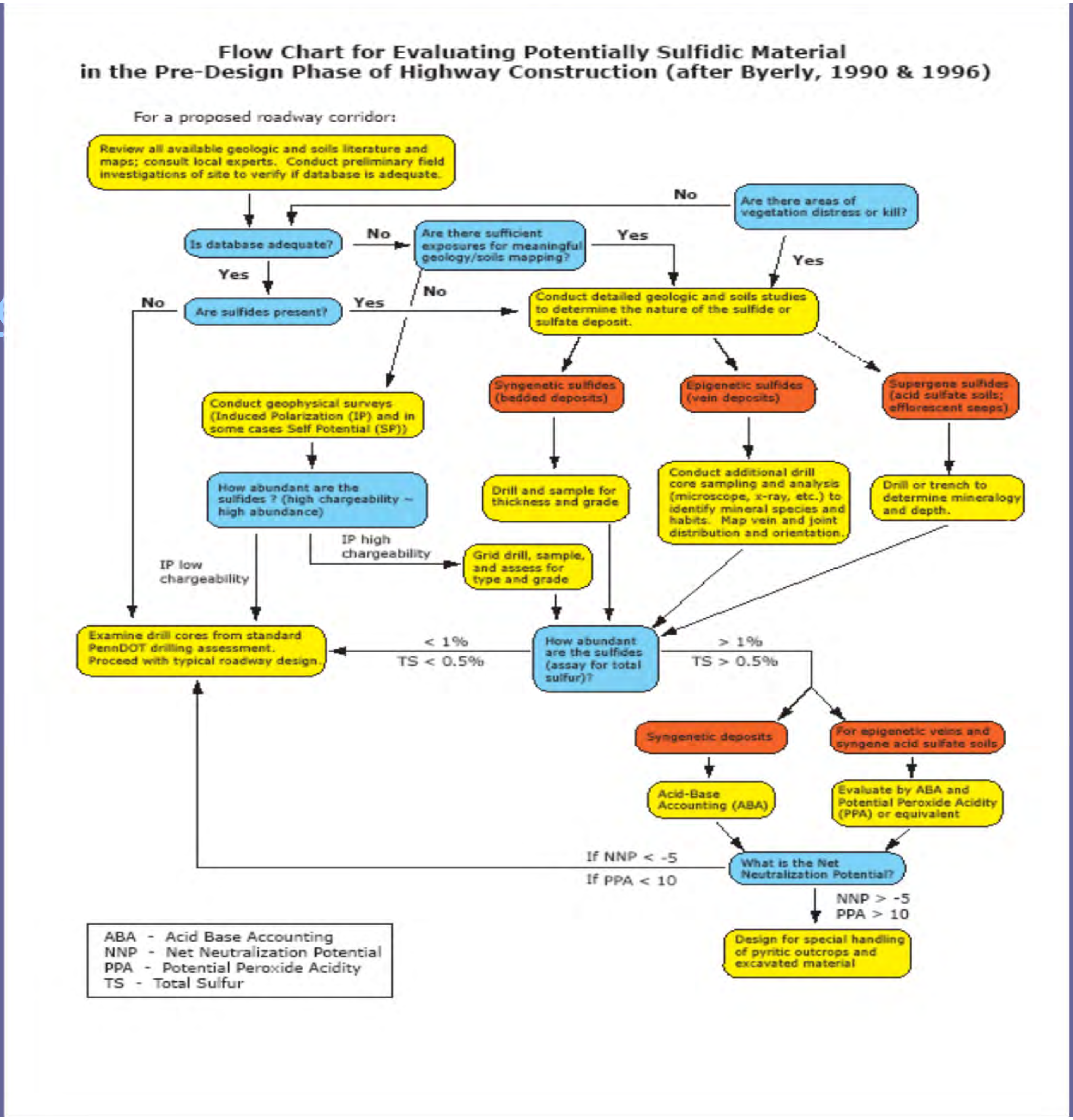
Timeline


October 2002 Excavation Begins on Section A-12
July/Aug 2003 ARD found: Soda Ash Treatment Begins
July 2004 Interim Remediation Begins
Aug 2007 Final Remediation Begins
Fall 2008 Immovable TO BE completed
Construction Halted 12/2003 to 8/2007
2002
2003
2004
2005
2006
2007
2008
March 2003 Increasing Pyrite Found: DEP Recommends limekiln dust
Sept 2003 DEP Issues Notice of Violation
May 2004 PennDot submits remediation plan to DEP
May 2008 Moveable Rock Relocation of ERPA Complete

Towards a Protocol

- Is database adequate? Unlikely – soles of the boot field work is cheap.
- If sulfur anomaly is identified, determine nature and type of deposit.
- Adjust sampling strategy and plan to determine – size, shape and grade.
- Plan excavation to minimize exposure of pyrite:
  - develop plan to neutralize and buffer or render inactive excavated pyritic rock;
  - develop plan to cover pyritic rock in bedrock cuts;
  - develop plan for long term water treatment.

- [Sulfide 4.pdf]



Acknowledgements

- PennDOT has been positively reactive in understanding the anomalous conditions at Skytop, and proactive in developing preventative protocols.
- Open File Reports available on PennDOT and PADEP websites: also at
- http//www:geosc.psu.edu/news/feature/gold/skytop.htm
- Amer. Soc. Civil Eng., 2008. Eastern Section, 23rd Proc. Paper 1. 23p.

Category 7: Landslide in inert colluvium