Egg-Crate Mine Subsidence – Adding LiDAR

Mike Dunn, OSMRE, Pittsburgh

Disclaimer

This reporting is based on very limited study of phenomena attributed to pre-World War II room-and-pillar mining of the Pittsburgh coal in Southwestern Pennsylvania. Applicability to other regions largely depends on whether they have similar conditions and mining histories. Because over 2 million people live and work in the Greater Pittsburgh region, nearly every mining feature has potential AML implications.

Introduction

- In 2006, AML projects in southwestern PA (an underground mine fire and a mine pool discharge) led two of us to independently discover “egg-crate” patterns over extremely shallow underground coal mines.
- In both cases, the fixes were more difficult and expensive than expected.
- Thousands of acres and people are “at risk” where similar conditions exist.
- Analog/digital Remote Sensing and GIS techniques offer potential for adding these areas to the AML inventory.

Identification –
The Fire

- Began when unmined coal caught fire from trash burning at the coal outcrop.
- The fire grew at a rate of feet/day, which is unusually fast for fires in old room-and-pillar mines.
- A site visit found the fire was under hummocky terrain resembling egg crate foam packing or mattress pads.

1270909
EXPLORER

Identification

The Fire (cont'd)

- Site characterization used all available maps and photographs for the worst-case scenario.
- Modern topo maps and aerial photos lack detail and don't show mining effects.
- 1973 Soil Survey maps area as "mine spoil."
- 1938 aerial photo show geometric pattern in the fire area.
- 1914 mine workings mirror this pattern, indicating water stress and/or almost complete subsidence.

1938 Aerial Photograph

1914 Mine Map

1938 Aerial Photograph

Identification

The Fire (cont'd)

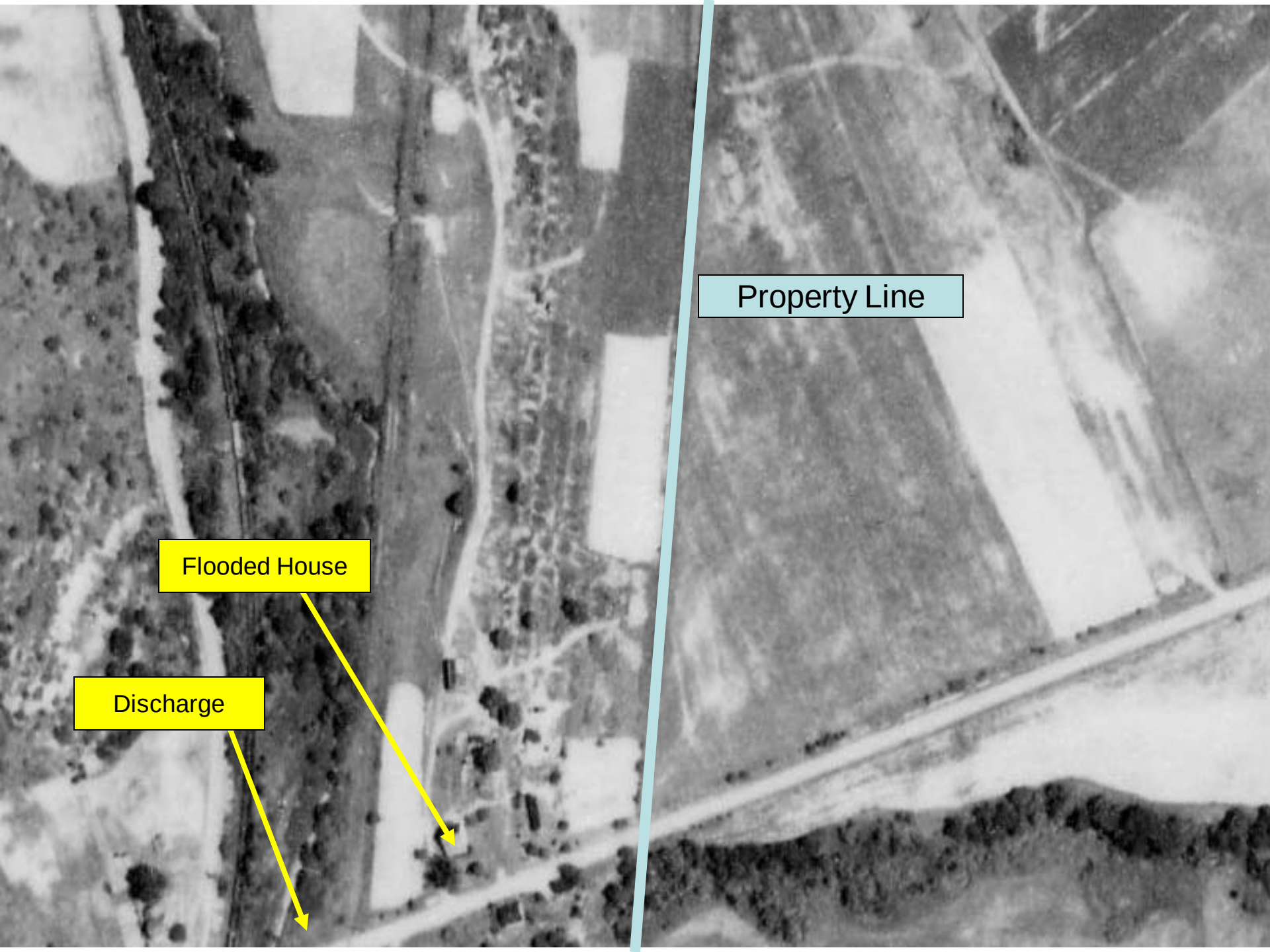
- At mine level, the cutoff trench and maps show that all mining was:
  - Advance only, no retreat.
  - Long rooms and long pillars; few crosscuts.
  - Shallow - less than 20 feet of cover.
  - In the weathered zone and often in the rooting zone.
  - Without any outcrop barrier.
- The trench also confirmed that near total subsidence had occurred.

CATERPILLAR
ONE CALL RENTALS
1 888 595-RENT
CAT Rental
CAT
315C L
CAT

Identification

Mine Pool Discharges

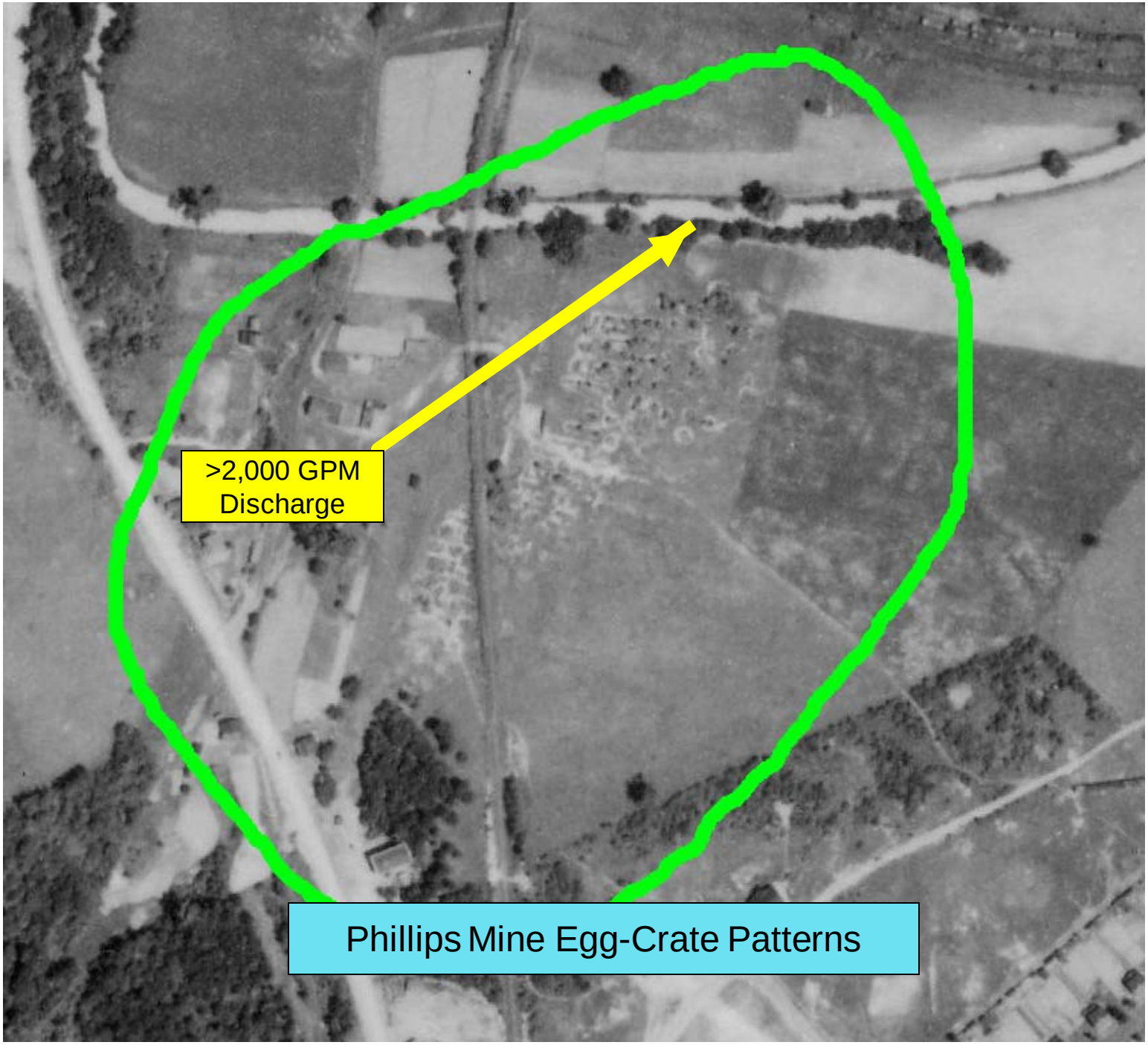
- Mine water flooding a house has been controlled but degrades the receiving stream.
- There's no mine map but adjacent maps and drilling indicate very shallow (<30 feet) mining from the outcrop to a property line. A 1939 aerial photo shows patterns similar to those over the mine fire.
- In the 1950's, an adjacent mine broke into the old works along the property line. The later mine is now part of a major mine pool that periodically discharges through the old mine directly toward the house.


Property Line
Flooded House
Discharge

Identification

Mine Pool Discharges (cont'd)

- Elsewhere on the same mine pool, shallow mining nearer the deepest part of the coal basin is allowing perpetual discharges of several thousand GPM.
- Control and treatment are unlikely in the near future. The outlets cover a large area, precluding consolidation; the sole discharge is just above stream level.


>2,000 GPM
Discharge
Phillips Mine Egg-Crate Patterns

Phillips Mine Discharge

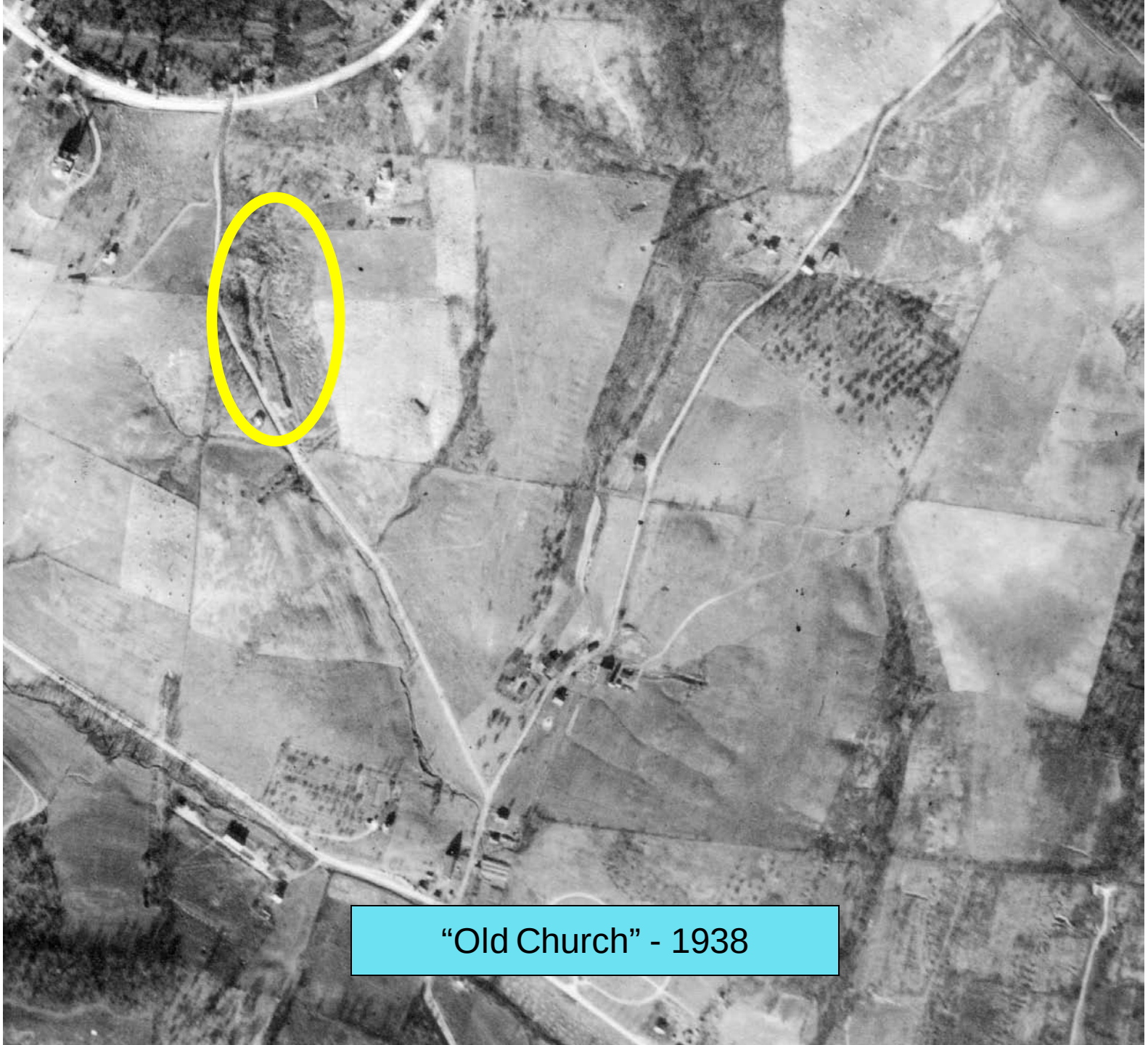
Identification

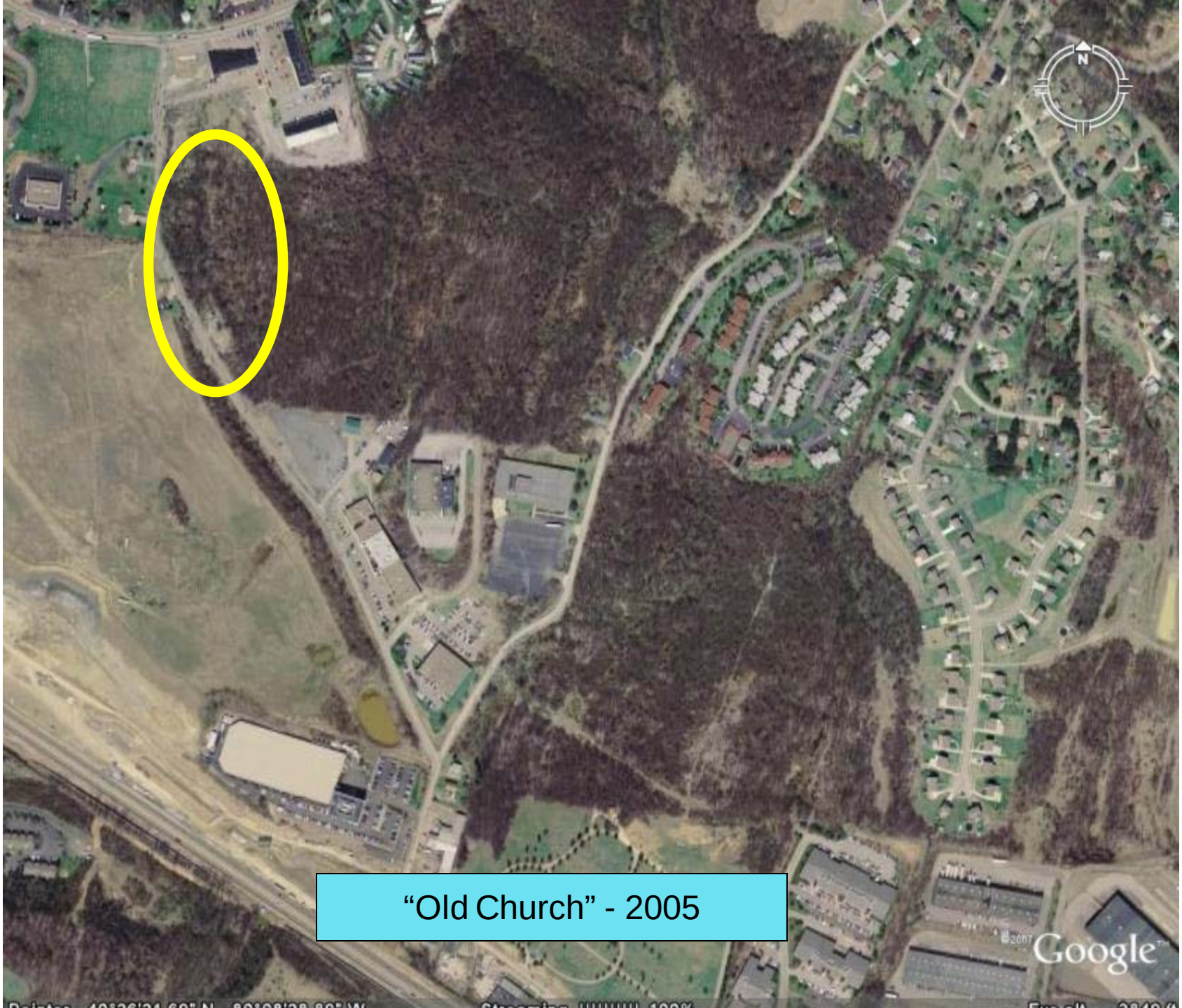
More Old Aerial Photographs

- Because the Pittsburgh Coal averages over 6’ thick and has been mined since the 1830’s, similar settings to those of the fire and the discharges were sought on the 1930’s photos.
- Dozens of sites were found and several were compared to recent high-resolution color aerials.
- While many sites have been obliterated by remining and development, a surprising number are intact and in unmanaged woodlands.
- Several examples, including pictures of recent visits follow:

Oakdale - 1938

Oakdale - 2005
© 2007 Europa Technologies


“Old Church” - 1938

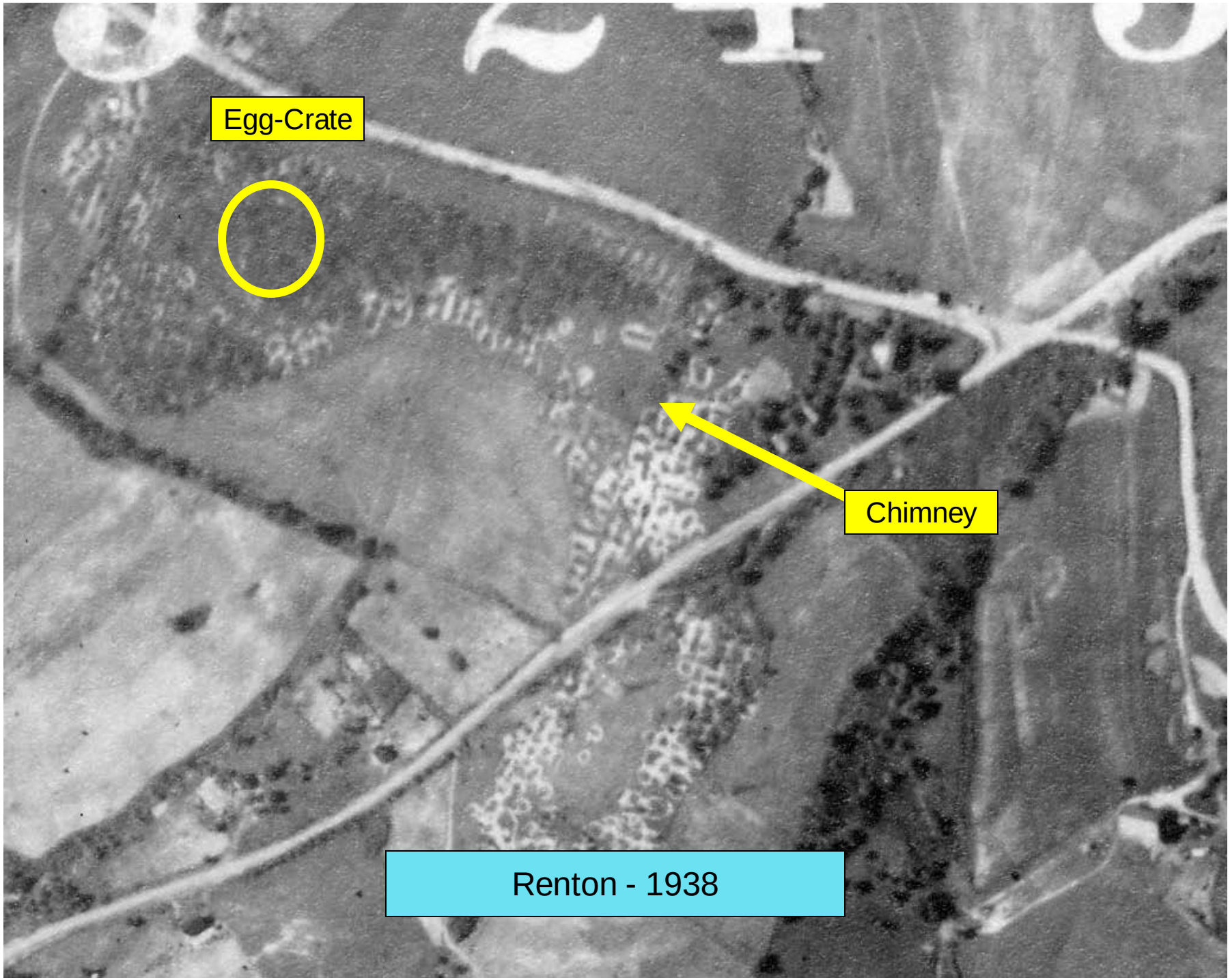

“Old Church” - 2005
Google

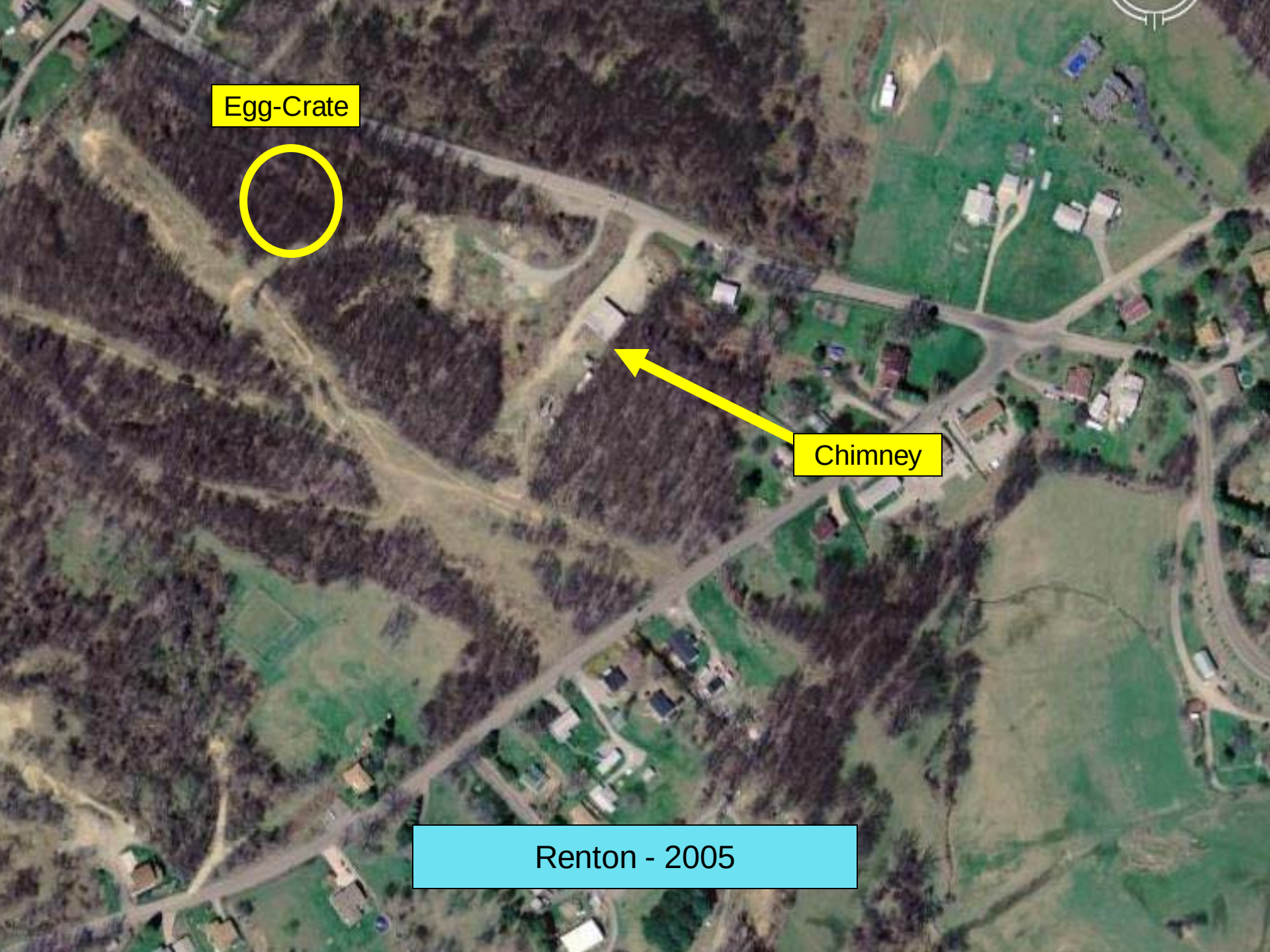
“Old Church” - 2007

“Botanical Gardens” - 1938

“Botanical Gardens” - 2005

“Botanical Gardens” - 2007


Egg-Crate
Chimney
Renton - 1938


Egg-Crate
Chimney
Renton - 2005

Renton, Egg-Crate - 2007

Renton, Chimney - 2007

Major Common Factors

- Thick coal
- Immediate roof in weathered zone
- Gentle to flat terrain
- Second mining rare (roof problems?)
- No crop barrier
- Widely evident in late 1930s

Some AML Problems

- Lots of fuel and air for fires
- Minimal resistance to water and gases
- Hazardous terrain
- Polluting, often diffuse, discharges
- Unknown extent

Is an Inventory Needed?
(No and Yes)

- The mine pool discharges and water pollution are long-standing, known nuisances that rarely become emergencies.

- Fires are another matter. If a fire starts in these shallow, fuel-rich areas, immediate and very aggressive control measures are essential. An inventory and maybe pre-characterization could easily pay for itself in savings on a serious fire.

Some Detection Problems

- Modern mapping seldom shows these features.
- Lost, non-existent, or low-quality mine maps.
- Obscured by scrubby, unmanaged vegetation.
- Obscured by development and farming activities.

Prototype Inventory
(Might Work, Might Not, Let's Try)

Despite the known problems, I think an inventory is very "doable" for some areas.

The ***TIPS*** Remote Sensing Team has selected topics for research:

- AML inventory of orphaned highwalls
- Acid mine drainage inventories
- Revegetation success in support of bond release
- Terrain change quantification
- Special status species habitat analysis
- LiDAR software evaluation and prototyping

The techniques expected to arise from the inventory studies coupled with newly available PA LiDAR products have potential for an egg-crate inventory.

Prototype Inventory
Data

- Of the sources used for the fire and mine drainage projects, only two “captured” egg-crated areas:
  - Vintage aerial photographs
  - USDA County Soil Surveys
- In Fall, 2007, LiDAR data and derived products for the Bituminous Region of Pennsylvania became available. With a working density of one point per 2 sq m, the raw data form a “point cloud” of every reflection that could reveal mining features even under dense canopy.

Prototype Inventory
Vintage Photography

PROs:

- Proven best source for open and lightly-treed areas
- Already digital and available
- Show water stress and depression shadows
- One-foot resolution

CONs:

- Not georeferenced
- Variable quality and flight attitude
- 2nd generation from original
- Lossy compression

- In their present form, these photos are eminently usable. With practice, anyone can recognize the stress/subsidence patterns and outline them in paint programs.
- There are ***TIPS*** tools for:
  - rapid georeferencing against standard digital products
  - Photogrammetry (topo map creation)
  - Outline, and possibly, “feature” extraction
  - GIS and modeling

Prototype Inventory

County Soil Surveys

PROs:

- Based on fieldwork and photointerpretation
- Largely fills pre-WWII/Present day gap (mid-1950's to 1980's)
- High quality photography and SP grid used for base maps
- Has been converted and standardized into GIS format (SSURGO)

CONs:

- High reliance on interpretation and interpolation between representative traverses
- Decreasing detail - trend from "splitting" to "lumping"
- No distinction between strip and deep mine damage
- Inconsistent terms
- Standards may have further blurred details

- The "CONs" sound really bad but the SSURGO product overwhelmingly offsets them by providing a digital "first cut" for GIS.

Prototype Inventory

LiDAR (Light Detection and Ranging)

PROs:

- Can pierce thick canopy and ground cover
- Precision avionics and GPS “stamp” every point with position and “metadata.”
- Fast collection and delivery
- Straightforward XYZ point clouds; no mysterious “ultraspectral datacube” dissectible only with the “inverse hyperbolic suckback function”

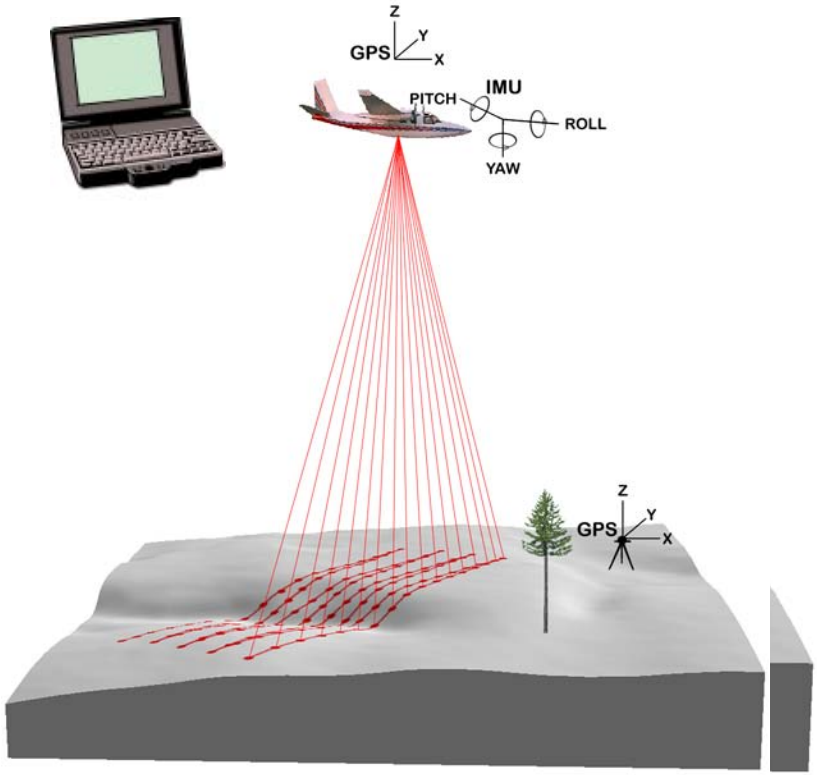
CONs:

- $$$
- Collects ALL reflections, including thick canopy and ground cover (and birds and cars and powerlines, etc., etc.)
- HUMONGEOUS datasets leading to storage and processing issues
- Processing software is $$$
- Cost of vendor-supplied standard products may be twice the cost of semi-raw point clouds

- Good news - several States are getting LiDAR coverage and will make the raw and finished data freely available.
- More good news – storage is getting cheaper.
- More, more good news - the ***US Forest Service*** and other agencies are developing “homegrown” processing solutions.

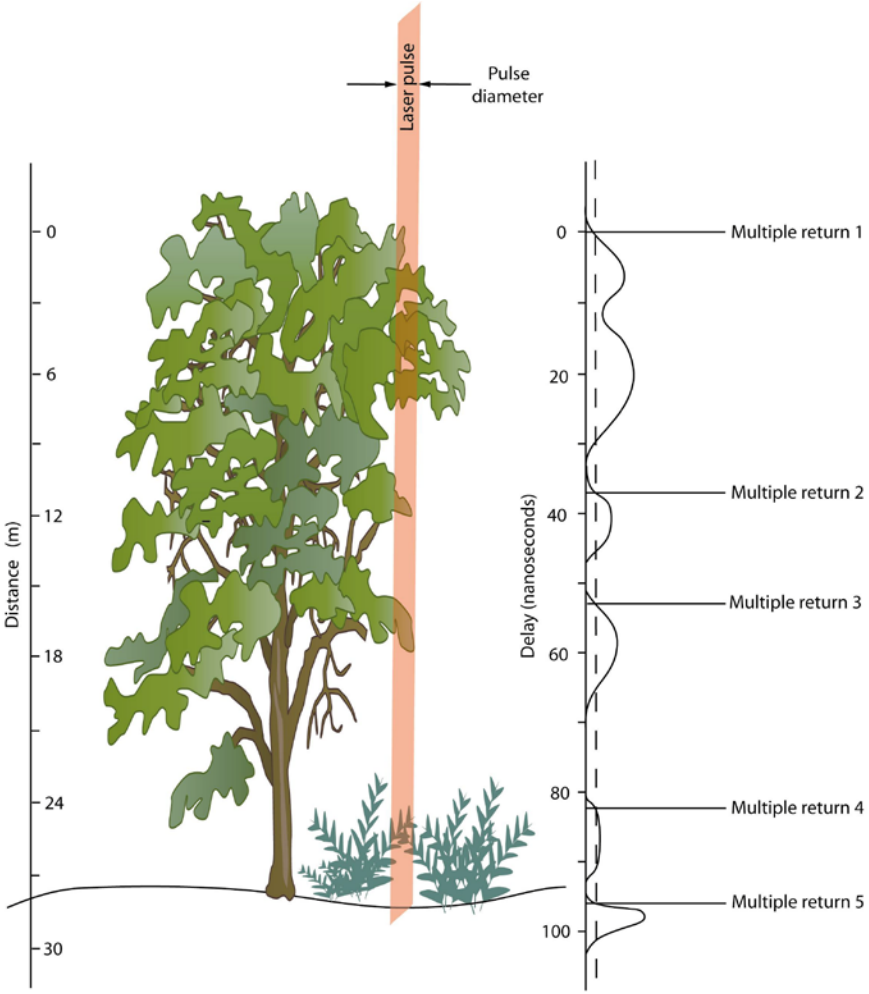
Airborne Laser Scanning (LIDAR) System Components

- Active sensor emits 40,000 – 150,000 infrared laser pulses per second
- Differentially-corrected GPS
- Inertial measurement unit (IMU)
- Computer to control the system monitor mission progress
- Interesting targets



Airborne Laser Scanning (LIDAR) Technology

- Acquires 1-5 reflections (returns) per pulse
- Typically 1 -10 measurements per m^2 or 4,000 – 40,000 measurements per acre
- Data delivered as XYZ points in a "data cloud"
- **<u>Direct</u> measurement of 3-D structure**
  - **Terrain**
  - **Forest vegetation**
  - **Infrastructure**



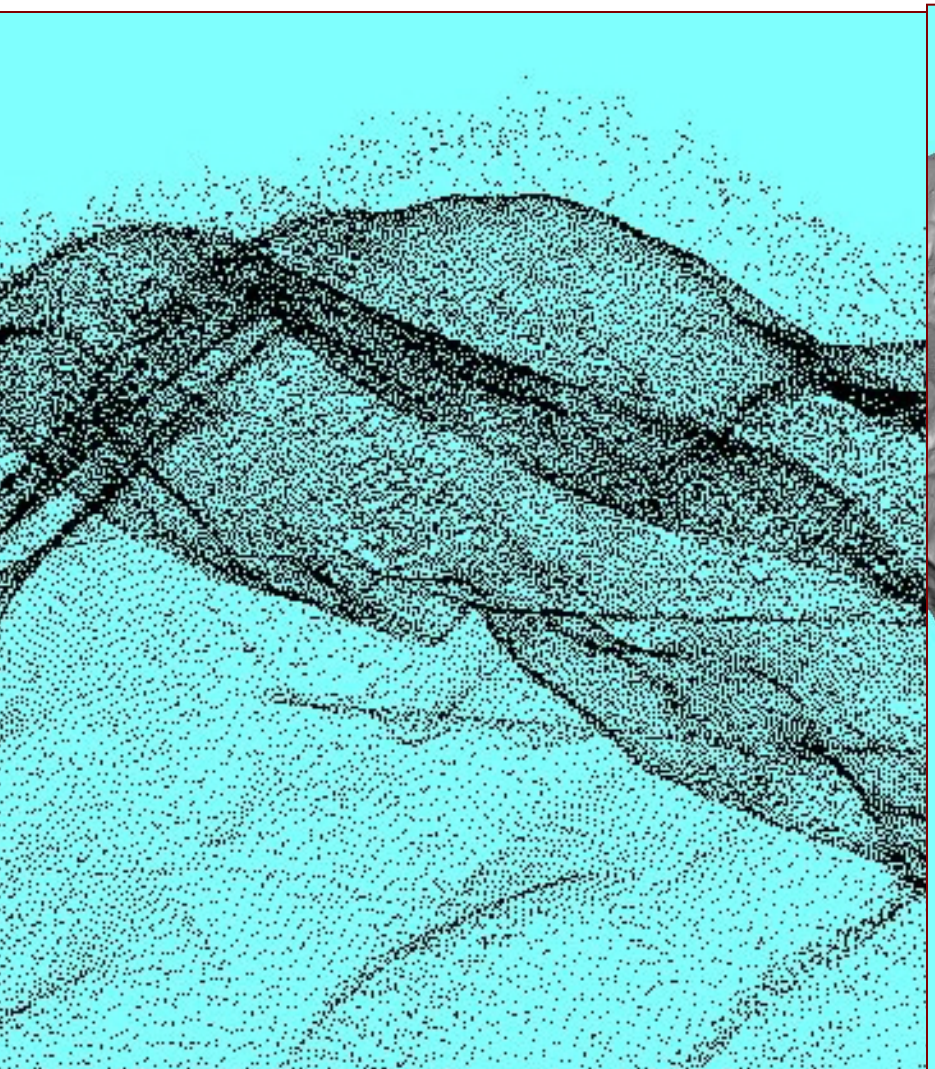
Adapted from Lefsky et al. (2002)

LiDAR

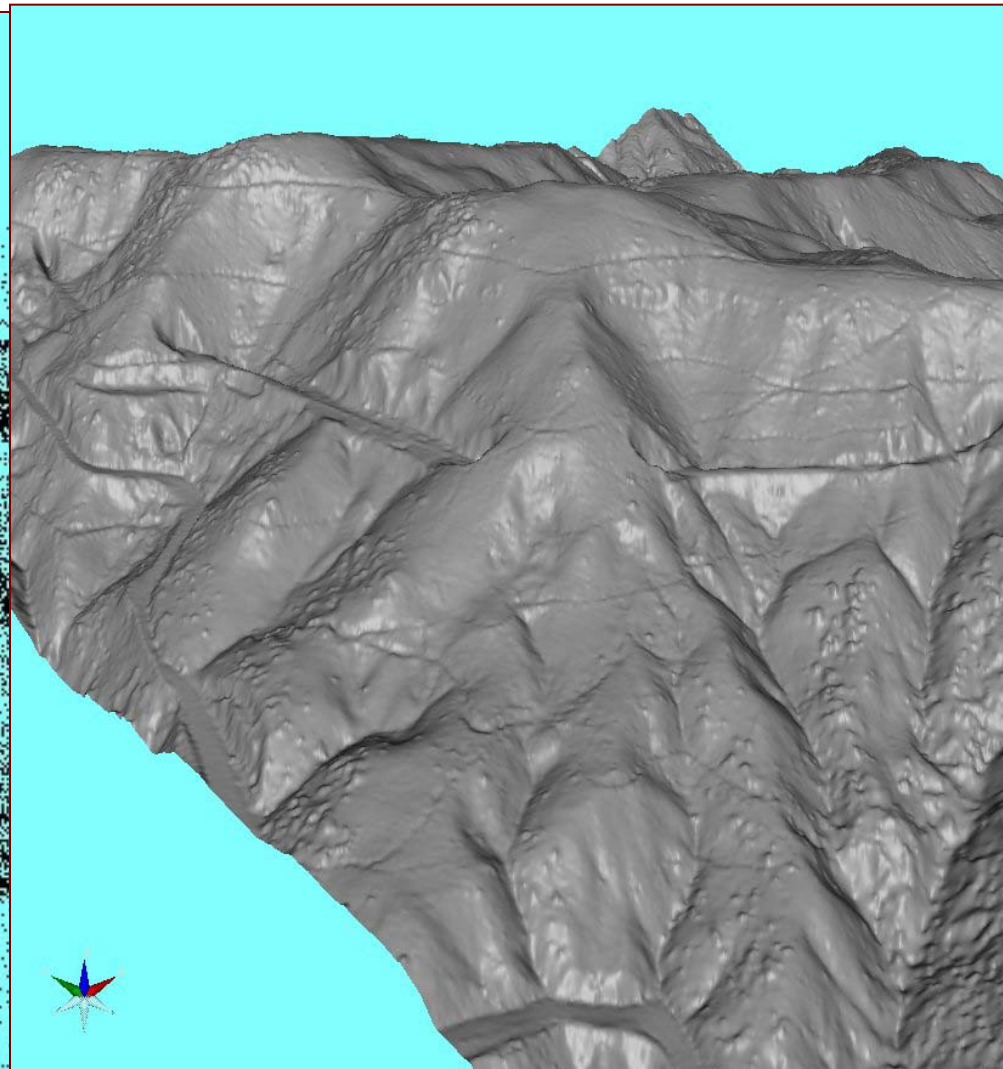
- The Forest Service solutions:
  - An ARC macro script
  - “FUSION” - a graphical interface and command line tools
- Both can handle millions of points.
- Both can filter for canopy and ground using different but tunable algorithms.
- FUSION has powerful tools for data subsetting, import/export, and creating “trees” from above ground returns.

Typical DTM from USFS Tools

Raw Point Cloud



Last Return Surface



What’s Next?

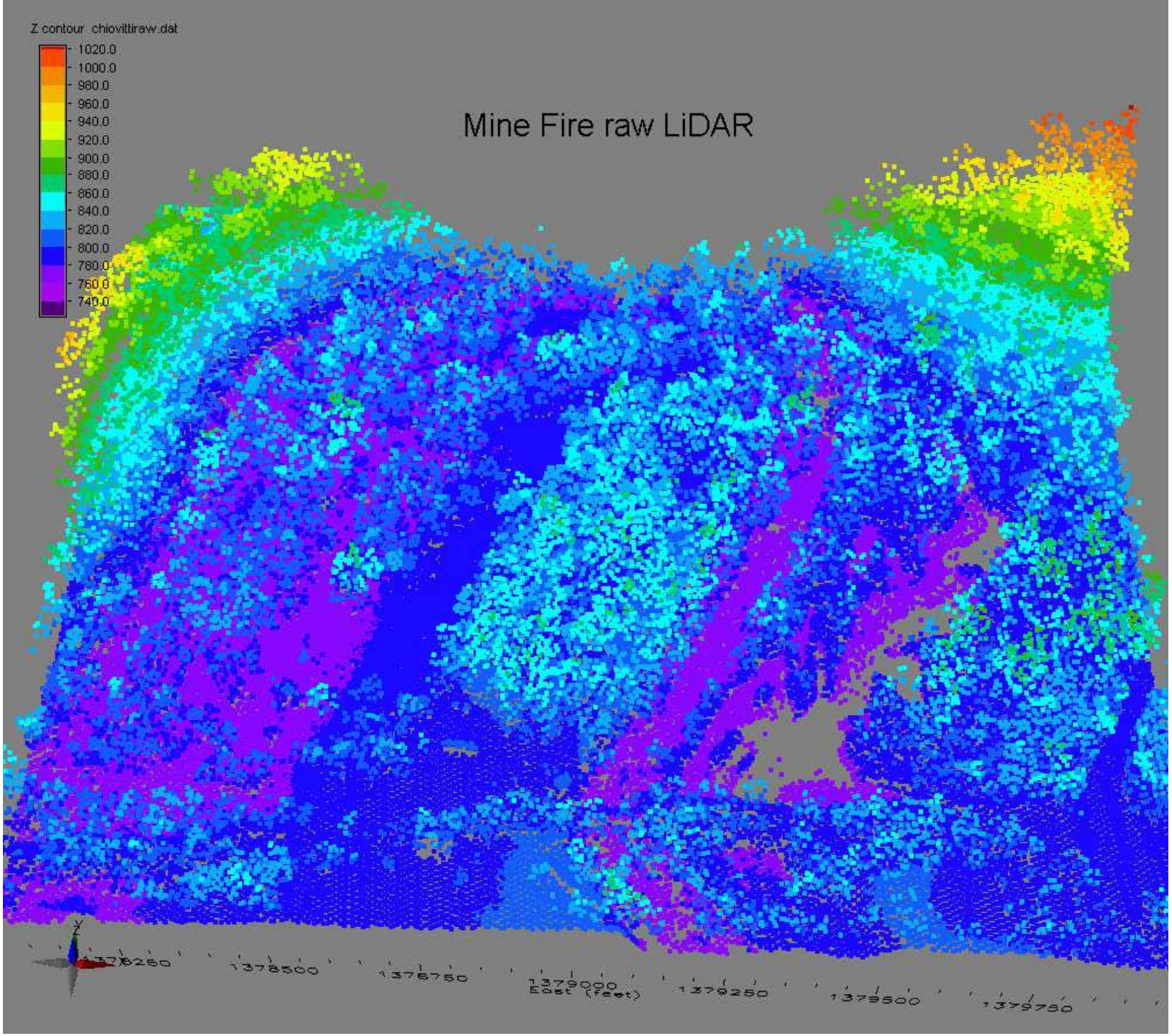
- “Beta” LiDAR data for the Pittsburgh region is available – both raw LAS and derived products:
  - DEM
  - Breaklines (mostly for road edges)
  - 2-foot contours
- The derived products are very good for larger areas but too aggressive for fine details
- Subtle features buried in LiDAR point clouds will include egg-crated ground and may be “extractable” using existing software.
- 8 to 10 egg-crated sites will be evaluated in detail to determine whether 2-meter LiDAR has value in an inventory.
- An expected finding is LiDAR’s feasibility for revealing old highwalls, benches, and coal refuse beneath dense canopy.

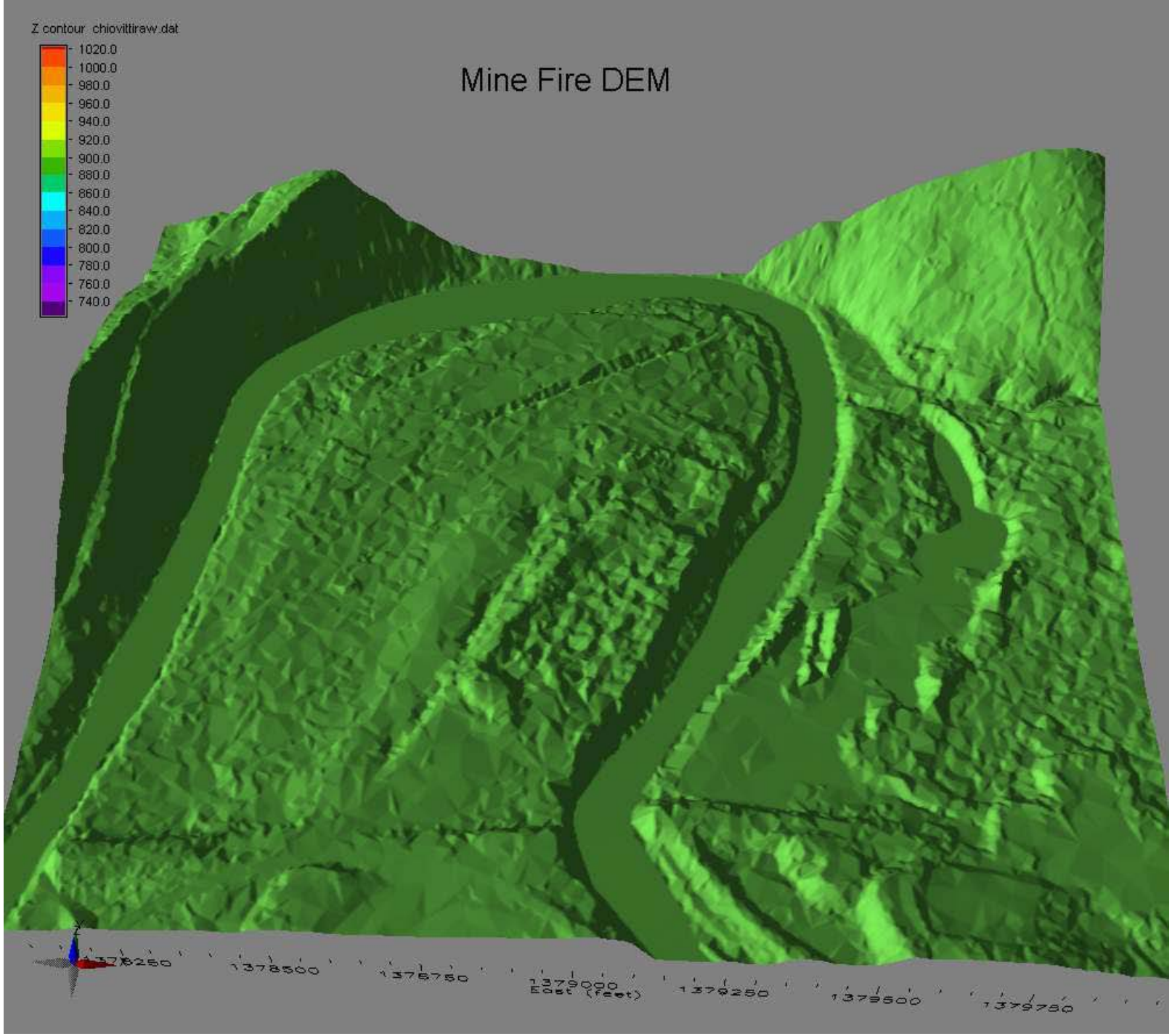
Old Photos vs LiDAR

"First Returns"

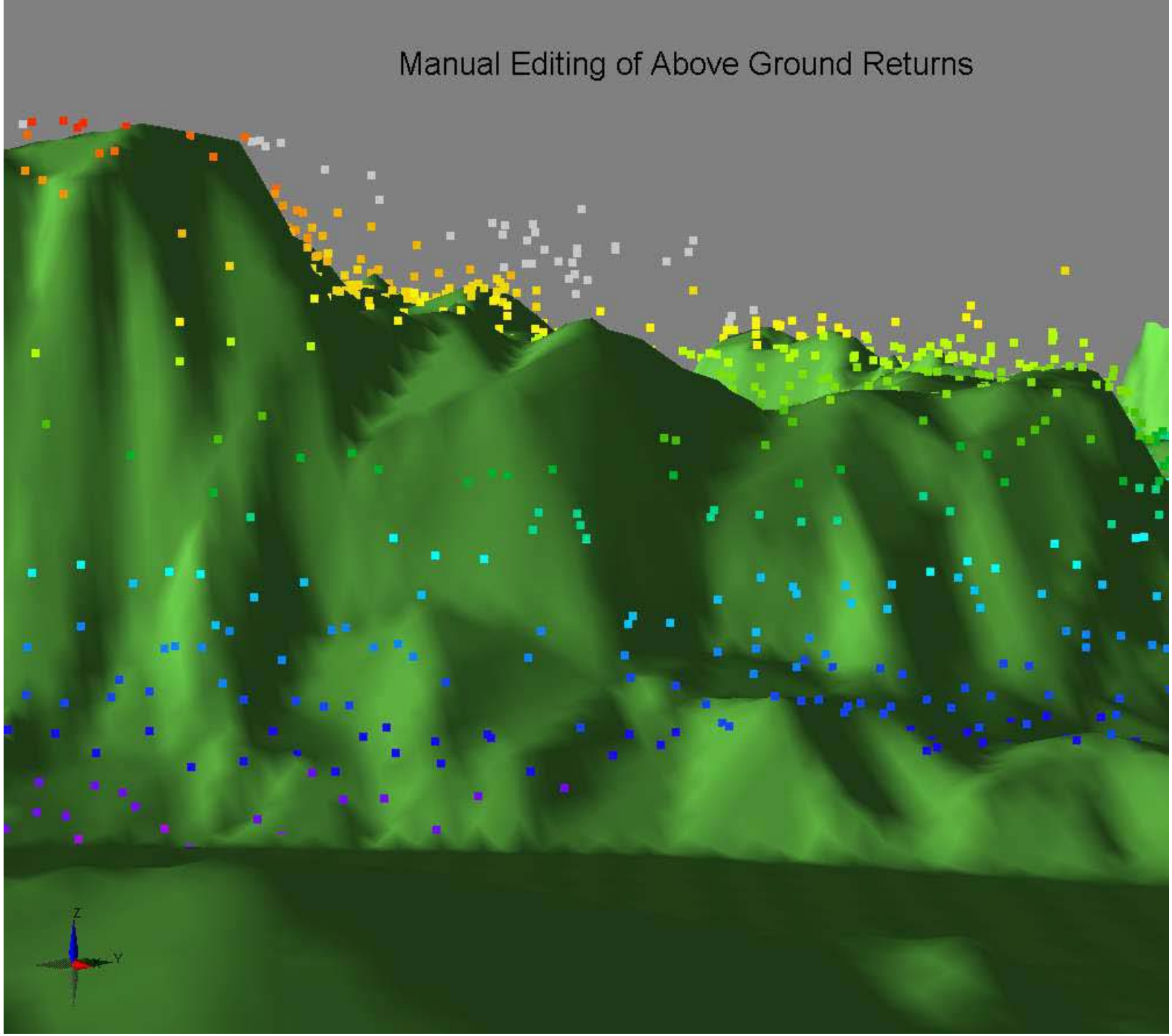
- The following slides revisit 3 of the sites presented earlier
- LiDAR raw data are extremely noisy and the derived DEMs rarely capture true bare ground.
- With careful editing to remove every non-earth point, far more detail survives

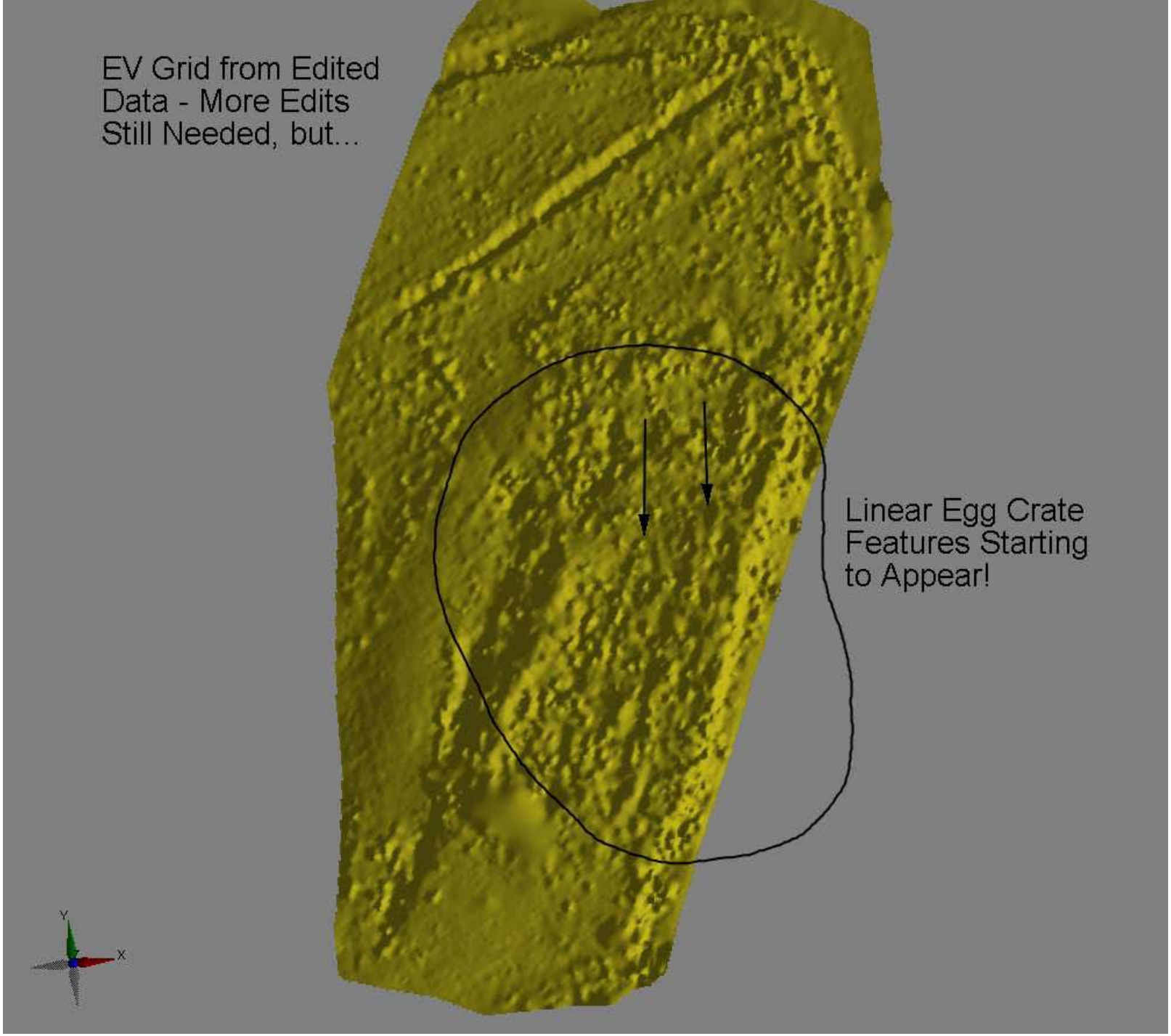
1938 Aerial Photograph


Z contour chiovittiraw.dat
1020.0
1000.0
980.0
960.0
940.0
920.0
900.0
880.0
860.0
840.0
820.0
800.0
780.0
760.0
740.0
Mine Fire raw LiDAR
1378250
1378500
1378750
1379000
East (feet)
1379250
1379500
1379750


Mine Fire DEM
Z contour chiovittiraw.dat
1020.0
1000.0
980.0
960.0
940.0
920.0
900.0
880.0
860.0
840.0
820.0
800.0
780.0
760.0
740.0
1378250
1378500
1378750
1379000
East (feet)
1379250
1379500
1379750

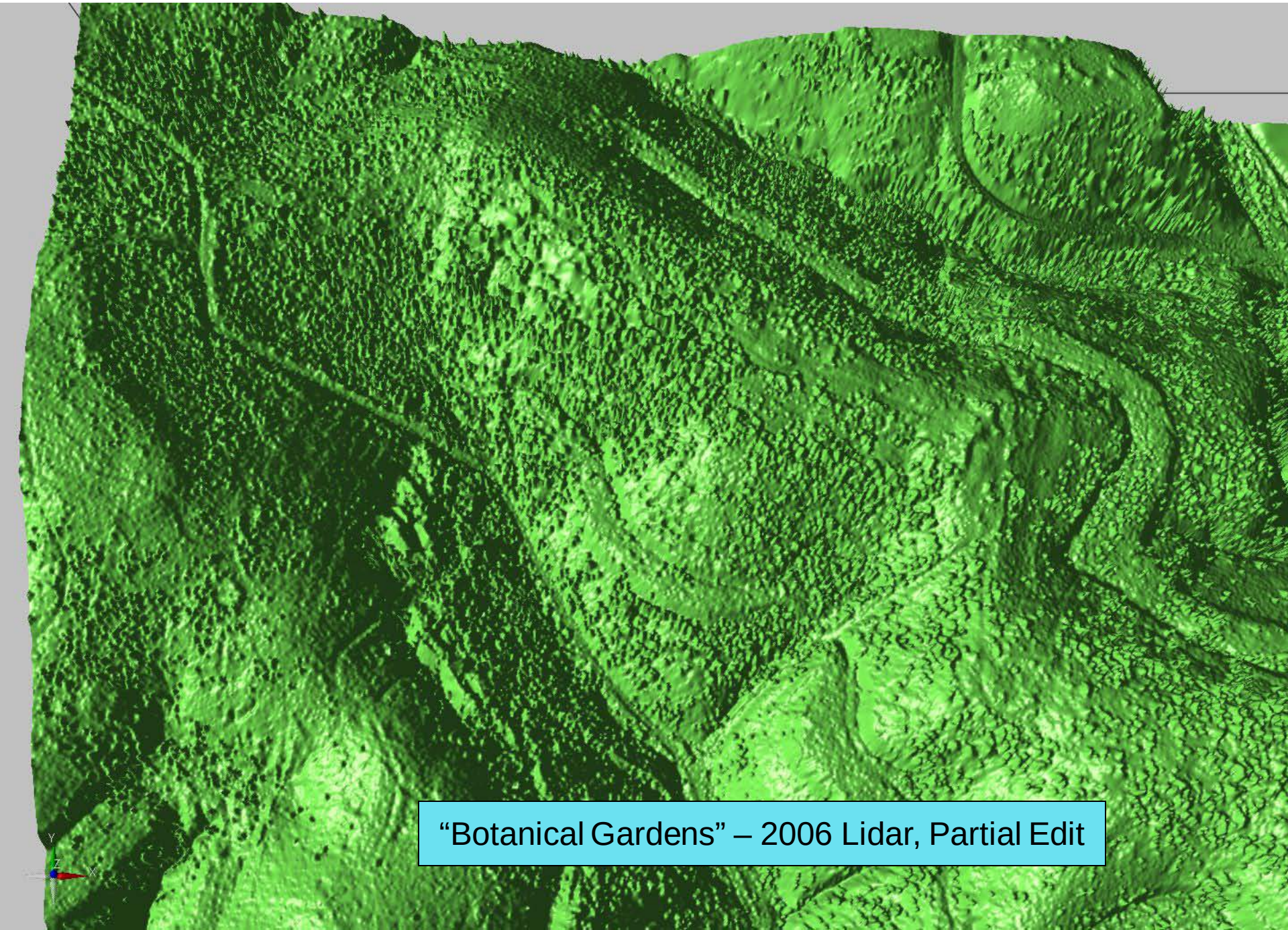
Manual Editing of Above Ground Returns

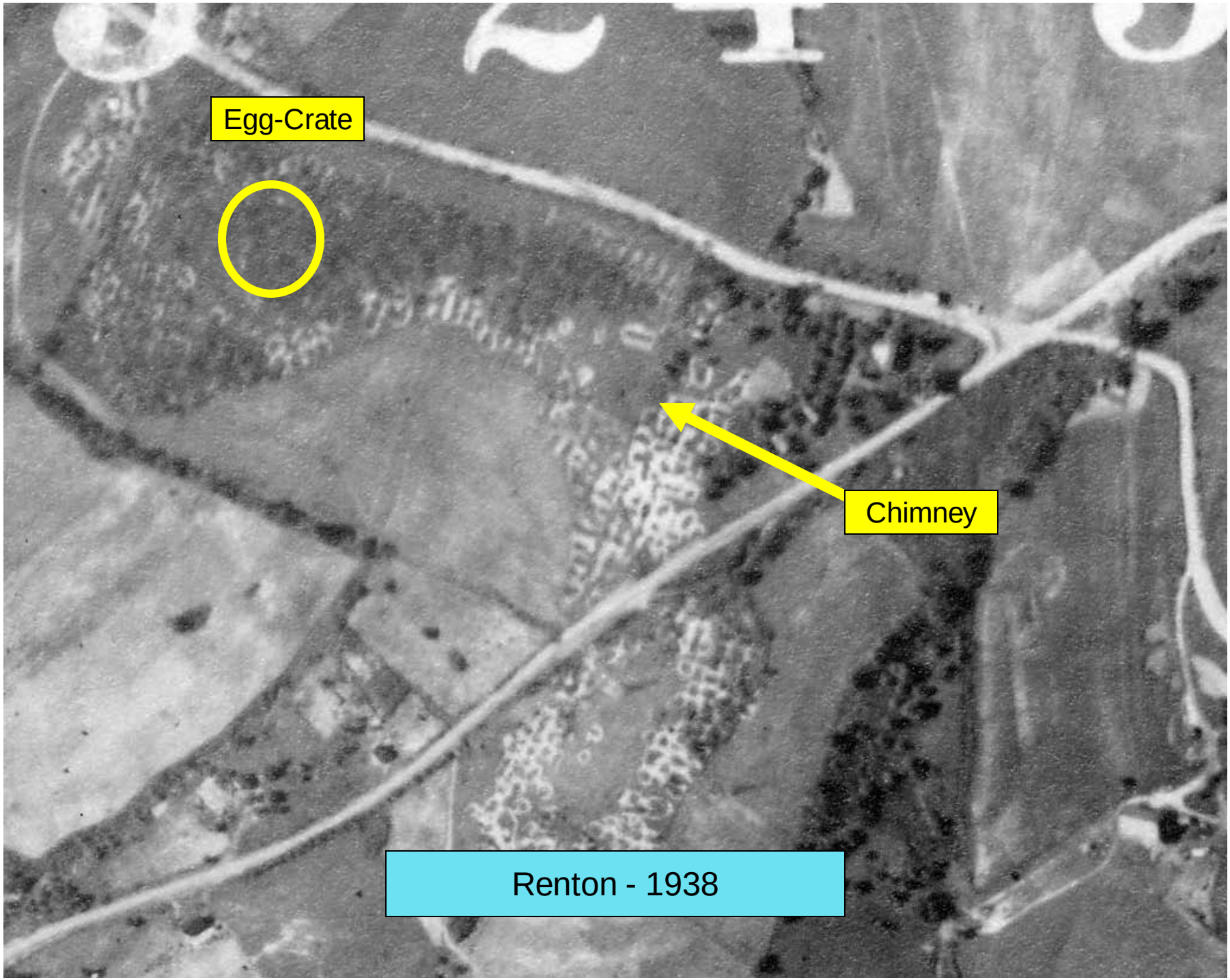


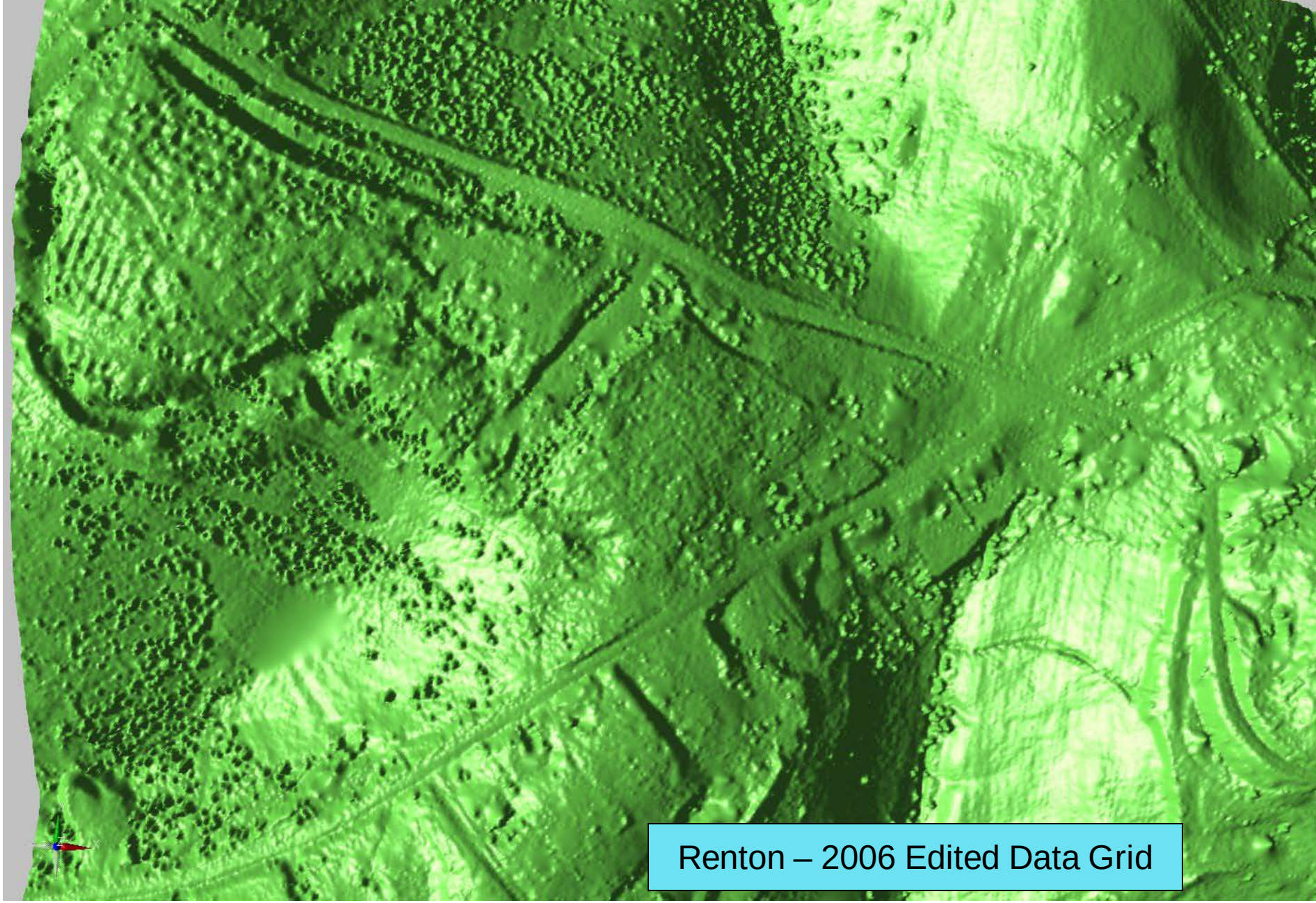

EV Grid from Edited Data - More Edits Still Needed, but...
Linear Egg Crate Features Starting to Appear!
Y
X

1938 Aerial Photograph

“Botanical Gardens” - 1938


“Botanical Gardens” – 2006 Lidar, Partial Edit


Egg-Crate
Chimney
Renton - 1938


Renton – 2006 Edited Data Grid

Adding LiDAR?

- First returns are encouraging even though rushed to get into this talk
- True ground is doable but potentially not worth the work for a meaningful inventory
- Other mass processing algorithms may produce better DEMs but truly believe won’t find anything better than the old aerials.
- Once again, stay tuned!