

Chapter 2. Structural, Tectonic, and Geospatial Aspects of the Sterling and Franklin Zinc Mines, Sussex County, New Jersey

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ABSTRACT

Computerized, architectural models of the New Jersey Zinc Company (NJZC) mines at Sterling Hill and Franklin, Sussex County were built for the 2025 GANJ conference and are being shared on the Internet. These mines hold rare and unique mineral species with respect to their fluorescent-mineral assemblages. Mine models were built using Trimble, Inc.'s SketchUp Pro (SUP) architectural software (ver. 2024), with some model features also exported as object models for display and manipulation in Google Earth Pro (GE). The models were built using plan maps and cross sections of the mine adits, drifts, cross-cut tunnels, and stopes that are held by the Sterling Hill Mining Museum, Inc. in Ogdensburg, and include geological aspects of other maps and documents kept by the New Jersey State Museum in Trenton. The models are used to interpret the structural and tectonic nature of these ore deposits in an effort to understand the where, when, and how they formed. The Sterling computer model is the most complete of the two, with the Franklin model including only a small portion of the information that is available.

“Where” the ore bodies occur was determined by registering the computer models in geographic space (WGS84) using SUP and GE and sets of reference buildings and roads on historical aerial imagery. The mines are located with estimated accuracies of ± 10 feet. “When” they formed is constrained by radiometric ages to the Middle Proterozoic (~1100 Ma), although multiple generations of mineralization have occurred. “How” they formed is the least understood, but this work supports a metasomatic replacement origin through fault-mediated ascent of the mineralizing fluids. Ferrous fluids were fed into a limestone and clastic sedimentary protolith by old faults that cut older gneiss intruded by hot, felsic plutons that were being sheared, folded, squeezed, and deeply buried. The Sterling Hill deposit includes a dike-like core structure striking ~N80E across the strike of metamorphic layering (~N20E) exhibits localized plasticity along its margins with adjacent, mineralized layers. This cross structure has also branched “cross members” leading from the core to mineralized zones lying above and below it. The zinc ore at the mines average ~20% bulk and locally exceeds 30% where layers are enriched in zincite.

This work also includes a digital method for determining geographical coordinates for mined features using north and west coordinate feet and the NJZC reference grid. The mine grid is rotated 19° clockwise from true north with respect to its origin point at zero ft north and zero ft west. This Microsoft Excel spreadsheet was programmed using trigonometric functions to convert mine coordinates into geographic latitude and longitude (WGS84). Please visit www.ganj.org/2025/data/ to access online data archived for this year's conference.

INTRODUCTION

This chapter covers structural, tectonic, and geospatial aspects of the zinc-ore bodies in Ogdensburg and Franklin boroughs in Sussex County as portrayed in historical mine maps, cross sections, and reports of the New Jersey Zinc Company (NJZC), supplemented by a week of field work. Virtual, three-dimensional (3D) computer models covering the NJZC Sterling and Franklin mines were built in 2024-2025 and are being shared for the 2025 Geological Association of New Jersey annual meeting. These models together cover about 300 surface acres, portray mine workings extending nearly one-half mile below ground, and are illustrated and explained below in detail following a brief overview of the historical and regional setting, and mineralogy (figs. 1 to 4). The Franklin mine was formerly called “Mine Hill” until 1897 and is located in Franklin, NJ (Dunn, 2002).

I met Michael (Mike) Di Maio, this year’s Geological Association of New Jersey (GANJ) president, for the first time at the 2024 GANJ conference and learned about the 2025 focus on the Sterling mine at Sterling Hill in Sussex County, New Jersey. Upon also learning that Mike is a mine guide for the Sterling Hill Mining Museum (SHMM) in Ogdensburg, I expressed enthusiasm for this Highlands theme as I’d previously been in the mine before it closed in 1986, had descended to the -1850-foot level in one of the elevator cars on its inclined west shaft, and had helped move and store many boxes of rock core collected by NJZC during mining operations just prior to the closure. Some of the boxes were trucked to the Rutgers University warehouse for rock core while others were kept by the New Jersey Geological Survey (NJGS), my employer at the time. The NJGS lot was eventually transferred to Rutgers where they also now reside. Robert (Bob) Metsger, the mine manager and chief geologist of the NJZC had arranged the site visit and core-transfer work that took a couple of days with the crew of six field mappers and Richard Dalton, the bureau chief of geology and topography. It was the first operational mine that I had been in, and I remember thinking how warm, stark and dark it was at depth. To think that these were the everyday conditions for men working twelve-hour shifts impressed me with a sense of awe and respect, for what they did was naturally perilous.

Now, almost forty years later, with my continuing interest in the structure and tectonics of the New Jersey region, I asked Mike Di Maio if it were possible to get access to the cache of mining maps generated by the NJZC and now held by the SHMM to build a detailed model of the ore body to advance our understanding of the structure and tectonics of a famous zinc deposit, now known worldwide for its rare, fluorescent minerals. With Mike’s help the museum agreed to my request, and immediately shared the set of twenty-six level maps (-180 ft to -2550 ft) of the Sterling Mine by the end of October 2024. Mike, Jim Peterson, and I soon after spent half a day inspecting the open cuts at Sterling Hill for the first time, including the Passaic and Noble pits (fig. 3). I had yet to see the large saw cuts made shortly before closure of the Sterling Mine in 2017 by contractors hired by the SHMM on behalf of the American Museum of Natural History in New

York City to extract thin slabs of the zinc ore for display using ultraviolet light. These cut across a southeast-dipping ore pillar and provide visual insights into the ore petrology and genesis (fig. 4).

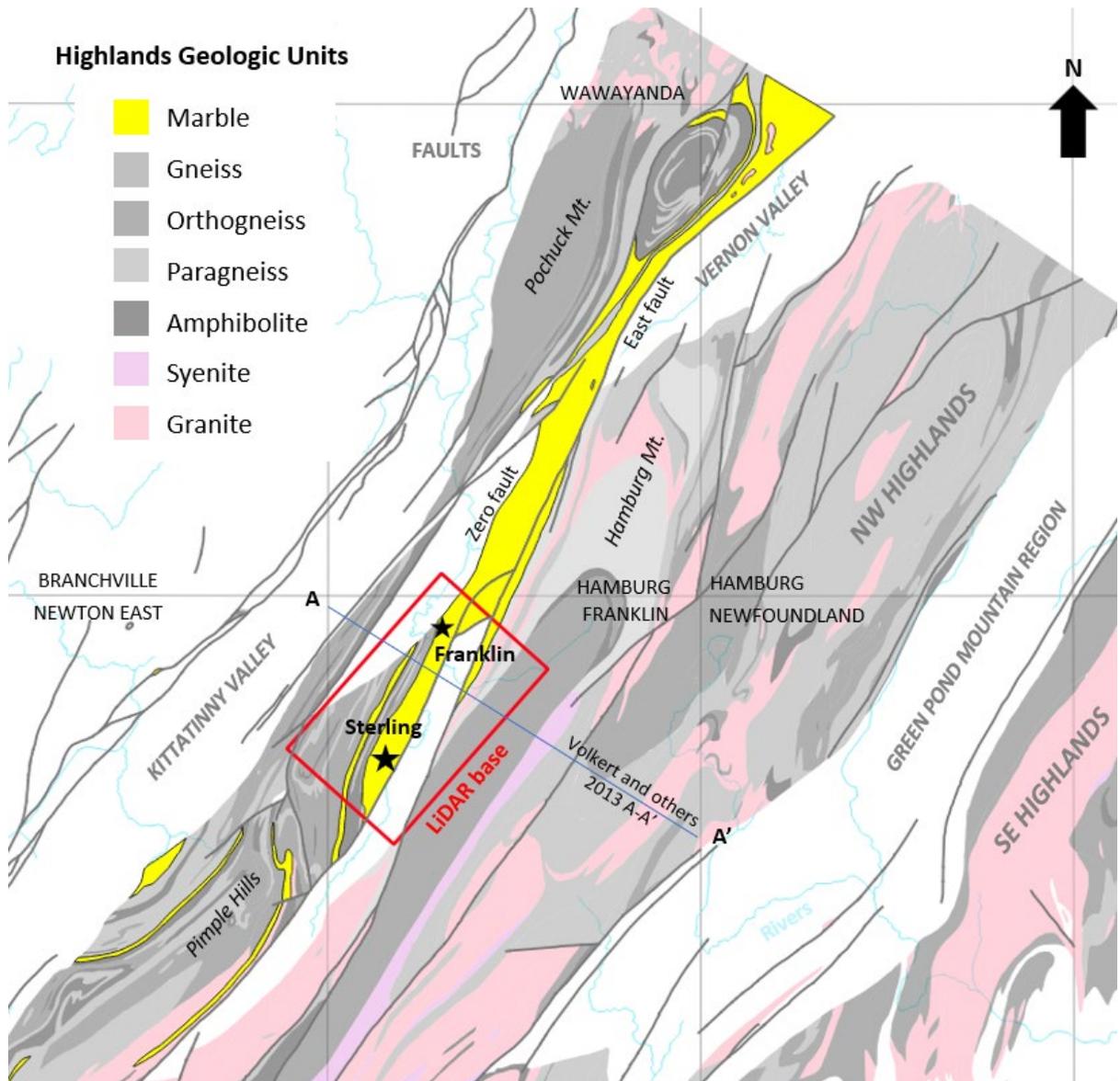


Figure 1. Generalized bedrock geology of the northeast part of the New Jersey Highlands with Mesoproterozoic marble highlighted yellow and the locations of the Franklin-Sterling Hill ore bodies noted. The map trace of a bedrock cross section is shown along with prominent physiographic and structural features. Field notes in Mesoproterozoic bedrock were collected near cross section A-A' in 1985 during my first year of employment and the NJ Geological Survey shortly before the Sterling Mine closed.

After assembling preliminary versions of the Sterling mine model using Trimble Inc. SketchUp Pro (SUP) software, the study was then expanded to include the adjacent Franklin Mine in order to portray both ore bodies and place them into a uniform, digital, geospatial and structural context for the first time (figs. 2 and 5 to 7). Because the Franklin Mine was added later, and because it is a uniformly dipping layered sequence that is truncated and segmented by faulting, only part of that model was developed with certain components that were selected to adequately portray its extent and represent the structural nature of the ore body. For this report I depart from primarily using metric distances as the mine workings are based on the standard foot measure which is also followed herein, with only limited use of metric units.

Following is an explanation of the methods used to convert and integrate the analog mine maps and stope sections into 3D models generated by computer processing. The 3D digital model

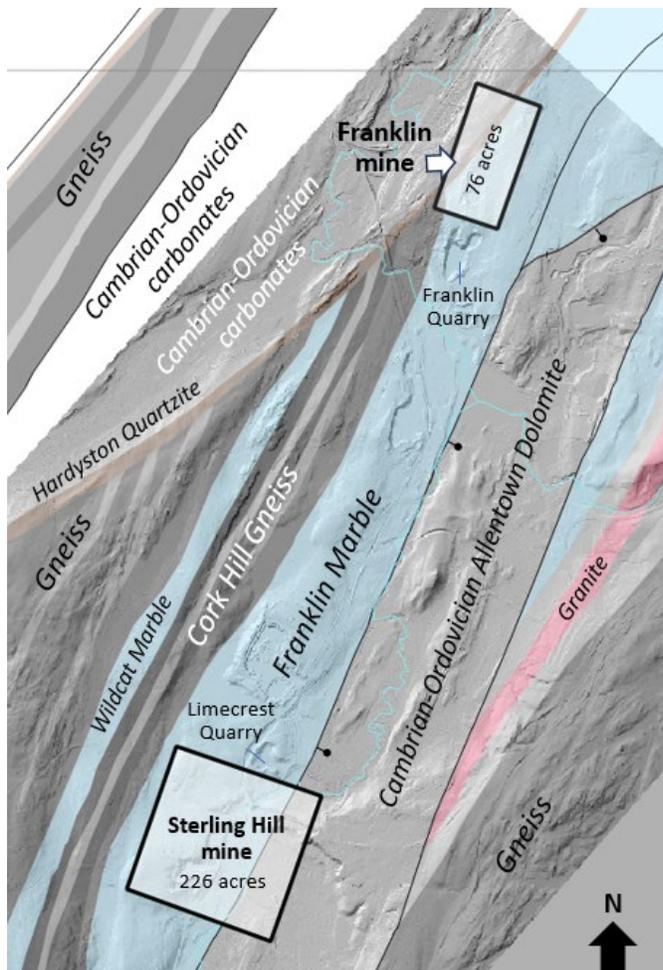


Figure 2. Bedrock map of the study area covering the Sterling Hill and Franklin mines. Balls and sticks placed on downthrown fault blocks.

of Sterling Mine includes over 35 miles of tunnels following the ore bodies to a depth of 2,675 feet. The subsurface modelling was complemented by six, half-days of field mapping around Sterling Hill and Franklin with colleagues to see the remaining visible mine infrastructures and outcrops showing geological structures. This effort therefore uses precise underground records and surface outcrops to help decipher complex structural elements within the repeatedly tectonized Precambrian Highlands of northern New Jersey (fig. 8).

After one year of planning, discussions, field mapping, seeking resources in institutions, and building digital models, I am herein reporting the results and sharing the models online.

GEOLOGICAL REVIEW

The ore bodies at Franklin and Sterling Hill are unique and among the most concentrated zinc deposits in the world. According to the US Geological Survey (USGS) National Minerals Information Center, zinc is the 23rd most abundant

element in the earth's crust (~ 70 ppm average) with similar concentrations for copper (~ 60 ppm), and nickel (~ 84 ppm). By comparison titanium (5650 ppm or 0.56%) and iron (~ 5.6%) are far more abundant. Three principal ore minerals occurring at Sterling Hill and Franklin are the oxide minerals zincite (ZnO) and franklinite ($ZnFe_2O_4$), and the nesosilicate willemite (Zn_2SiO_4). Recognition of this unusual ore as a profitable commodity in the late 18th century led to litigation over mineral rights in the 19th century that forced a more thorough scientific understanding and definition of ore and the methods to produce it (Dunn, 2002). The consolidation of mining rights and interests with the founding of the NJZC in 1897 enabled successful production afterwards until closure in 1986.



Figure 3. A Google Earth Pro historical image (2002) showing the Sterling Mine site and some notable features. Reference buildings outlined in red were used to aid in georeferencing imagery and other geospatial themes.

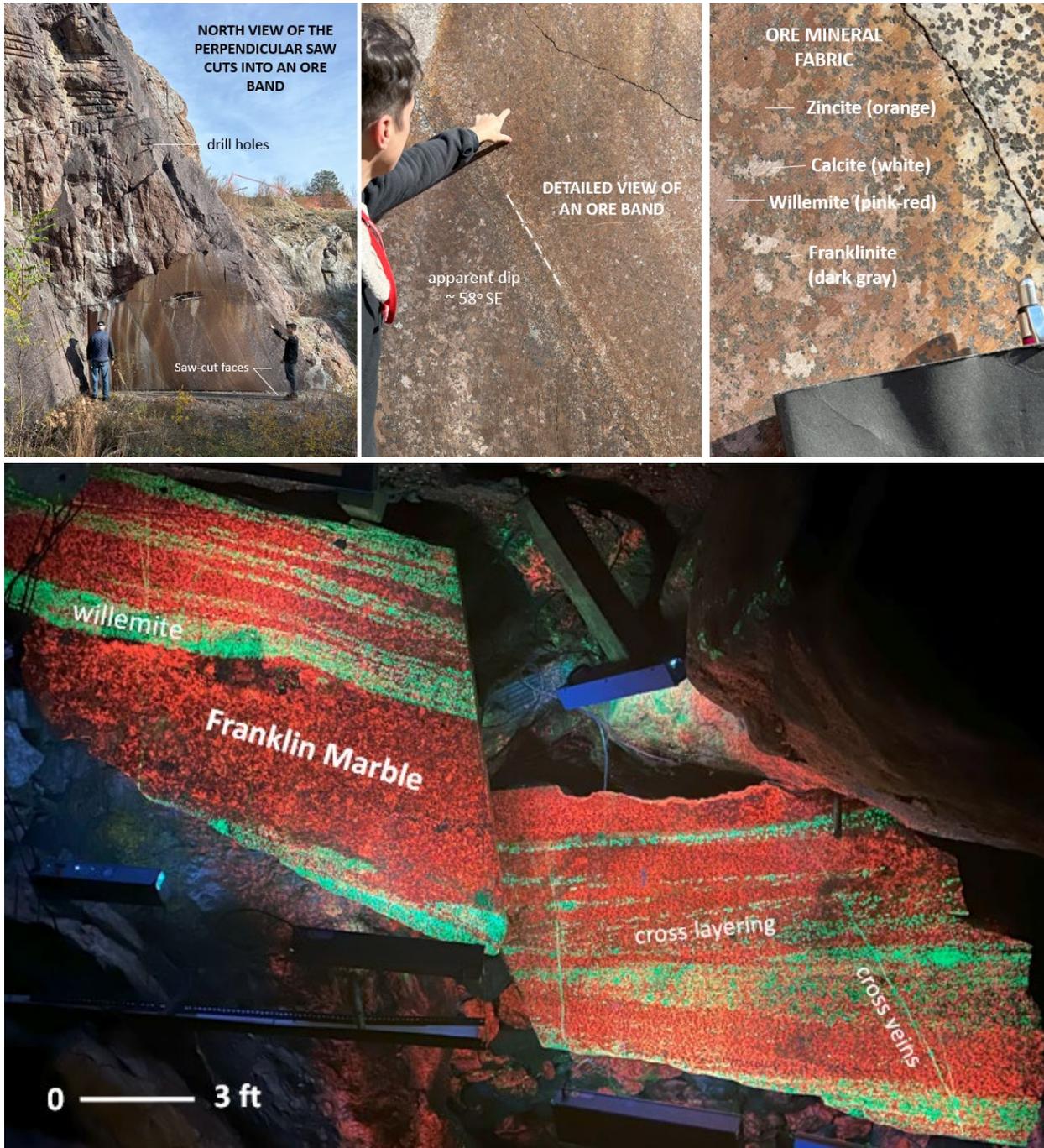


Figure 4. Rock slabs from the Passaic Pit outcrop are now housed at American Museum of Natural History in NYC and at the Sterling Mining Museum in their "slab room," viewable under ultraviolet light as part of their underground mine tour. Those pictured are not geologically orientated. They were cut from the first upper layers striking about N60E and dipping $\sim 60^\circ$ SE (fig. 10). Willemite fluoresces light green and highlights siliceous seams within the marble (calcite fluoresces red-orange) in the form of metamorphic cross layering. Also note a different generation of willemite filling secondary fractures cutting through the layering at cross angles.

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Old, detailed mining records and maps are lacking for the surface and upper-level workings prior to the establishment of the NJZC which joined the Franklin and Sterling Hill Mines as part of a single enterprise (Dunn, 2002). The Franklin Mine produced 22 million tons of ore over the mine life, while the Sterling Mine is reported to have produced 11 million tons (Dunn, 2022). Edwards (1962) states that “At Sterling Hill, the New Jersey Zinc Company mines zinc ore, crushes and grinds the ore to size; and ships the powder to the Palmerton smelter for further treatment. Production in the 1962-65 period averaged 1000 tons per day. Company estimates as of December 1st, 1965 indicate an ore body of 4,750,000 tons of proven ore, averaging 20.1% zinc.” Please see Dunn (1995) and Wilkerson (1962) for a comprehensive review of the mine histories and mineralogical review.

The plan maps and cross sections (stope sections) acquired for this study were compiled by geologists, miners, and draftsmen employed by the NJZC using various mining and cartographic techniques at the two separate facilities over time. Detailed maps and sections of the Franklin Mine were first drafted in February 1908 with ore volumes tallied at the -1150 ft subsurface level. At that point in time, exploratory drilling and shaft construction had been completed and the first detailed records of ore stoping were compiled for mining conducted at the bottom of the fish-hook shaped ore body where it’s the flattest, thickest, and widest (figs. 5, and 9 to 11). Mining at Franklin continued upward toward the surface through systematic, shrinkage stoping, mining of the pillars by top-slicing, and backfilling (Haight and Tillson, 1917) until mining ended in July 1954. The first subsurface work noted on the SHM stope maps are dated September 1932 with records compiled through May 1986 (fig. 9). Edwards (1962) summarized the mining methods at Sterling as “horizontal cut and fill for stopes and square sets for pillar recovery; all excavated openings are refilled with gravel.”

The bedrock geology of the mined area is well mapped and documented by many workers including Hague, Baum, Herrmann, and Pickering (1956), Baker and Buddington (1970), and Volkert and Monteverde (2013). A NJZC cross section constructed by Bob Metsger in 1975 details the structural nature of the Franklin-Sterling Hill syncline in which the zinc-ore resides (fig. 12). The section is based on rock coring across the valley and depicts a tight, upright syncline with a hinge area cut by the steep, southeast-dipping Zero fault. As noted by Hague and others (1956), both ore bodies occur within the Franklin marble positioned between the siliceous Cork Hill and Median Gneiss layers at horizons favorable for mineral replacement and growth during metamorphism. They also report a general composition of Franklin ore being 40% franklinite, 23% willemite, and <1% zincite with the remainder of gangue silicates and carbonates. The ore mineralogical proportion at Sterling Hill is reported at 33% franklinite, 16% willemite, and ~1% zincite, with the remaining gangue calcite. These values closely agree with an earlier assessment by Palache (1929). Both ore bodies have hook-shaped keels in cross section (figs. 5, and 9 to 11).

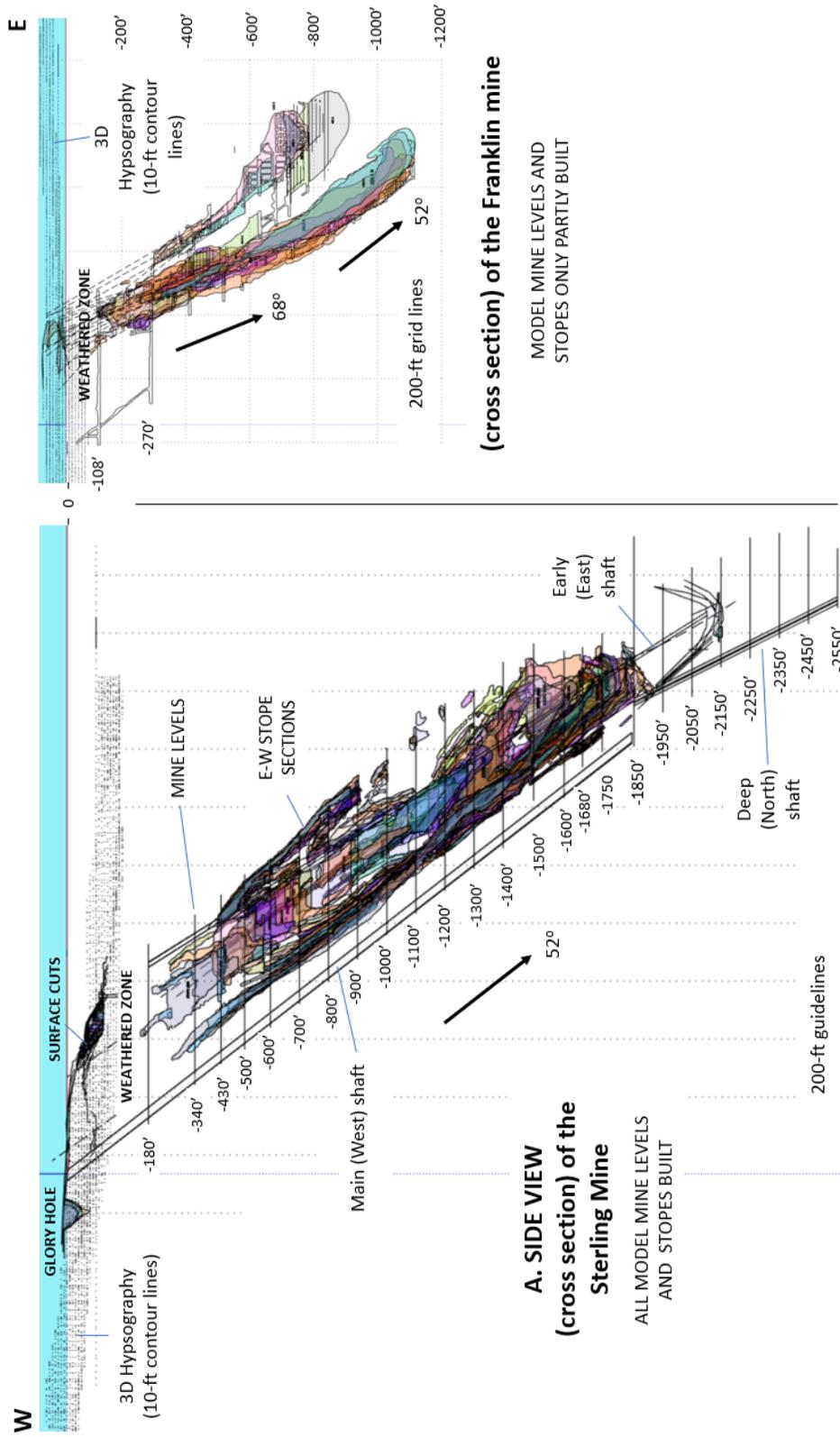
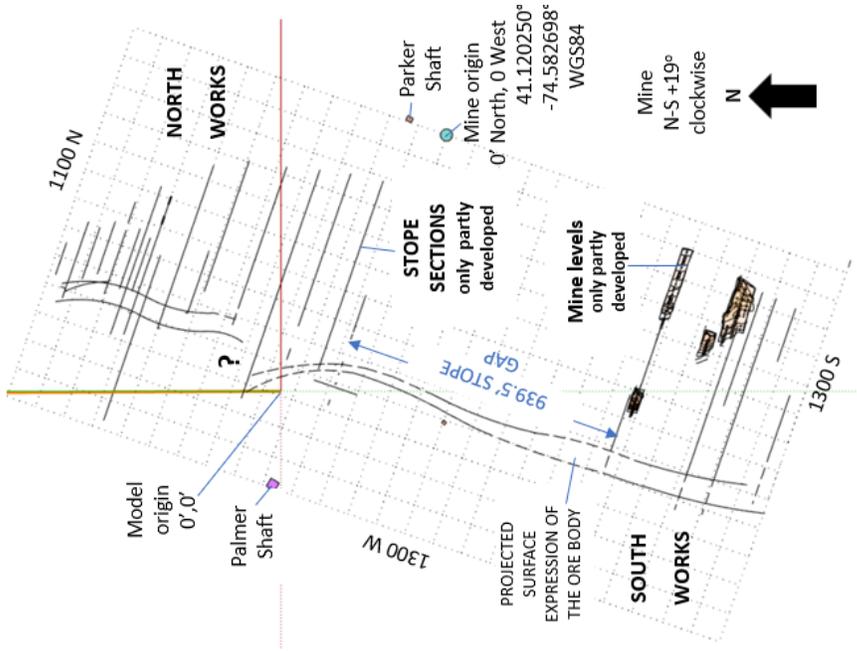


Figure 5. Cross-section views of the (A.) Sterling Hill and (B.) Franklin mines looking north at the same scale. Notable features are labeled and discussed further in the text. Please note that the Sterling Hill model used all available maps and stope sections whereas the Franklin model used only a fraction of the total archived. Both ore bodies occur in the hinge area of an upright syncline that's cut by the steeply southeast-dipping Zero fault as detailed in figure 8.

B. TOP VIEW (map) of the Franklin Mine



A. TOP VIEW (map) of the Sterling Mine

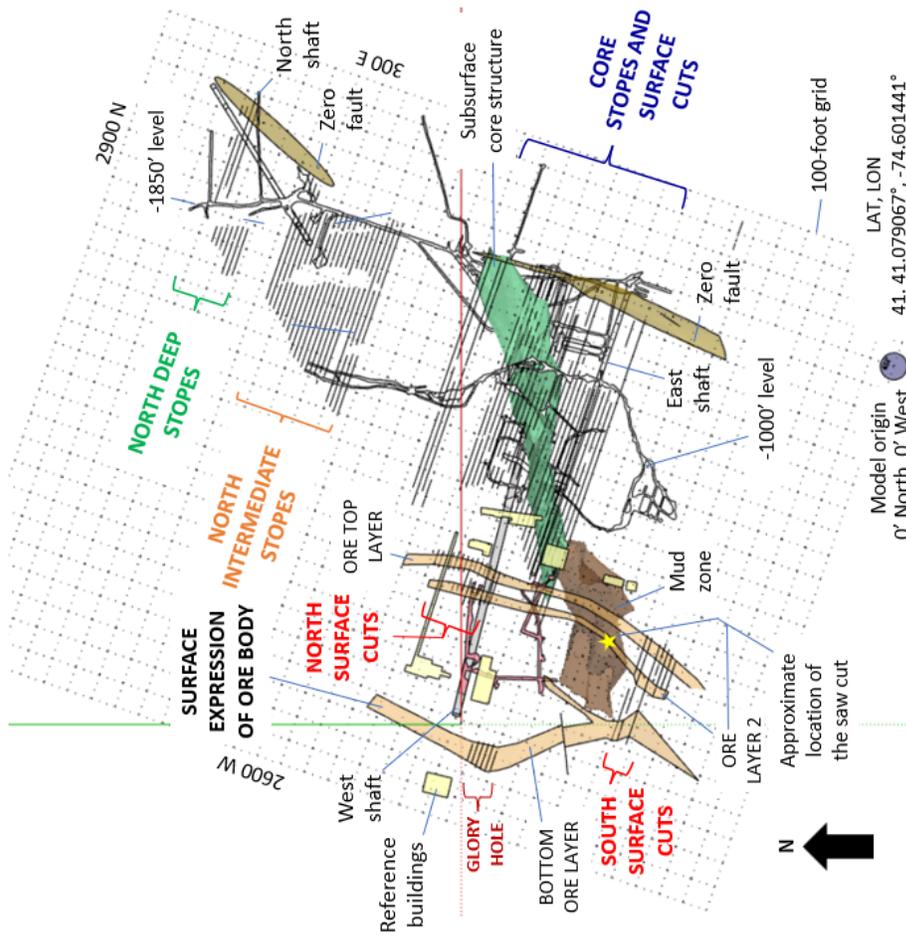


Figure 6. Maps of the (A.) Sterling Hill and (B.) Franklin mines at the same scale. Notable features are labeled and discussed further in the text. The ore body at Franklin is offset and noted using a question mark.

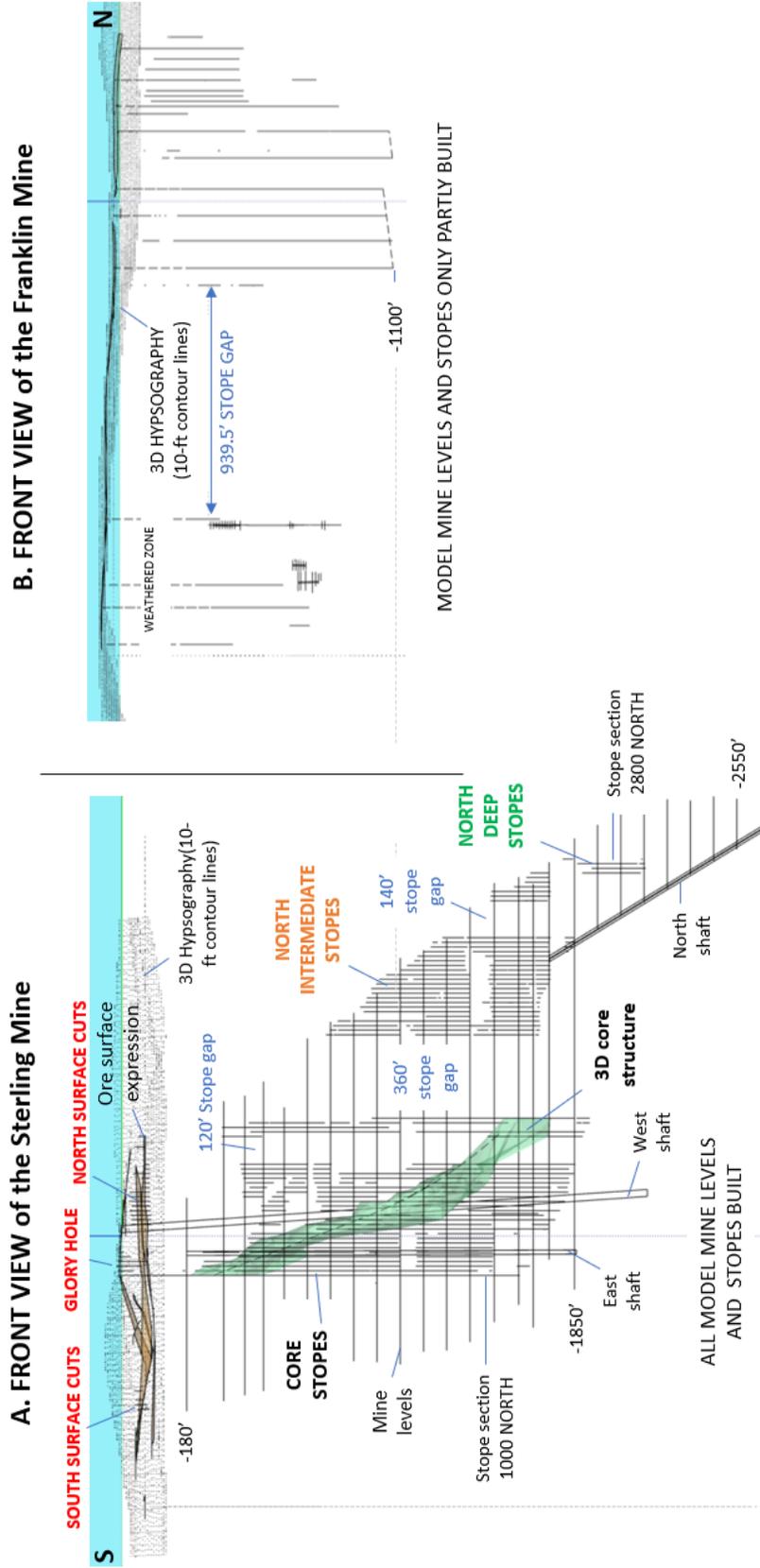


Figure 7. Front views (longitudinal sections) of the (A.) Sterling Hill and (B.) Franklin Mines at the same scale. Notable features are labeled and discussed further in the text. Please note that the Sterling Hill model used all available maps and stope sections whereas the Franklin model used only a fraction of the total archived. The spatial density of stope sections for both the north and south cluster of stopes at Franklin are developed most in the upper right corner as an example of representing only part of the available information.

There is a focused cluster of stopes and surface cuts at Sterling Hill situated in the structural core of the ore body where the zinc ore accumulated along the margins of a fattened, ovoid, dike-like structure striking about 080° (figs. 13 to 16). This core structure is what Hague and others (1956) refer to as a “cross vein”. Metsger, Tennant, and Rodda (1958) describe it as a complicated “cross member” that’s greatly thickened in its middle portion, and they indicate it joins the west and east limbs. Outcropping structural aspects of the core structure are detailed in the field guide.

A long-standing misconception about the Sterling Hill structure is that the ore resides in an overturned syncline, such that the east and west ore layers were once coplanar but now form an isoclinal fold wrapped around a marble and gneiss core structure. But a NJZC cross section that was constructed through the area by Bob Metsger in 1957 disproves that (fig. 12). This is partly the basis for a fault-mediated hydrothermal-plume origin proposed for the ore body as depicted in figures 14 through 16. At both locations the ore bodies thicken at depth and to the south, and

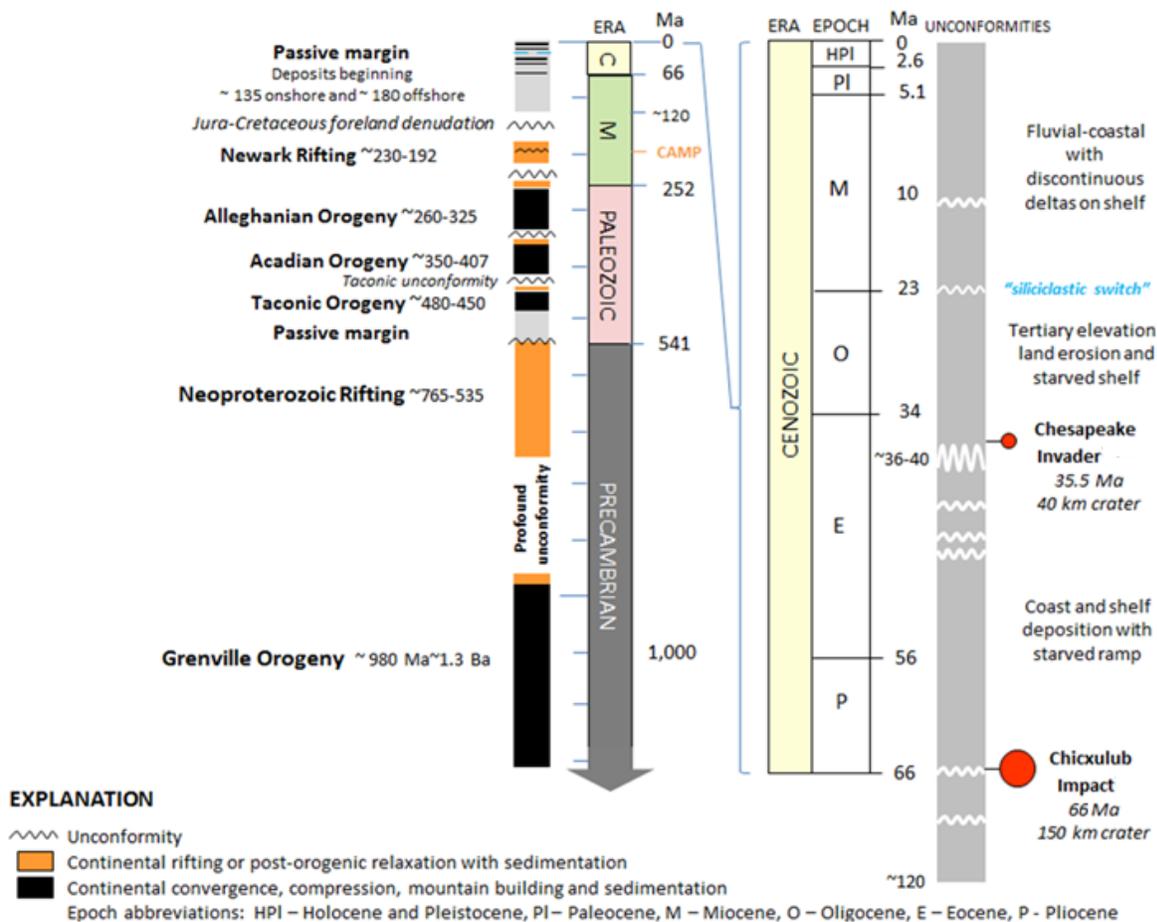


Figure 8. Chronology of Appalachian tectonics in the New Jersey part of the central Atlantic region of North America (adapted from Herman, 2015).

taper to the west. The original dips of the infiltrated strata are unknown, but the beds were originally deposited with sub horizontality. They were then folded and faulted during Mesoproterozoic compression and subsequent extension (figs. 15 and 16). The current attitude of the ore bodies is likely not the same as during infiltration. At Sterling Hill, a portion of this core structure is composed of black willemite, which under high magnification appears to be composed of colorless willemite peppered through with minute inclusions of highly magnetic

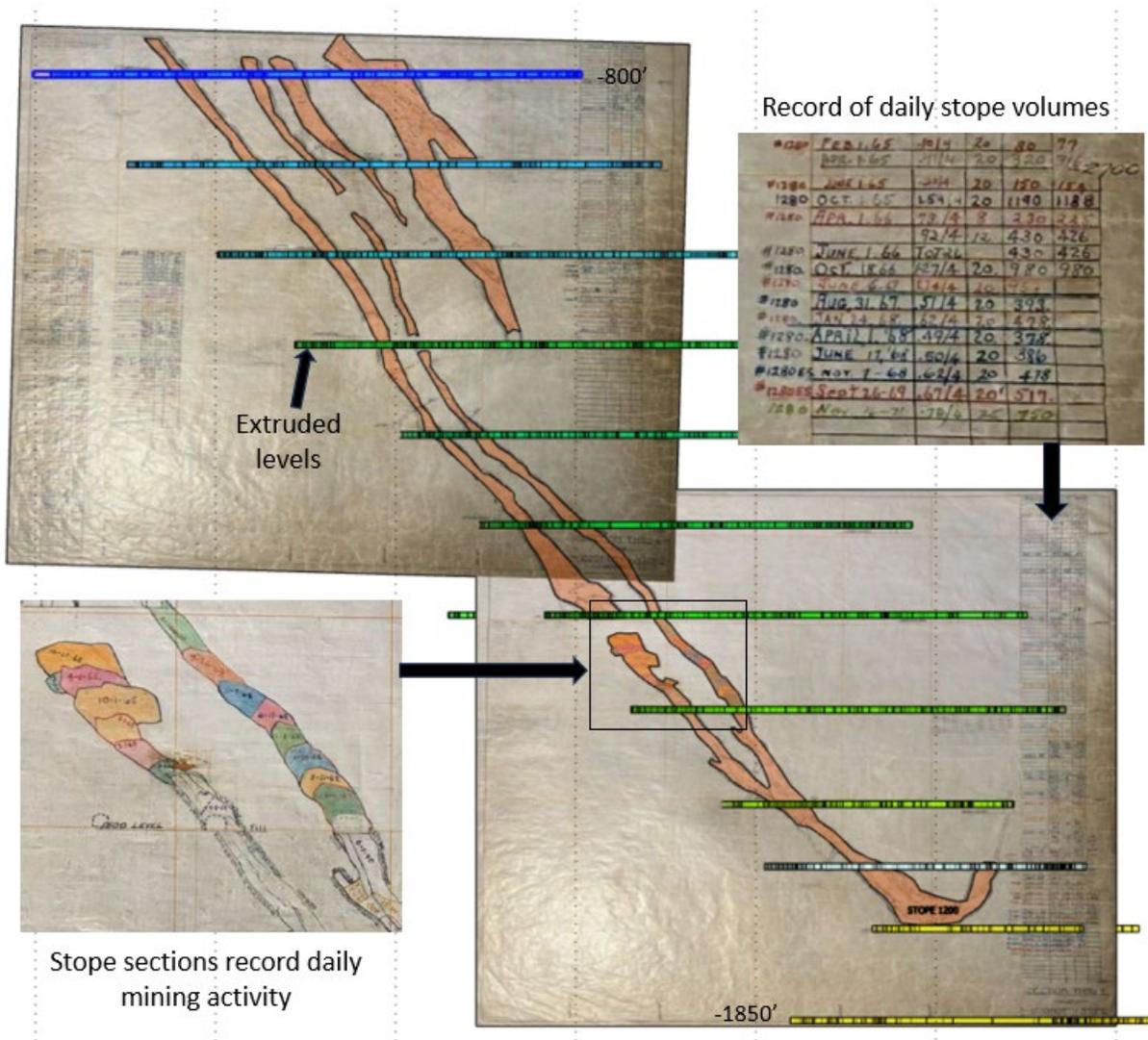


Figure 9. Captured screen views of the 1200 North stope section of the Sterling model showing two registered and overlapping stope sections with an example of how the ore-mining records were kept. The orange polygons are 2D vector-based faces that were manually digitized from the raster imagery. The digitized polygons of the multi-colored mine levels were also extruded seven feet vertically as shown. The slight clockwise rotation of the top raster image shows how small (<1.5°) angular rotations were introduced from using a hand-held smartphone camera to digitally photograph the stope records.

black franklinite that approaches magnetite in composition (Metsger and others, 1958). So, it appears that the heaviest minerals crystallized along the core structure and basal sections of adjacent, infiltrated layers. (figs. 14 to 16).

THE STERLING HILL AND FRANKLIN COMPUTER MODELS

This section details the methods and tools used to build and share the mine models. The CAD models were built using the SketchUp Pro (SUP) 2024 3D design software by Trimble, Inc. SUP is powerful and versatile architectural-design software that includes geolocation tools for positioning models in geographic space using the WGS84 reference system. The models use imperial feet as the standard unit of measure. The representative accuracy is estimated to be ± 10 ft both vertically and horizontally for both models. The models were exported using a *.dae file format for model output that was exported as 3D objects into Google Earth Pro (GE) for additional visualization as detailed in the last section.

However, these results only illustrate a fraction of the information that the mine maps provide. My focus was on building a 3D mine model and using it to portray the structural position

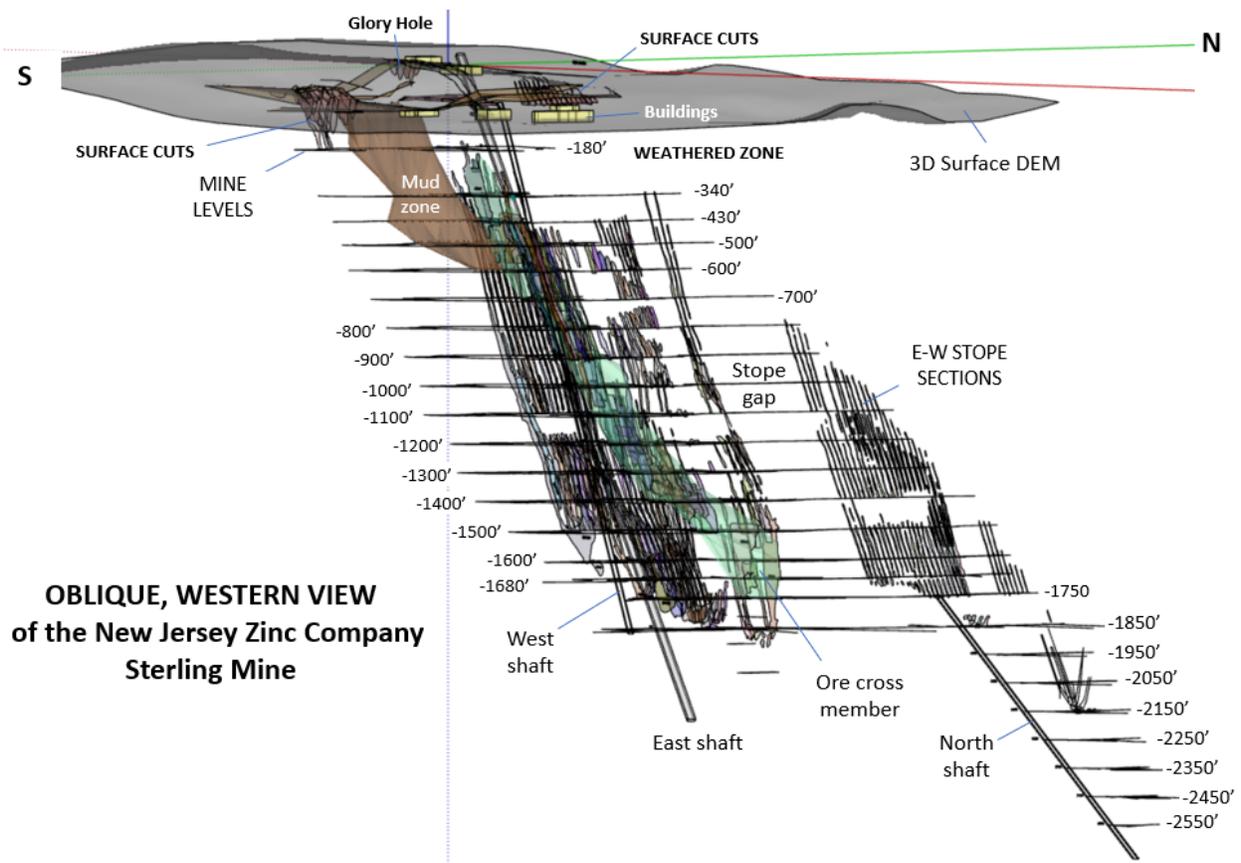


Figure 10. Western view of the NJZC Sterling Mine SUP model.

and complexity of the ore body including the primary metamorphic layering with metalliferous banding that is cut by many secondary structures resulting from many tectonic episodes throughout geological time (fig. 8). I also considered building geometric envelopes around groups of stoped sections as part of the model in order to calculate extracted ore volumes, but upon building one and comparing the resulting volume with those recorded on the stoped sections, there was 99% agreement between the two (fig. 17), so I didn't need to develop those further because the historical records are available that include amounts and dates of extraction. These records can also be used to reconstruct the working history of the mines if one is compelled to do so.

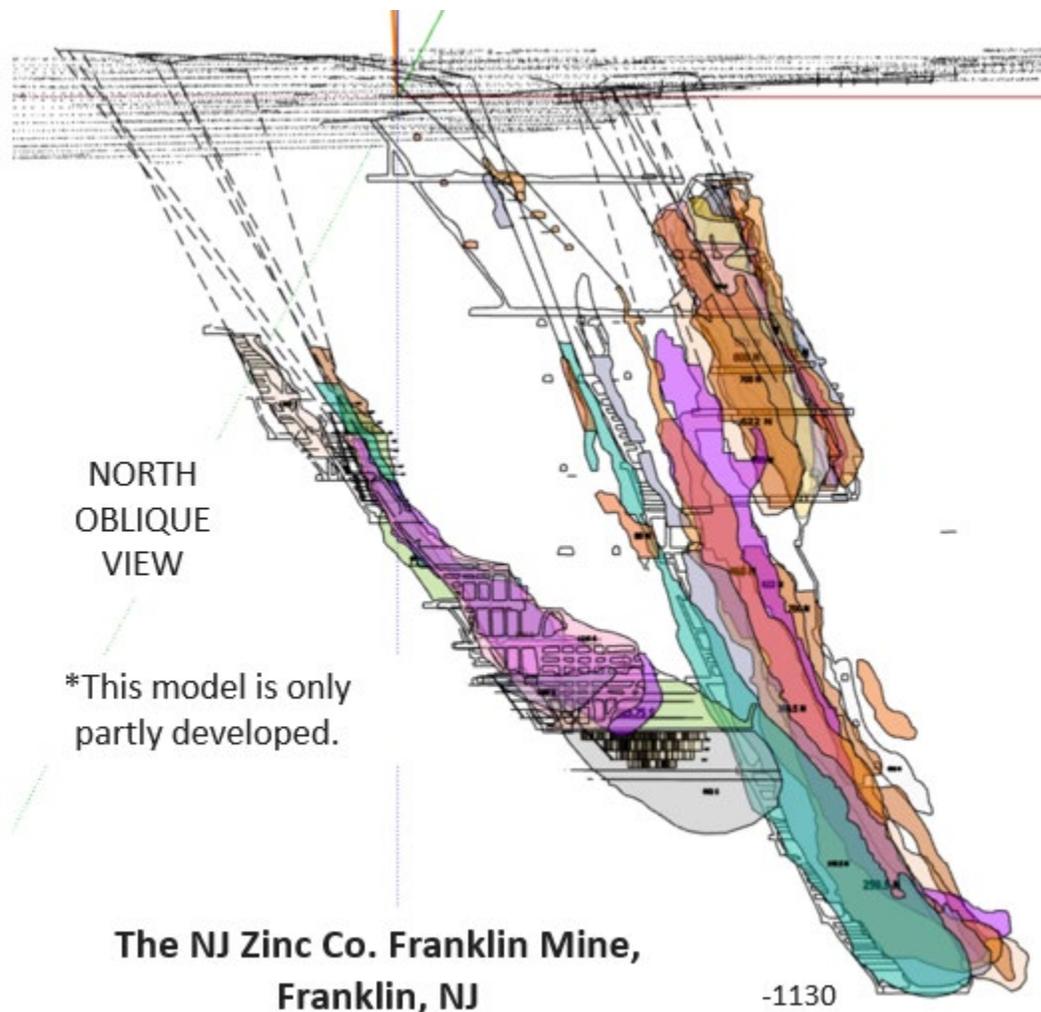


Figure 11. North view of the Franklin mine SUP model with semitransparent stoped sections.

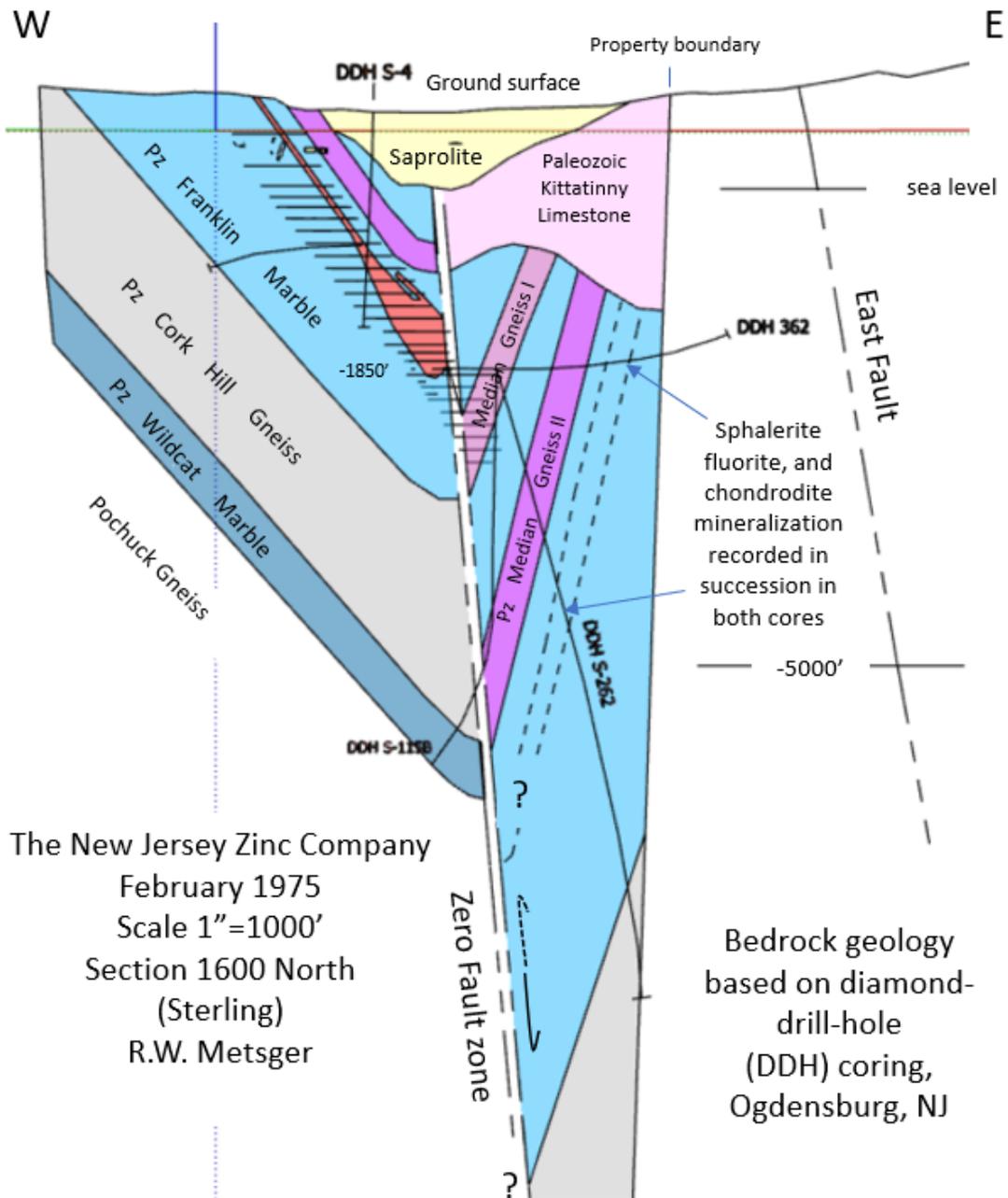


Figure 12. A formerly proprietary NJZC cross section constructed by Bob Metsger in 1975 is now part of the New Jersey State Museum Metsger collection, and is reproduced and augmented here. Please see the section below about the museum collection. The cross section, constructed along the 1600 north stope, details the structural nature of the Franklin-Sterling syncline in which the zinc-ore resides. It's based on five rock cores (labeled DDH) that were drilled to over a mile underground. This confirms that the mines are developed in a synclinal hinge cut by the steep, southeast-dipping zero fault. The dissected fold limbs are upright and dip moderately to steeply toward one another. The Sterling ore deposit is depicted to thicken in the fold hinge area. The location and length of core DDH S-262 is listed in table 1, and the core resides in the Rutgers University core repository.

Table 1. Locations (feet) and lengths (feet) of rock core from the Sterling (S) and Franklin (F) Mines and where they are kept. Written communication from Dr. Earl Verbeek, June 24, 2025.

Hole #	North	West or East	Elevation	Length	Rutgers	Sterling Hill
S-33	1200	806 W	-2088	212		212
S-56	1200	179 W	-2394	426	426	
S-58	900	490 W	-2393	259		259
S-109	1335	764 W	-1696	450		450
S-110	1211	574 W	-1894	250	250	
S-138	1049	899 W	-1513	27'	273	
S-144	950	1084 W	-1336	277	277	
S-153	2772	103 E	-3146	182	182	
S-154	2860	544 E	-2838	1791		1791
S-155	2791	282 W	-2845	483		483
S-156	2858	550 E	-2838	4784		4784
S-240	1570	645 W	-2087	91		91
S-250	2526	486 W	-2386	1005		1005
S-257	1639	534 W	-2186	70		70
S-262	1588	305 E	-2186	4652	4652	
S-263	1559	153 W	-2850	71		71
S-286	1200	267 W	-2092	150		150
S-288	2997	175 W	-2090	70		70
S-290	1320	356 W	-3498		410	
S-292	1319	356 W	-2692	142		142
S-300	960	825 W	-2096	340		340
S-304	801	944 W	-1594	275		275
S-308	1300	447 W	-1993	376	376	
S-343	2946	325 E	-3442	166	166	
S-351	1640	254 W	-2389	97		97
S-363	1023	257 W	-2393	259		259
S-401	1140	189 W	-2496	110		110
S-402	1340	681 W	-2189	155		155
S-403	1444	494 W	-2185	159		159
S-404	1444	496 W	-2184	155		155
S-405	1550	438 W	-2189	89		89
S-421-2	1540	379 W	-2491	176		176
S-424	1300	256 W	-1796	120.5		120.5
S-427	1498	108 W	-2708	97	97	
S-432	1460	93 W	-2708	111.5-150		38.5
S-449	1037	1008 W	-1598	45-91		46
S-450	1045	1005 W	-1598	56-82		26
S-451	1037	1005 W	-1598	49-88		39
S-452	1020	1034 W	-1515	63-101		38
S-453	1020	1034 W	-1512	63-134		71
S-454	1360	741 W	-1790	57-76		19

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S-455	1335	927 W	-1790	93-221		128
S-457	1335	927 W	-1790	60-220		160
S-459	1300	554 W	-2287	43-112		69
S-460	1540	544 W	-2186	90-148		58
S-461	1444	495 W	-2183	81-130		49
S-462	990	1091 W	-1424	60 -100	40	
S-463				85-113		28
S-465				101-208		107
S-466				56-126		70
S-467				85-125		40
S-468				95-132		37
S-115-b	1589	298 E	-2849	2992	2992	
F-155	750 S	2727 E	663	1965	1965	
F-156	1744 S	1680 E	607	1686		1686
				Total	12106	15952

Subsurface mining of the main ore bodies started below 180 ft at Sterling Hill and below 100 ft at Mine Hill owing to deep weathering of the Franklin marble (figs. 11 to 12). The larger mining gap across the weathered zone at Sterling Hill prohibited a well-constrained interpretation of how the surface cuts connect with the mined sections below. Other mining gaps occur between clusters of stope sections at both mines presumably because of ore degradation or bedrock instabilities stemming from even deeper weathering occurring along brittle cross faults that strike parallel with those observed in and around the Newark Basin as seen in historical aerial imagery and LiDAR (fig. 18 and Herman, 2009; 2015).

The Franklin model only includes a subset of level maps and stope sections that capture the mining approach and its 3D spatial arrangement in two separate north and south areas separated by a 930.5 ft horizontal gap in the mining works for unknown reasons, but likely owing to deep weathering and structural instabilities stemming from late-stage, brittle cross faulting. Weathering beneath the Passaic Pit extends downward to nearly 700 ft (Kroth, 1993) where the mineralized marble layers are reduced to a mud zone that has the width and inclination of the deeper ore body (fig. 6). Ore mining therefore was generally focused below the -600 ft level at Sterling Hill (fig. 5).

The ore surface drifts, saw cuts, high walls and stope sections at Sterling Hill helped constrain the model so that the interpretation of the ore body is compiled and represented as best possible given the limitations. I'm satisfied with the results when portraying the structural complexity of the ore body stemming from multiple tectonic episodes as discussed in more detail below in the following sections.

Mine Locations

Accurately locating the Sterling Mine model proved challenging until May 2025 when I met Earl Verbeek. He used and shared a detailed site map by Kroth (1993) to map faults and slickenlines of the Sterling Mine (chapter 3). Kroth's map includes the mine-coordinate system, the tunnels used for the SHMM mine tour near ground level, and some upper mine levels that are projected to the surface, thereby allowing accurate placement and rotation of the Sterling Mine model relative to true north (fig. 20).

Registration of the Franklin model relied upon a set of roads depicted at ground surface on the southern group of stope sections. In particular, section 842N includes a drafted surface trace running across Nestor, LaRue, Main, and Mill Streets in Franklin Borough that limited the position of the model and constrains its accuracy to the width of LaRue Street (rather, Larue in GE) that runs approximately normal to the ground-surface trace (fig. 20). The two adjacent mines use the same vertical datum but different horizontal datum (fig. 6).

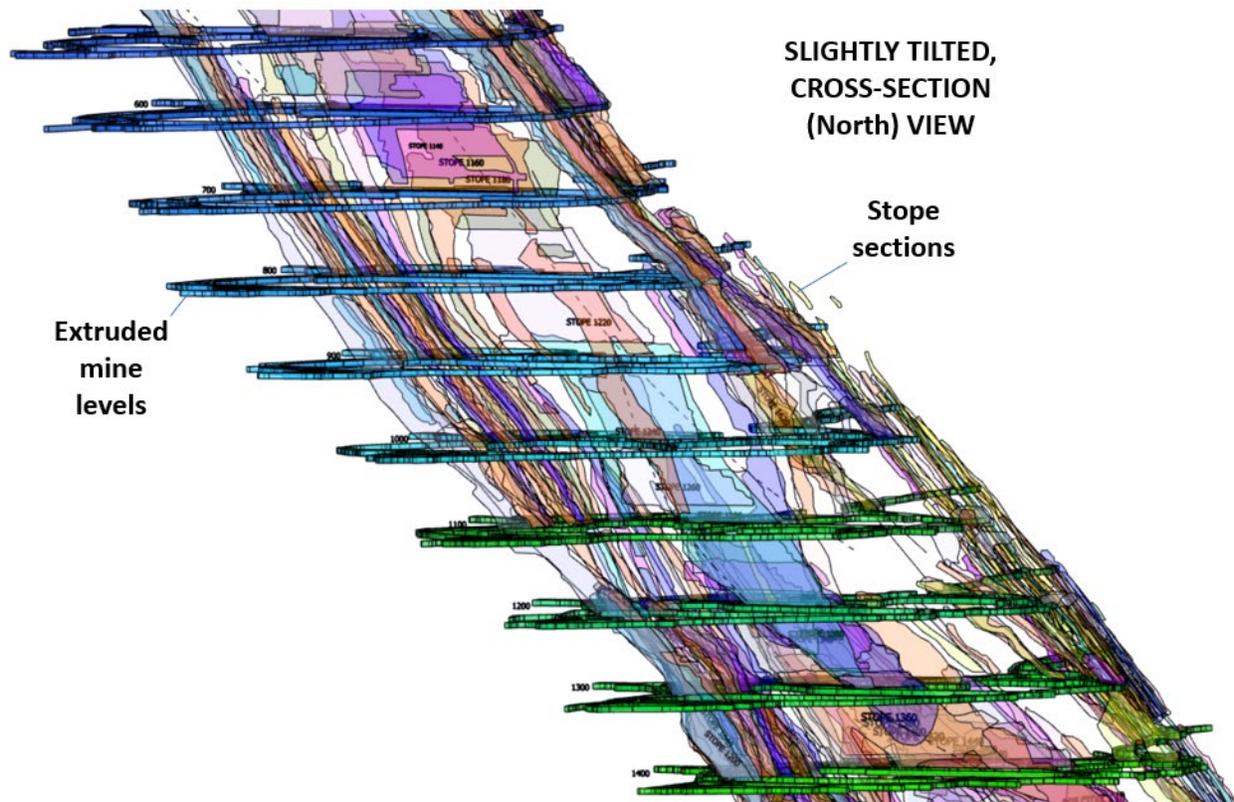


Figure 13. North view of part of the Sterling Mine model showing sets of semi-transparent stope sections and mine levels that exemplify the mine workings and structural complexity of the ore body.

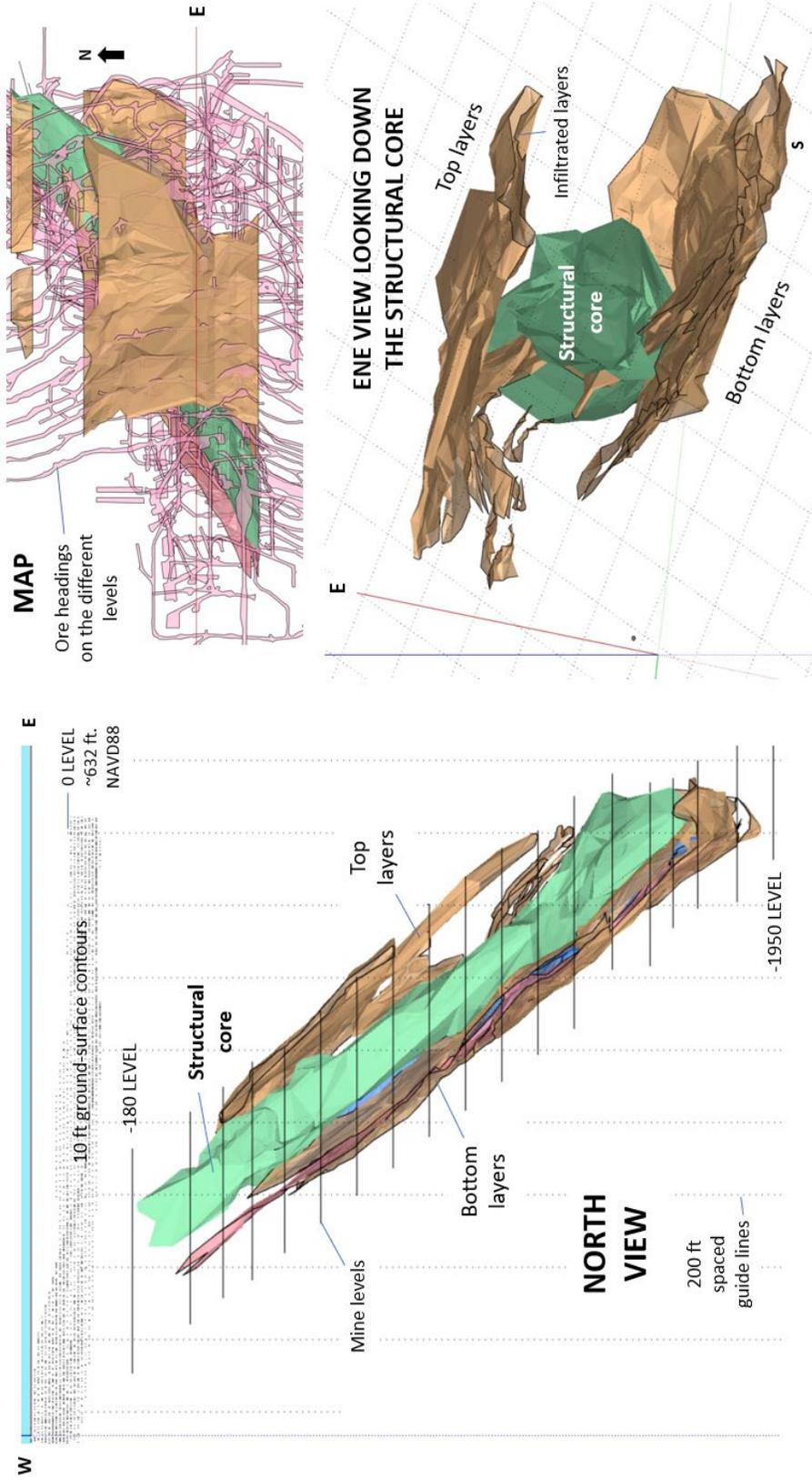


Figure 14. TIN surfaces were manually built around the structural core (green) and along the tops and bottoms of ore layers (light brown) defined by the set of core slope sections in order to visualize the main part of the Sterling ore body (fig. 6). Mine-level polygons are colored pink. The structural core is a round- to oblong-shaped, elongate structure that fed metallic fluids into adjacent top and bottom layers. Zinc-enriched fluids preferentially invaded the hinge zone of an upright syncline along this dike-like core structure that could strike parallel to the paleo-tectonic compression axis (fig. 15). The bottom, hook shape of the ore body arose from several tectonic episodes involving both reverse and normal faulting on the bounding zero fault system (fig. 8).

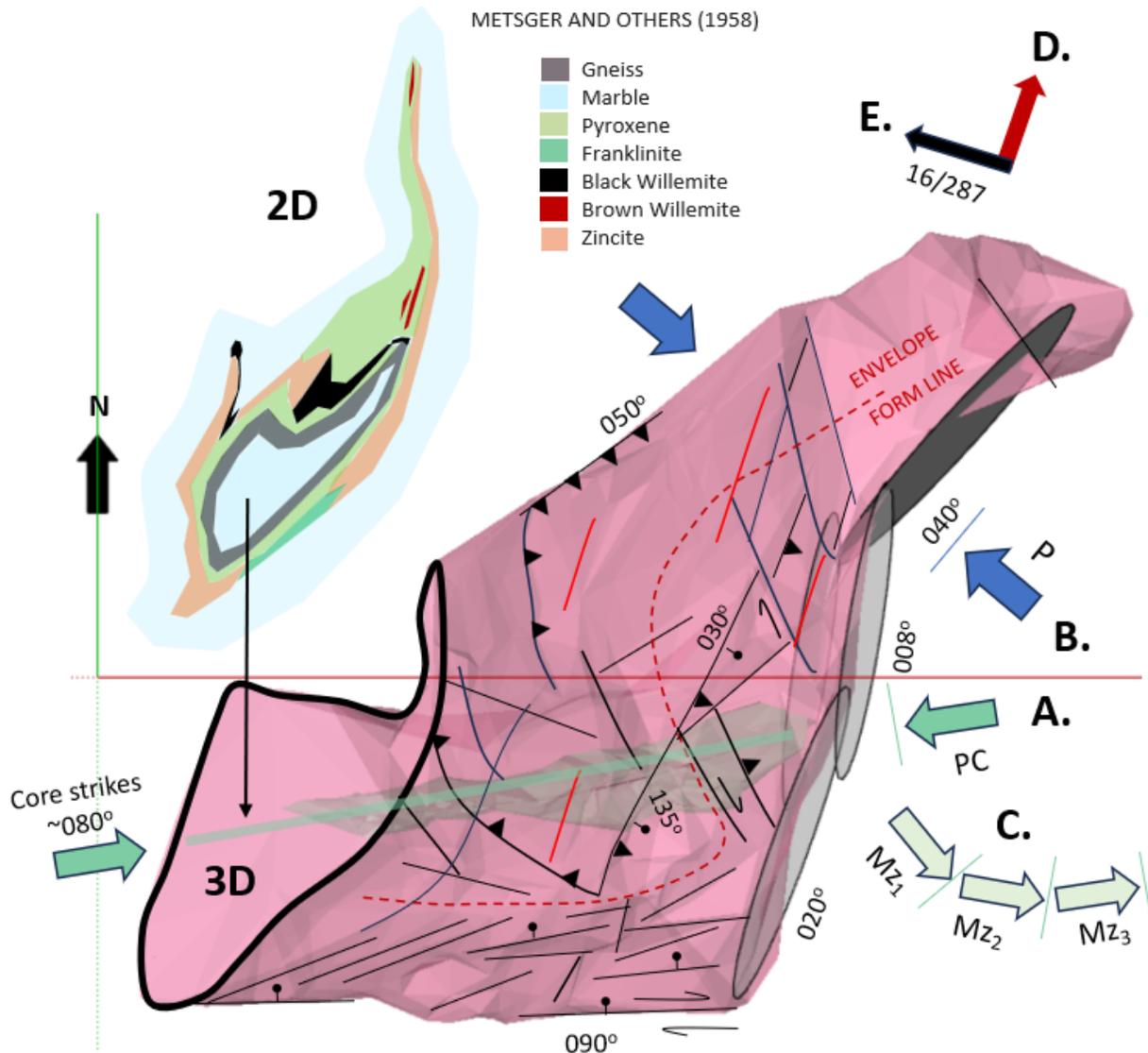


Figure 15. Map view of the Sterling Hill ore body in 2D on the upper left and in 3D to the lower right. The Metsger and others (1958) 2D map demonstrates mineralogical heterogeneity in the ore body (layers colored by primary mineralogy). The 3D diagram shows an enveloping surface constructed around the ore body that highlights its structural creases and flexures resulting from incremental tectonic strains. A.) The ore body was first emplaced during Mesoproterozoic compression (Precambrian-PC) along faults feeding Fe-Zn-Mn rich fluids into the Franklin Marble. B.) The mineral deposit was then deeply buried before ductile-brittle compression and shearing during Paleozoic (P) Appalachian Mountain building that raised it towards ground surface. C.) Mesozoic (Mz) incremental stretching segmented the ore body and displaced it downward during continental rifting, of which there were at least three incremental stretching phases. D. and E.) Two phases of Cenozoic compression have also impacted the region (Herman, 2015) including compression and uplift down range of the Chesapeake Invader meteorite impact (D.) and current compression stemming from passive drift toward the NW (E., 16 mm/year toward azimuth 287°).

Data Input and Processing

The models were built in stages as the data were acquired. The SHMM had previously digitized the twenty-six levels of mine workings so these files were received as individual Adobe Portable Document files (PDFs) that were converted to raster images using the TIFF file type. Many of the longer maps were split in half in order to preserve image resolution because SUP dithers imported images, with larger images losing a greater degree of definition. Altogether, forty-four map images of the mine levels were digitized as closed 2D polygons that were later extruded seven feet for rendering 3D levels (figs. 9 and 13). An iPhone 14 was then used to photograph the stope sections and resulted in the introduction of small, angular rotations that required adjustments within the vectorized model (fig. 9). The JPG file-image format was used for working with stope-sections raster imagery. The integrated levels and stope maps detail the 3D form of the ore body and reveal the nature and orientations of secondary structures within and bounding the ore bodies (figs. 13 to 15).

The following list summarizes the data gathering, processing, and interpretive steps in building and sharing the Sterling model. Many of these steps were then followed when building the Franklin model. An iPhone 14 was used photograph the level and stope maps for Franklin. The location of the Franklin Mine Palmer and Parker shafts were located and added using Sanborn (1920) maps.

- 1) Established a model origin from which 100-ft reference grid and 200-ft spaced vertical guidelines were constructed to aid in the 3D positioning of the imported level maps and stope sections as raster images (figs. 5, 6, 9, and 10).
- 2) Converted the PDF files for the twenty-six mine levels into forty-six raster images using TIFF image format supported by SUP. Many of the PDF maps were split into halves in order to preserve image clarity for manually digitizing the line traces (fig. 19).
- 3) Positioned the model in geographic space (WGS84) using the SUP geolocation tools using a set of reference buildings and the location of the headframe of the main shaft to constrain the alignment of the model and imagery (fig. 3). The SUP geolocation tool includes an option for generating a 3D digital-terrain model (DTM) that more than doubled the file size of each mine model.
- 4) Generated 3D hypsographic contours from the imported DTM using the SUP courbes de niveaux plugin (ver. 1.1.4) downloaded from the online SUP Extension Warehouse.
- 5) Manually digitized the line tracings of the ore body on each mine level as closed 2D polygons constrained to the XY model plane (fig. 14 and 21).

- 6) Extruded each level polygon seven feet vertically along the z-axis to construct multicolored 3D levels (figs. 9 and 13).
- 7) Added the zero fault where it cuts the deep levels as portrayed in NJZC glass-box model (fig. 22)
- 8) Rotated the model 19° clockwise relative to true north (figs. 6 and 20).
- 9) Digitized Kroth's (1993) 2D polygons of the mud zone at the 0 (ground), -340, -430, -500, and -600 levels in and below the Passaic Pit (fig. 23). Digitized Kroth's (1993) 2D polygons of the current tunnels used for the SHMM mine tour (fig. 23). These were constrained using a set of surveyed benchmarks embedded in the tunnel walls that Picatinny Arsenal recently used for robotic tests.
- 10) Digitized the NJZC cross section of the area constructed at the 1 in: 1000 ft scale (fig. 8; Metsger, 1975).
- 11) Assembled and digitized part of the zero fault and some associated, footwall shear zones mapped in the NJZC report detailing the geologic nature of the sheared, southeast limb of the ore body at the 1 in: 100 ft scale (figs. 24 to 26; Baum and Williams, 1947).
- 12) Digitized Kroth's (1993) 2D polygons of the current tunnels used for the SHMM mine tour (fig. 23). These were constrained using a set of surveyed benchmarks embedded in the tunnel walls that Picatinny Arsenal recently used for robotic tests.
- 13) Digitized the NJZC cross section of the area constructed at the 1 in: 1000 ft scale (fig. 8; Metsger, 1975).
- 14) Assembled and digitized part of the zero fault and some associated, footwall shear zones mapped in the NJZC report detailing the geologic nature of the sheared, southeast limb of the ore body at the 1 in: 100 ft scale (figs. 24 to 26; Baum and Williams, 1947).

Data Interpretation

- 1) Manually constructed 3D TIN surfaces around the core structure and top and bottom infiltrated layers (fig. 14). The volume of the core structure as interpreted is 28,059,466.73 ft³.
- 2) Manually constructed a 3D triangulated integrated network (TIN) surface that envelopes the mapped ore body with a volume of 779,881,868.92 ft³ (figs. 14, 15, and 18).
- 3) Identify and digitize representative geometric breaks in the 3D envelope reflecting localized faulting and offset of the ore body (figs. 15 and 18).

Chapter 2. Structural, Tectonic, and Geospatial Aspects of the Sterling and Franklin Zinc Mines, Sussex County, New Jersey

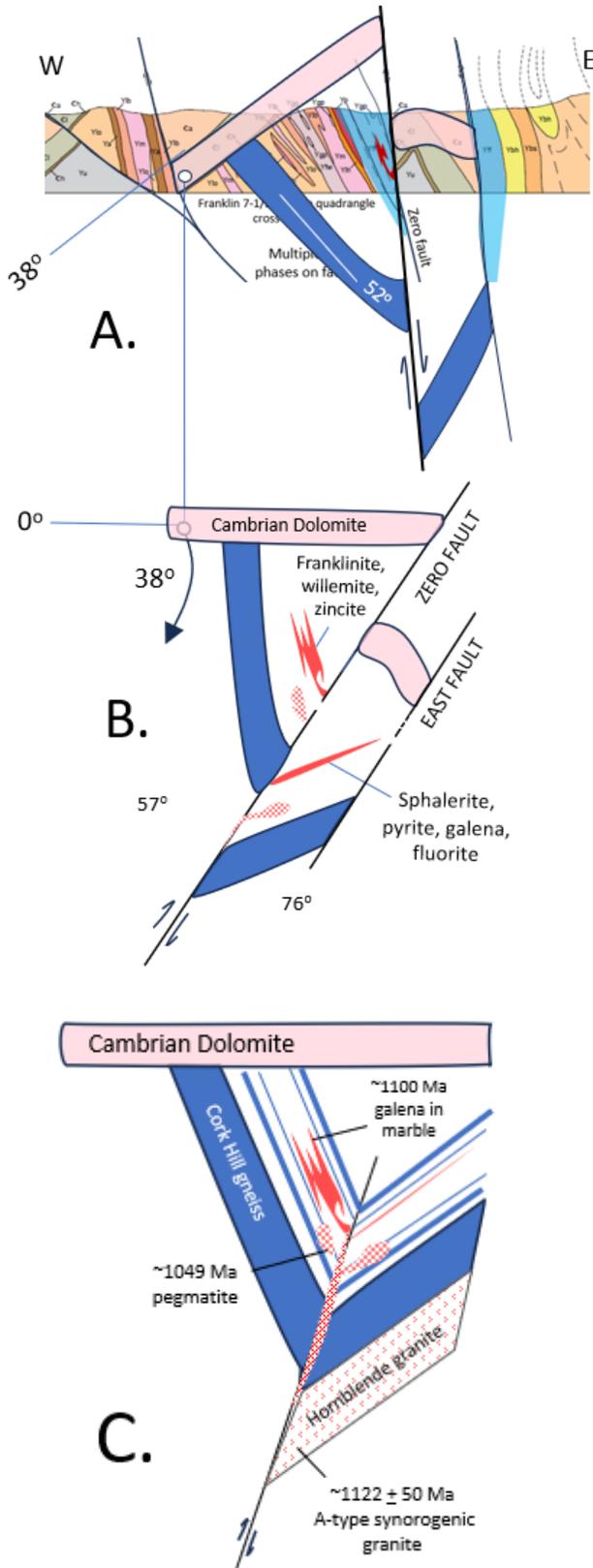


Figure 16. Structural restoration of the basal Cambrian dolomite to horizontal shows how the zero and east faults probably originated as northwest-dipping reverse faults during early Grenville tectonism. A.) Shows the current structure based on cross section A-A' of Volkert and Montverde (2013) as modified by details included on the NJZC cross section of figure 10. B.) If we assume that Proterozoic-age faults rotate with the overlying Paleozoic strata during subsequent tectonism, then upon restoring the Cambrian dolomite to horizontal, the zero fault restores to a reverse fault and a fault-propagation fold in Mesoproterozoic strata holding the ore deposits. The fold symmetry shows eastward vergence with the western fold limb dipping steeper than the east. C) Structural restoration of Mesoproterozoic strata into an open, upright syncline depicted with little offset of the ore body across early fault slip on the developing zero fault. The restored geometry is consistent with the structural grain observed in underlying Proterozoic basement in exploration seismic-reflection data (Herman and others, 1997).

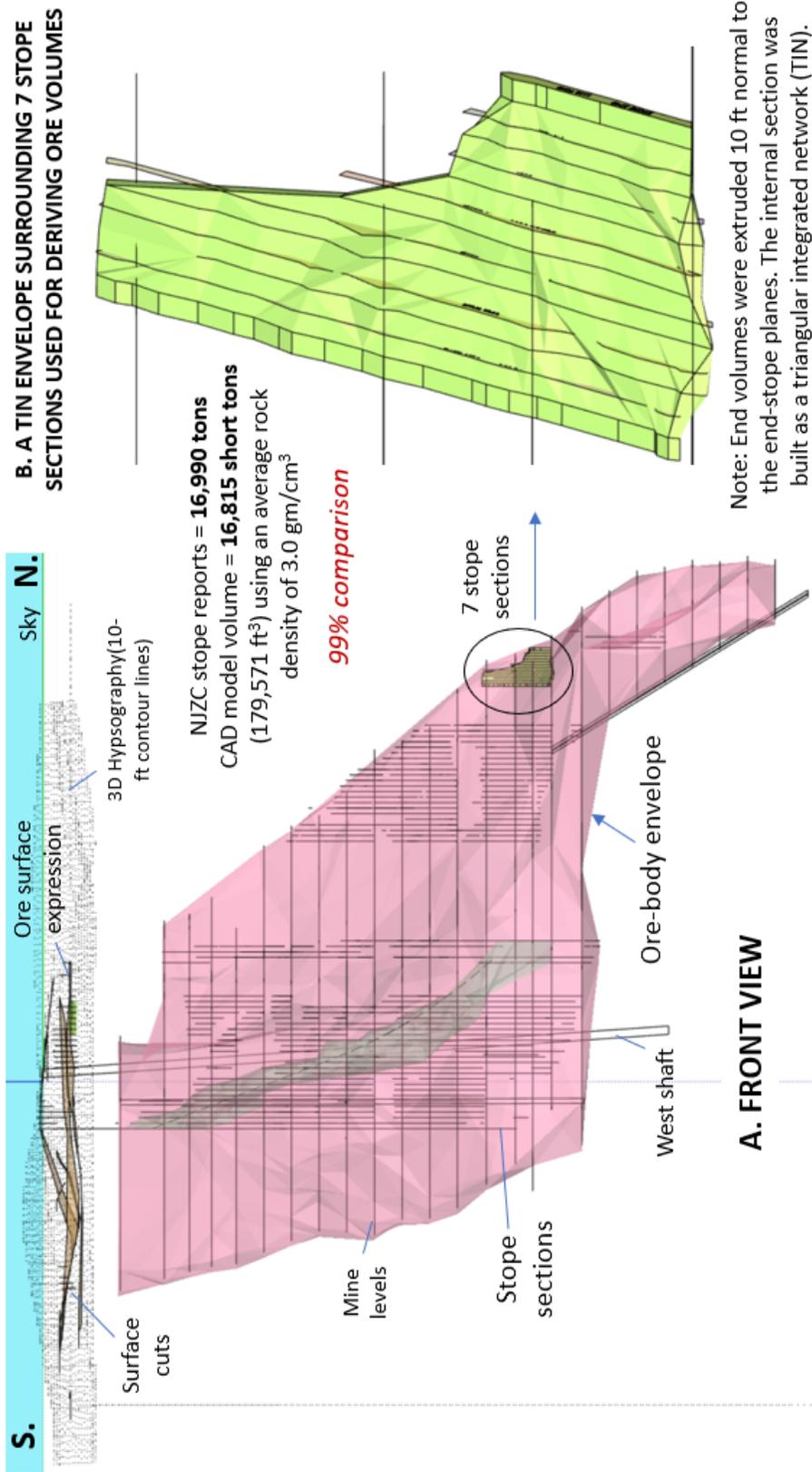


Figure 17. Longitudinal views of the Sterling Mine. A.) A pink-colored geometric envelope was built around the Sterling Hill ore body in order to compute its volume and provide geometric insights into its structural nature. B.) A comparison of the volume of ore removed from an area covered by seven stope sections was also modelled using a triangular integrated surface (light green) that resulted in a 99% agreement with the ore volume reported by NJZC.

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- 4) Insert and scaled 3D ellipses corresponding to interpreted faults (fig. 15).
- 5) Export the SUP mine model to an AutoCAD drawing exchange file (rev. 12; DXF file extension) that was imported into the QGIS (ver. 3.28.12) geographic information system. The QGIS Line Direction Histogram plugin (Tveite, 2015) was then used for azimuthal representation of the ore headings and cross cuts (fig. 21).

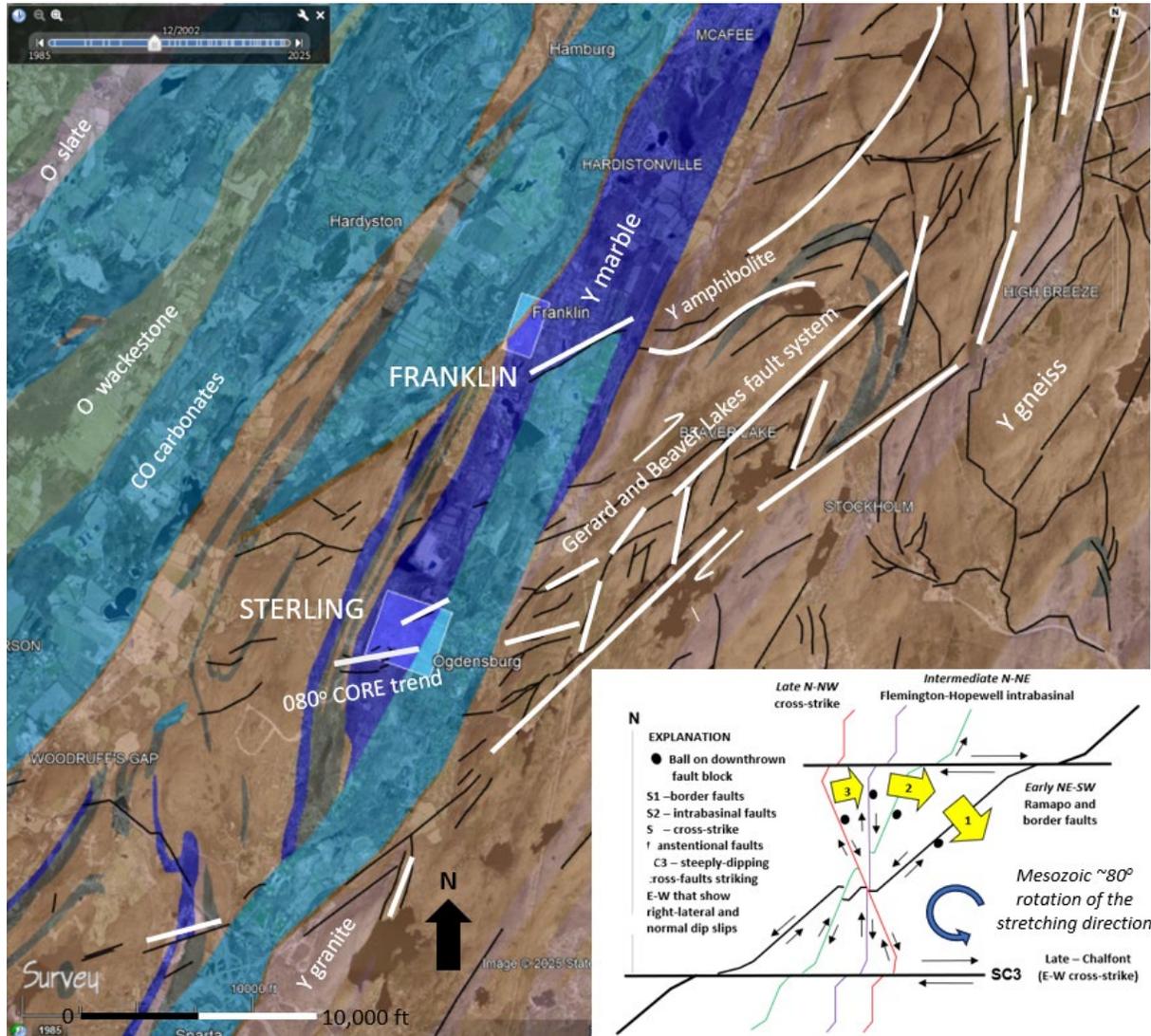


Figure 18. GE Pro was used to overlay the U.S. Geological Survey digital bedrock theme for New Jersey on a 2002 aerial image of part of the NJ Highlands covering the Sterling and Franklin Mines. A fault system crossing through Gerard and Beaver Lakes corresponds with topographic creases following surface drainage. This old fault system isn't depicted on bedrock geology maps, and strikes parallel to rift-related faulting of Mesozoic age in the Newark Basin to the southeast as summarized in the lower right panel (Herman, 2015). Ore metals may have been carried by fluids flowing through these faults that cross Mesoproterozoic bedrock through the Franklin Marble along the core trend.

STRUCTURAL AND TECTONIC ANALYSES

Despite having a constrained sense of how these zinc deposits have been repeatedly tectonized and strained throughout Appalachian history, questions remain as to how the protolith for the body of ore was originally structured. The nature of Grenville-age folding and faulting of the Franklin Marble and associated gneisses and ore bodies is complex. Hague and others (1956) summarized the nature of folding seen in these Mesoproterozoic rocks:

- Minor folds are small-scale, generally isoclinal folds observed in many of the gneisses throughout the area. Their amplitude ranges from a few inches to several tens of feet.
- The trace of the banding in places forms a serpentine map pattern, reflecting small-scale undulatory folds whose axes plunge nearly down the dip of the banding. The axes of these folds are oblique to the mineral lineation, and the folds were probably formed after the main period of deformation.
- Cross folds are present in the Lake Lenape syncline, in the Pimple Hills syncline, at the north end of Mount Eve, and elsewhere. Analysis of the attitude of folds in the area shows that the average bearing of major fold axes is N40°E and the average bearings of the two sets of cross-folds are north-south and N70°E. If the cross-folds are related to the major folding, the major compressive forces probably directed from the southeast to the northwest, probably had minor components of force directed so as to produce cross-folds oriented at roughly 30° to the major folds. If the formation of the cross-folds postdated the major folds, the cross-folds may have resulted from compressive forces from the northeast and southwest, roughly at right angles to the major compressive forces, or from horizontal movement along northeast-southwest shears.

Metsger (1980) proposed that the shape of the ore body is that of “an inverted diapir whose shape may have been influenced both by gravity and tectonics at an early stage of formation.” The evidence offered are:

- Ore textures grade from massive granulose and gneissose to disseminated "pepper and salt." The appearance of the gradation suggests that the ore minerals as well as the adjacent calc-silicates were friable masses which became disaggregated within an extremely plastic or, in part, even fluid carbonate.
- The shape of the ore body itself suggests a huge flow pattern influenced by a broken band of brittle gneiss fragments which it has engulfed. Where the sharply angular gneiss blocks are near ore, the ore banding is bent around them. Where they are isolated in marble, the flow pattern is revealed by contorted silicate and graphite bands (fig. 2).

- When the average density of the entire body (approximately 3.02) is considered together with the visual evidence for the plasticity of the enclosing marble ($d = 2.75$) it seems almost a certainty that the complex fold pattern of the ore body is due to its movement through the marble. It has therefore been proposed (Metsger and others, 1969) that the body acquired its present shape as it sank through the limestone as “an inverted diapir”, or density flow.
- Marble “dikes” are common in the gneiss and granulite associated with the metamorphic sequence. They were formed when the mobile carbonate flowed into fissures in the more brittle rocks. One such dike was observed in a pyroxene granulite fragment in the core of the Sterling ore body. The dike contained a vein of galena which occupied a fracture in the marble. The lead age of the galena, manifestly of more recent origin than the surrounding rock, was 1100×10^6 years.

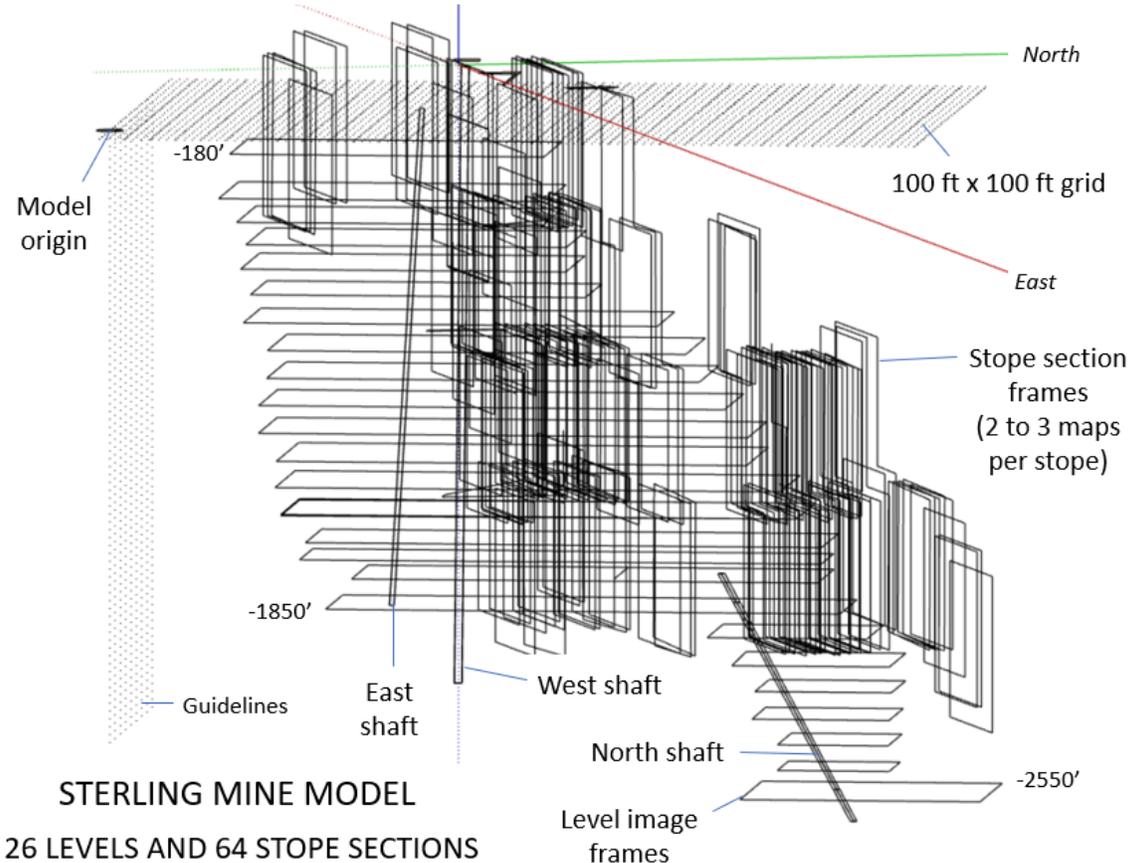


Figure 19. 3D tilted west view showing some model components including polygonal frames that were drawn around each registered TIFF and JPG image used to digitize the vector polygons. The frame borders were saved in the model to facilitate image reinsertion into the model. A total of 26 images of the level maps and 200 photographs of the stope sections were placed into the model using a horizontal mine grid with 100 ft cells and 200 ft vertical guidelines.

Matt, Peck, Mathur, Hurtgen, and Godfrey (2022) noted that the Sterling Hill deposits are layered with respect to chemical and isotopic composition and stated that “the absence of isotopic homogenization indicates a lack of pervasive fluid flow during metamorphism”. This is consistent with a scenario in which an iron and zinc-infused, hydrothermal plume emanated from a fault zone and infiltrated a mixed sedimentary assemblage prior to regional metamorphism (fig. 16). A central feeder structure formed beneath the contact of gneissic layers of greater compressive resistance than the adjacent carbonate protoliths. It’s possible that the core structure parallels the paleo stress direction and is an integral part of the old fault system seen transecting the highlands from west to east (fig. 18).

As seen in the mine models, the ore bodies at Franklin and the Sterling north sections are structured as a single, tabular sill-like body that is structurally segmented and offset along

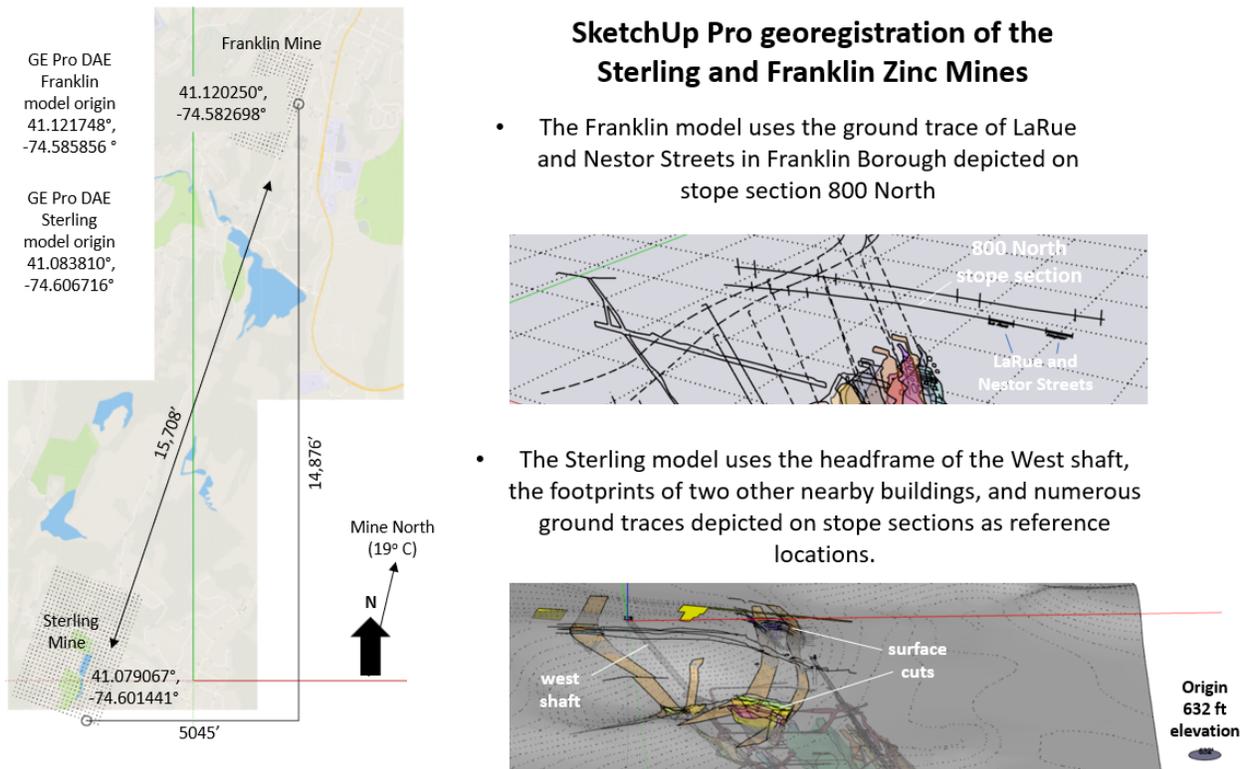


Figure 20. SketchUp Pro geolocation of the Sterling Hill and Franklin Mines relied on various criteria. The Franklin model is precisely located using the traces of LaRue and Nestor Streets in Franklin Borough as depicted on the cross section of the 800 North stope. The Sterling Hill mine used a set of reference buildings (yellow polygons) including the headframe of the west shaft, and a site map by Kroth (1993). The diagram on the left summarizes the arrangement of the two sites in geographic space (WGS84). Note the 19° clockwise (C) rotation of the mine-coordinate grids relative to true north.

strike (figs. 6, 7, and 11). But the core structure at Sterling Hill appears to have originated as an intrusive, metalliferous, fracture-and-fault-mediated hydrothermal plume with ferrous fluids infiltrating the carbonate layers, now located in the footwall fault block of the zero fault beneath the median gneiss (figs. 14 and 16). Tarr (1929) noted the necessity to assume that the ore protolith was originally a tabular mass within the limestone that may have developed “along a fissure of some type, or along some readily replaceable bed, either of which possibilities would (or could) permit the development of the tabular character, of the deposit.” He also noted that a branching bed at Sterling could be readily explained as a branching fissure structure.

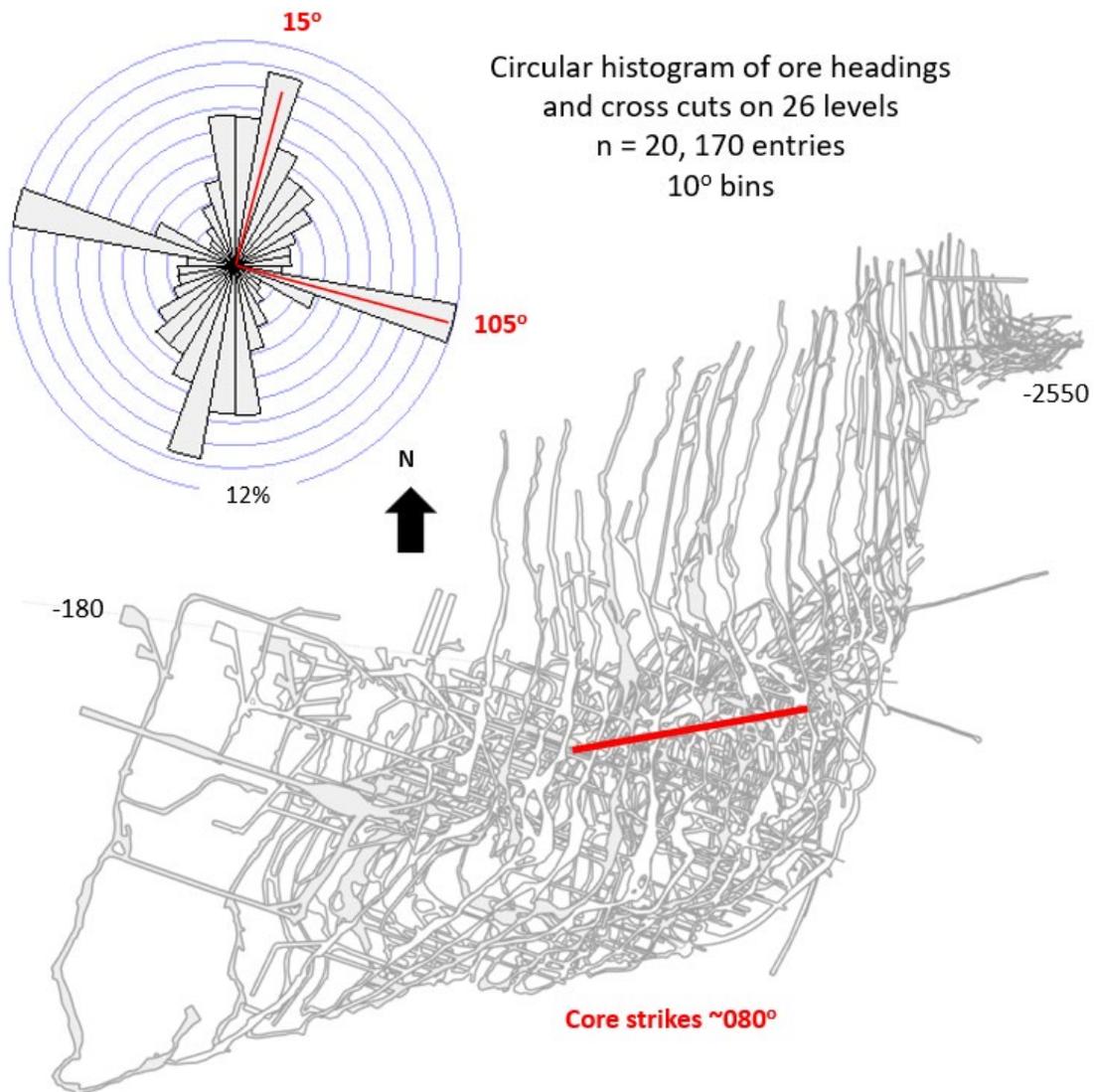


Figure 21. 2D polygons of the ore headings and cross cuts for the twenty-six mine levels of the Sterling Mine that were exported from SUP as a 2D AutoCAD DXF file and added to QGIS as a vector layer. The circular histogram is a plot of all of the headings for all of the different levels. The two dominant azimuths are 015° and 105°. The structural core of the ore body strikes ~080°.



Zero fault mapped at the -1850 to -2250 ft levels

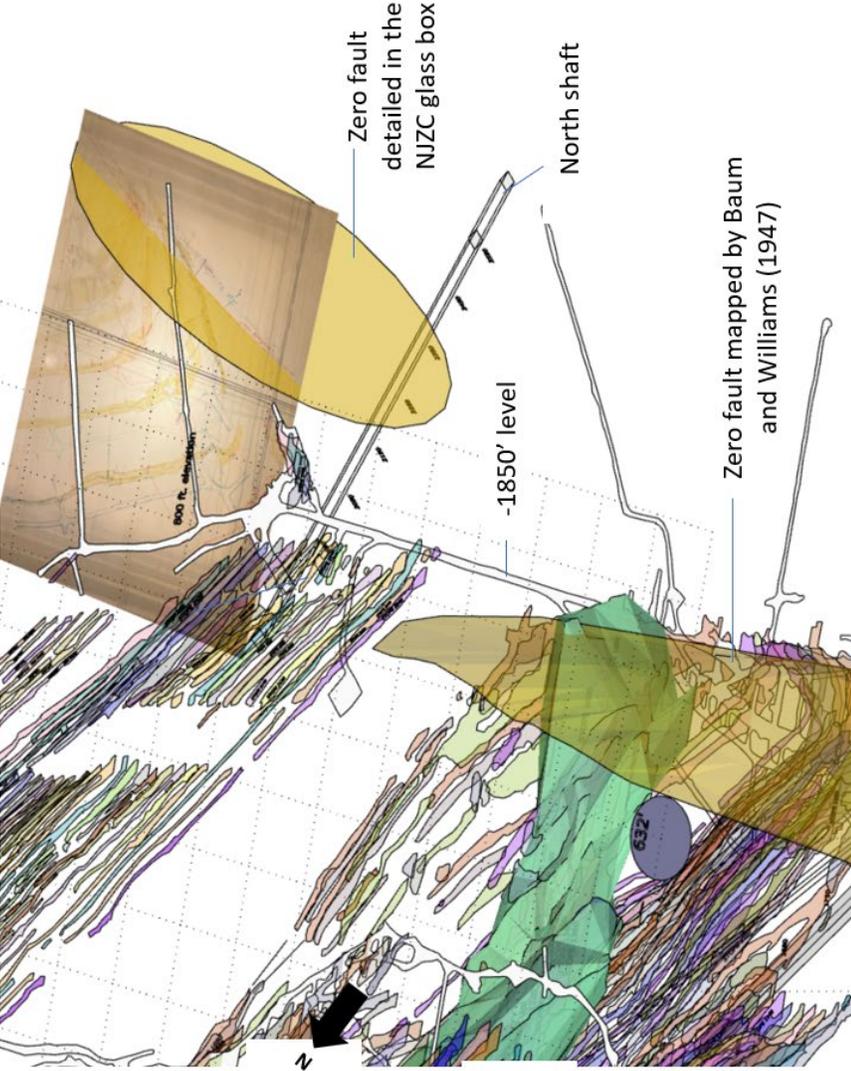


Figure 22. The zero fault was added into the Sterling model lower levels (left) based on its expression in the NJZC glass-box model (right photograph).

Rocks of the Losee arc predate the earliest Grenville tectonism and are characterized as a mobile arc complex, with the Franklin and Sterling zinc deposits likely originating in a back-arc basin (fig. 27 and Volkert, 2004). So, this was a tectonically active and thermally vigorous setting with concurrent igneous plutonism and faulting that helped drive crustal hydrothermal processes (fig. 16). The evidence compiled herein supports a metasomatic origin for these ore deposits that likely formed by infiltration of the Franklin Marble protolith by magmatically spurred, hydrothermal fluids discharged along an old reverse fault system that also cuts synorogenic type-

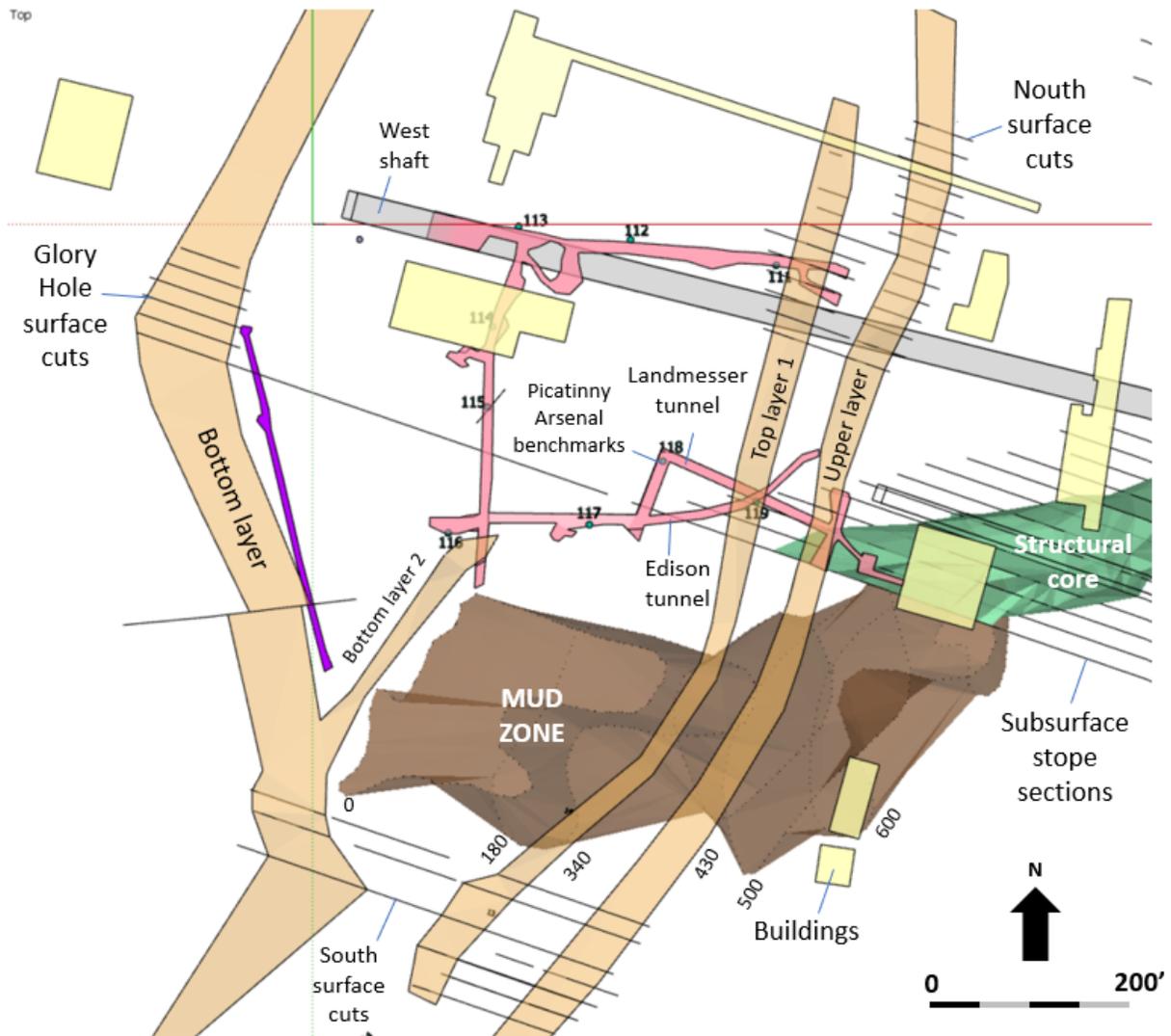


Figure 23. Top view (map) of the Sterling SUP model showing the mud zone relative to the structural core along with the tunnels used for the SHMM mine tour (pink). Other model elements include some SHMM buildings and subsurface features including the structural core (green TIN). Note where the sets of surface cuts occur.

A magmatic plutons (fig. 16). Puffer (2023) demonstrated that magmatically spurred anatectic melting and mineral fractionation occurred along the zero fault and other “penetrating structures” in the area where pegmatites associated with the Mt. Eve Granite occur. Metsger’s galena age (1100 Ma) overlaps with radiometric ages for the Byram and Lake Hopatcong A-type granite suites in the NJ Highlands (Volkert, Aleinikoff, and Fanning, 2010), and volcanism of the distant mid-continental rift (fig. 27). This must have been a huge tectonic event.

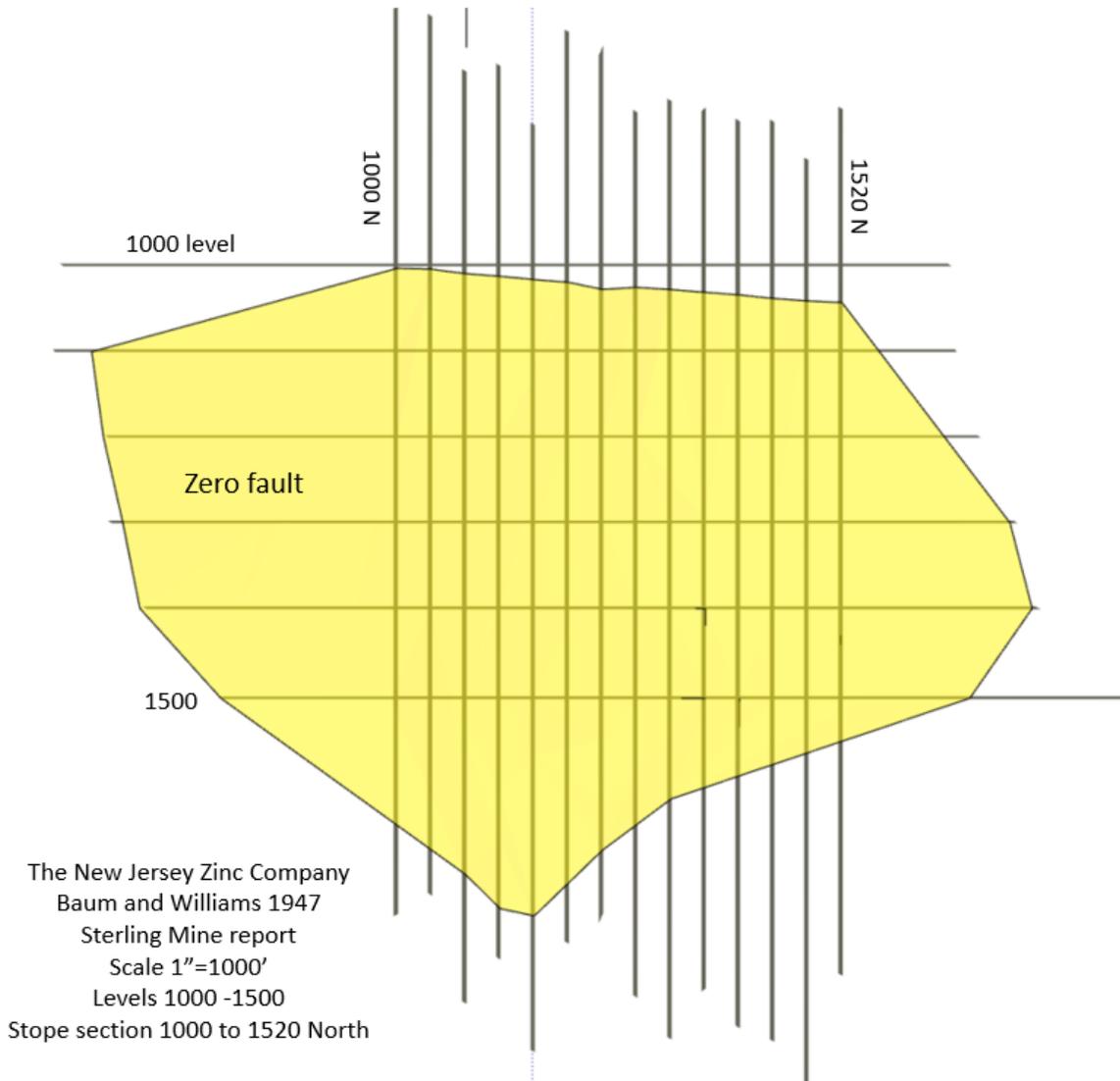


Figure 24. A NJZC internal report by Baum and Williams (1947) includes twenty maps and sections providing geological details on the structural and stratigraphic nature of the Sterling ore deposits for a 500 cubic-ft region of the deposit subject to faulting and shearing in the footwall of the Zero fault where the ore is spotty and lean (<8% bulk). The yellow area represents the Zero fault in longitudinal section based on its occurrence in the different levels and stopes.

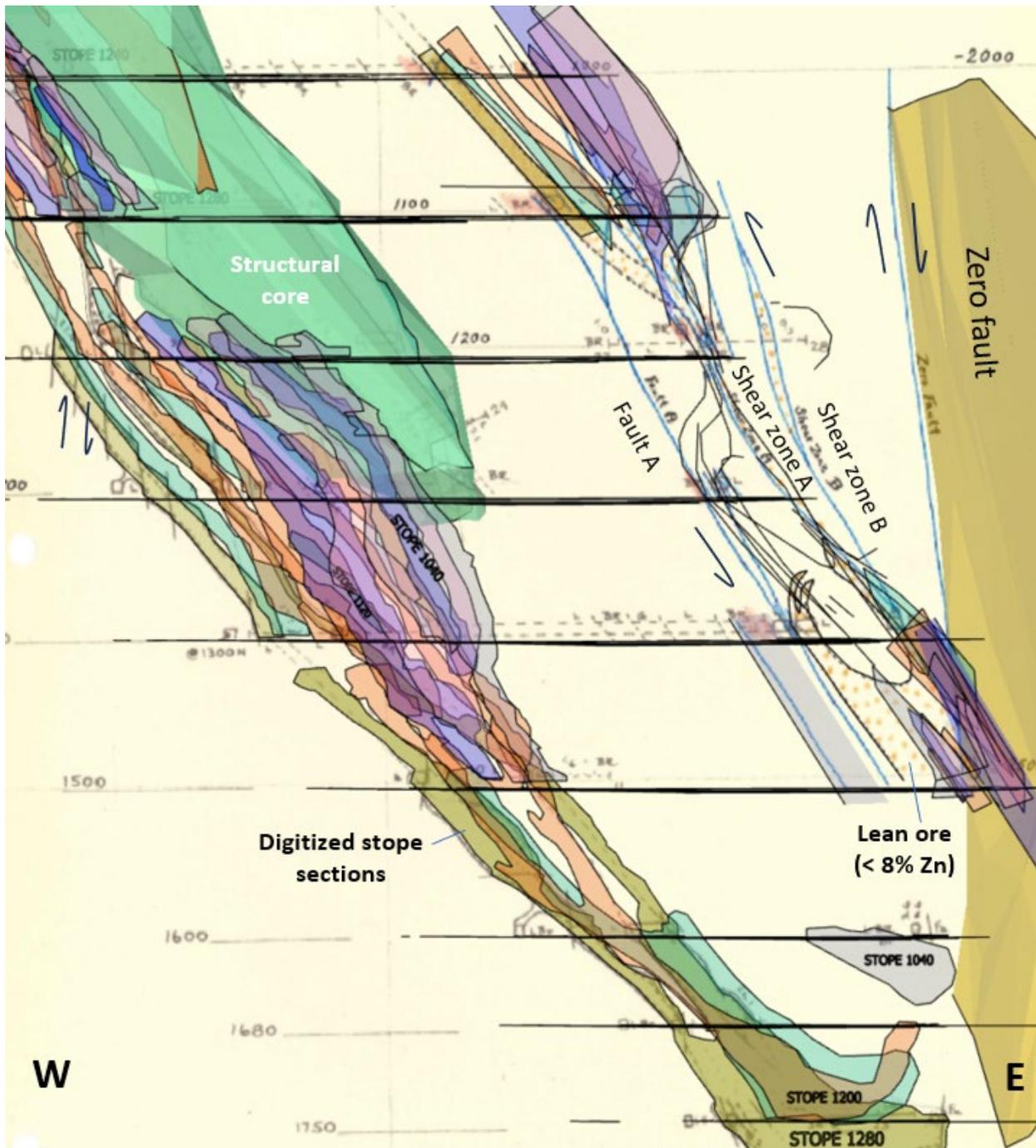


Figure 25. Part of the 1280 North stope section from the Baum and Williams (1947) Sterling report is shown with respect to some of the digitized ore layers and the structural core. The faulting history here is complex with reverse shear zones being subsequently stretched and down dropped along normal faults. The Zero fault likely has had several episodes of tectonic slip. Also note the faulting to the west that drops the ore layer down to the east, and the BR (black rock) layering beneath the upper ore.

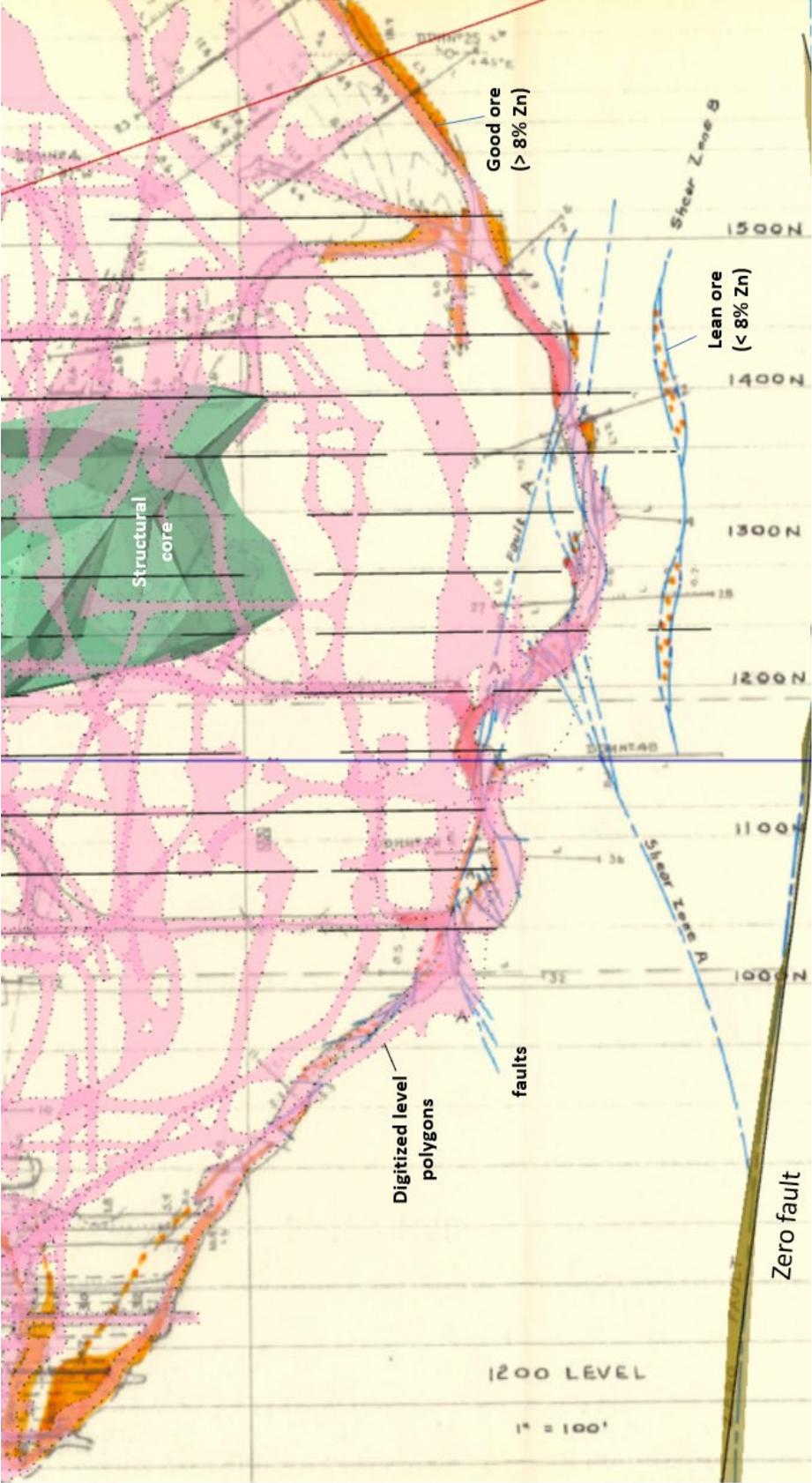
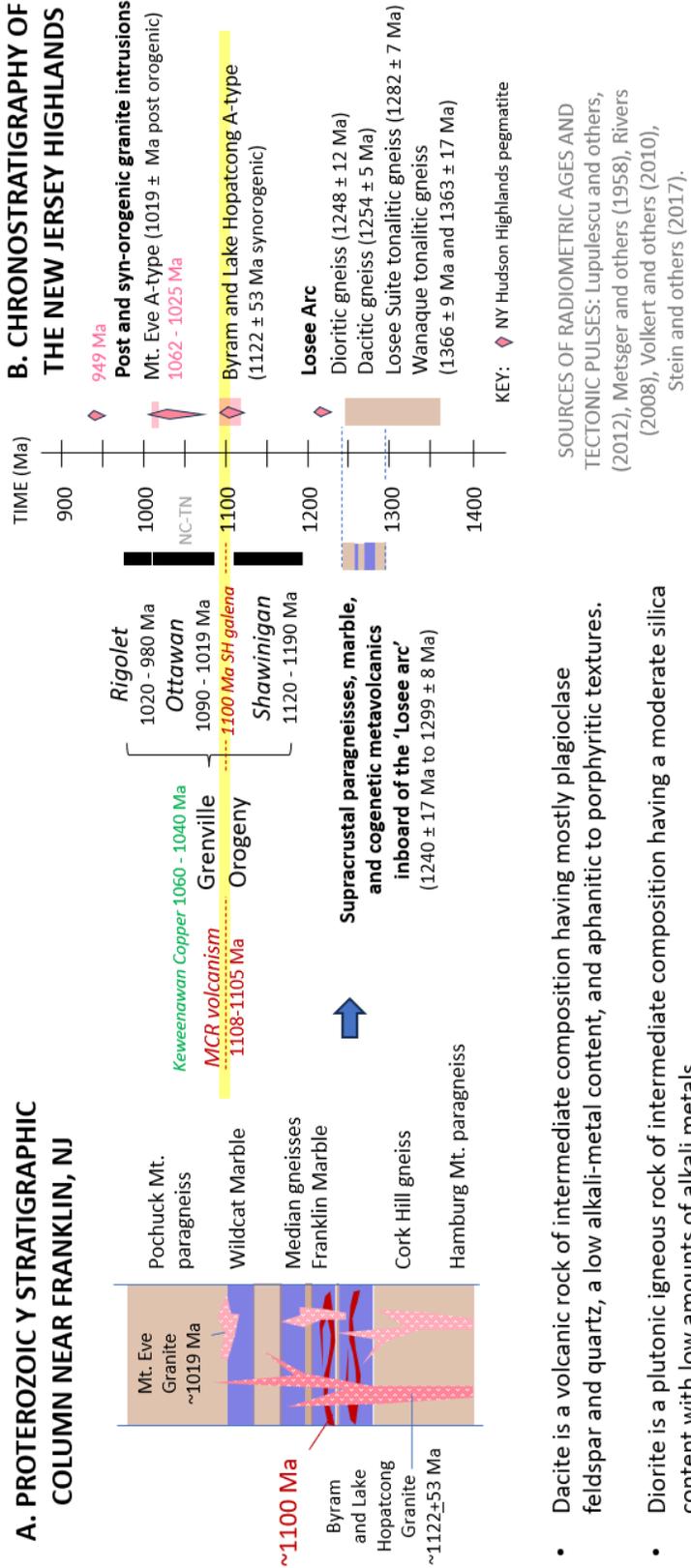


Figure 26. The 1200 level map from the Baum and Williams (1947) Sterling report shows how the upper, southeast layers of the ore body are locally sheared and stretched adjacent to the zero fault that has a complex movement history including reverse, normal, and oblique slips. The pink polygons are the digitized mine-levels, and the structural core (green TIN) is labeled. An 8% bulk concentration of zinc represent the cutoff between good (orange) and lean (orange stippled) ore. Drill and core holes are also noted on these maps in addition to smaller faults.



- Dacite is a volcanic rock of intermediate composition having mostly plagioclase feldspar and quartz, a low alkali-metal content, and aphanitic to porphyritic textures.
- Diorite is a plutonic igneous rock of intermediate composition having a moderate silica content with low amounts of alkali metals.
- Tonalite and Trondhjemite are plutonic, leucocratic igneous rocks of felsic compositions and phaneritic textures. Their bulk component is plagioclase feldspar with more than 20% quartz and less than 10% alkali metals. Amphiboles and biotite can be minor components with apatite, magnetite and zircon accessories. Trondhjemite is a tonalite with oligoclase.

Figure 27. Chronology of the Grenville tectonic cycle with respect to Mesoproterozoic (Y) stratigraphy near Franklin, New Jersey.

A mapped fault system shown in figure 18 cuts across the nearby northern highlands along the strike of Gerard and Beaver Lakes with ductile-brittle shear-zone geometry of possible Grenville origin. The angular gneiss blocks noted by Metsger and others (1958) that are entrained along the contacts with the hydrothermally charged marble makes sense when placed into a context of ductile-brittle, reverse shearing that is seen cutting across the highlands including the Franklin Marble where the ore occurs. The metalliferous plume likely flowed along and discharged from component faults in this system into the compressed and sheared footwall hinge zone of the Franklin-Sterling Hill syncline. This locally involved ductile flow of the marble protolith with entrained, brecciated blocks of a suprajacent, dark-gray protolith (figs. 12 and 16). Overall, the mineralized stratigraphic succession now holds dike-and-sill-like structures that were subsequently buried, compacted, metamorphosed, further sheared and tightened, then stretched and segmented by normal faults (figs. 15, 16 and 26) before Cenozoic exhumation.

The fluid nature of the ore infiltration can be directly observed near an excavated ore layer in the Passaic Pit where a webwork of franklinite weaves through dolomitic marble (fig. 28 and (field guide STOP 1). If Metsger's (1980) 1100 Ma age of the galena deposit within fractured marble is the age of initial mineral infiltration, then that phase of tectonism occurred after the first compressive pulse of the Grenville tectonic cycle (Shawinigan; figure 27). Grenville-age rifting also occurred in the area as evidenced by the hypabyssal, diabase dikes that crop out just a few miles south of Sterling Hill (Volkert and Montverde, 2013; Volkert and Puffer, 1995). But it's unlikely that the observed plasticity associated with the ore development would arise from post-orogenic relaxation and crustal stretching accompanying dike emplacement. It is however possible that another mineralization phase accompanied the post-Shawinigan rift event because there is more than one zinc-mineralization event at Sterling Hill as seen in figure 4 and reported by Verbeek and Grout (2018; 2025). An Alleghenian zinc-mineralization phase is also possible from fluid mobilization accompanying ductile shearing of the ore body as seen in the Baum and Williams report where the ore is lean. The Franklin-Sterling Hill ore deposit therefore appears to consist of metalliferous layers, and various cross-strike feeder structures that were emplaced then buried deeply, compacted and metamorphosed to sillimanite grade prior to uplift and partial surface exposure preceding deposition of the Cambrian Hardyston alluvium. Metsger (1980) noted the rubbly, weathered nature of the Precambrian erosion surface. Episodic hydrothermal alteration of these deposits has also repeatedly occurred here (Verbeek and Grout, 2018) and will likely occur again.

The structural form of the stope sections and outcropping structures also provide insights into the nature of probable Paleozoic orogenic strains that further shaped the ore body. For example, the Sterling and Franklin stope sections repeatedly show three- to twenty-foot subhorizontal, top-to-the-northwest offsets of the ore body that provide a measure of fault slip resulting from the brittle shear zones that permeate the region during Late-Paleozoic Alleghanian

orogeny (fig. 29). The sheared and slickenside-covered hanging wall of the ore excavation at field STOP 1 in the field guide exemplifies these reverse shear zones that later compacted and thickened the sequence during Alleghenian Mountain building and northwestward crustal translation (Herman, 1992;2002). Structures in the southern highwall of the Sterling Noble Pit (field STOP 4) also shows this. The samples of smeared-out mylonitic ore in the Zobel Hall museum attest to the ductile component of the brittle-ductile incremental strains that accompanied Appalachian orogenesis after final crystallization of the marble and ore (fig. 30). This is congruent with what is seen elsewhere in the region; Alleghenian-age orogenesis prior to the onset of Mesozoic Newark rifting leading to the opening of the Atlantic Ocean basin (Herman, 2002; fig. 8). Nevertheless, all of the faults are of uncertain ages until radiometrically dated and of uncertain slip distances unless directly measured using offset indicators. No such indicators were observed in outcrop, but some can be traced in aerial imagery (see field guide). Structural interpretation only offers hypothetical solutions that can be tested and modified if necessary.

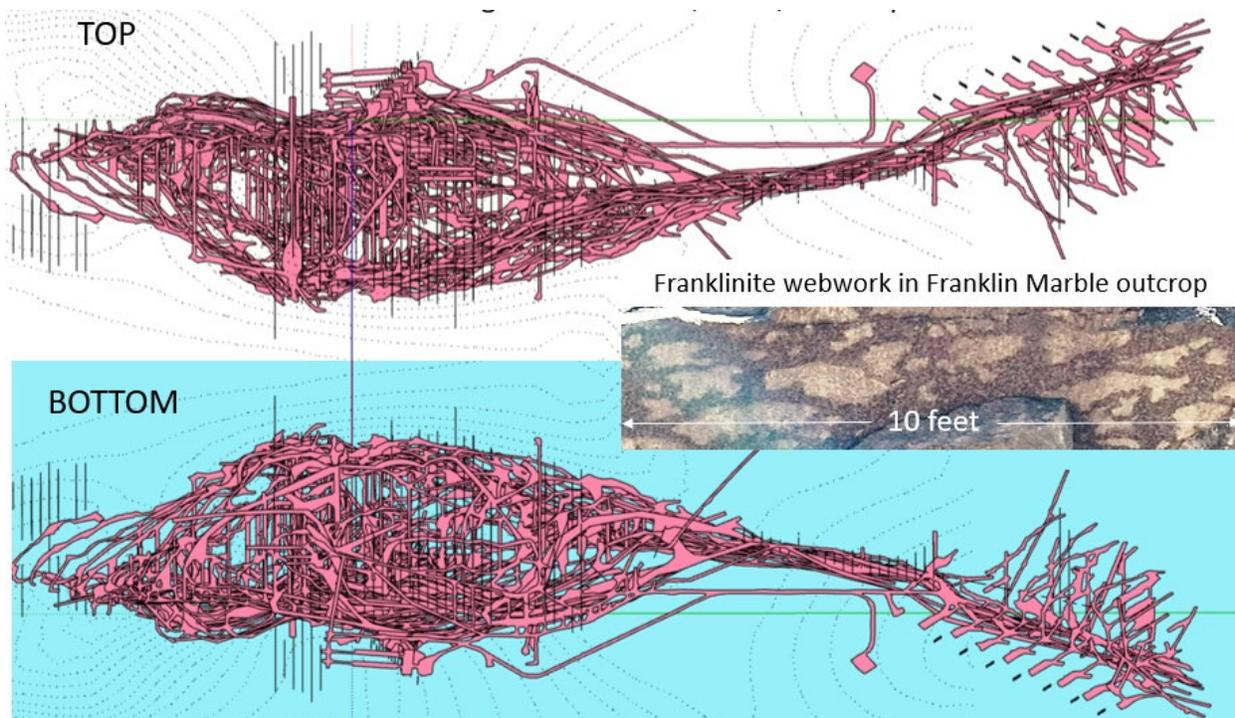


Figure 28. Top and bottom views of the composite Sterling Mine works including the digitized ore drifts and cross cuts on all levels, and the stope sections (thin black lines vertical lines). 3D hypsography is shown as thin dotted lines using 10-ft contours. The inset diagram shows the mineral-infiltration pattern of franklinite in marble as seen on the underside of a marble layer at field STOP 1. These analogous patterns suggest that the mineral complex was compressed and squeezed again after infiltration in a direction normal to these elongate mineralized layers. The deepest workings correspond to the fishtail on the right.

Please see chapter 3 of this volume by Verbeek and Grout (2025) for more information about the nature of faulting at Sterling Hill.

The southern high wall in the Noble Pit is an ore-bounding fault that's likely a Newark-age normal fault (figs. 3, 6, 15 and field guide STOP 3). Other, similar faults also offset the Franklin ore body in places as portrayed in figure 6B. These too are probable, Mesozoic faults that strike parallel to those involved in Newark rifting to the east (fig. 18). Extension through this region was extensive, with Jurassic dikes emplaced even further westward into Pennsylvania along the northern Susquehanna River Valley (Herman, 2013). Rodger Faill (2003) also recognized the widespread nature of mid-Atlantic Mesozoic rifting, but the importance and extent of widespread tectonic stretching only became more apparent recently with the advent and use of LiDAR and virtual globes like GE that bundle historical imagery into their visualization tools. In particular, their 2002 aerial imagery (fig. 18) is very good at revealing geologically induced topographic breaks along known Newark trends throughout the northern New Jersey region with north-to-south striking fault blocks that are inherited from a late stretching phase directed eastward (Herman, 2015). Accordingly, the mine and work gaps together with the offset of the

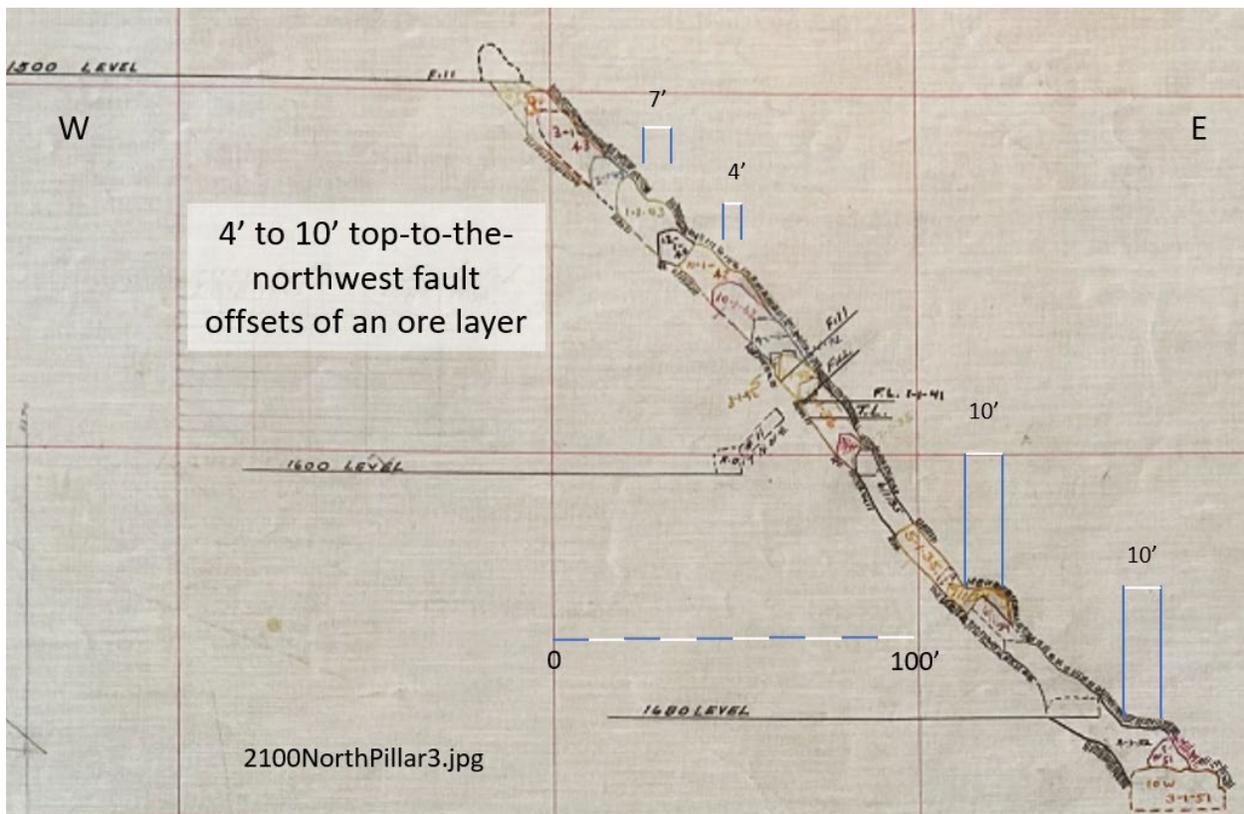


Figure 29. A photograph of the 2100 North Pillar stope section is used to illustrate how the ore layers are pervasively sheared with top-to-the northwest offsets. These offsets are likely Alleghenian faults that contracted, thickened, and elevated the New Jersey region during the Appalachian orogeny.

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ore bodies between Sterling and Mine Hills probably results from breakage and weathering along faults resulting in Mesozoic rifting and wrenching of the crust immediately prior to birth of the Atlantic Ocean. Altogether, the stope gaps and structural fragmentation and jostling of the ore body reflects incremental brittle and ductile compressional strains accumulated during bulk shearing and translation before segmentation and stretching with brittle normal faulting.

THE NJ STATE MUSEUM METSGER ESTATE COLLECTION (NJSM NH2013.15)

Most of the contributors to the GANJ 41 guidebook and conference proceedings met on May 4, 2025 near Franklin to begin coordinating activities. Earl Verbeek told us then that part of the NJZC information was given to the New Jersey State Museum (NJSM) in the late 1980s by the estate of Bob Metsger. I subsequently planned a trip to the museum on Friday June 27, 2025 to meet Rodrigo (Rod) Pellegrini, Registrar of Natural History, to review the NJZC materials. I drove there with J. Mark Zdepski and also met with Mike Di Maio and Julia Vastano, NJSM assistant curator for Natural History. We spent a few hours together combing through the archived samples, thin sections, maps, and documents that are now housed in the natural history specimen storage areas of the NJSM. We photographed select materials and learned about how the museum had begun cataloguing the collection. The collection has a preliminary index that was shared by the museum and is available on the GANJ/2025 website. Please see Rod Pellegrini's abstract at the front of this volume for more information about the NJSM Metsger collection.



Figure 30. Mylonitized zinc ore in Zobel Hall, Sterling Hill Mining Museum.

Despite having time to only glance at about half of the NJSM holdings, we located and copied two important internal documents during this visit that have a significant bearing on this study. The first one is a deep cross section of the area constructed along the 1600 North stope that is based on exploratory rock coring (fig. 12). It illustrates the bedrock geology of the Ogdensburg area to over one mile beneath the ground surface and shows the Mesoproterozoic rocks folded into a tight, upright syncline that is cut by the zero fault that dips steeply east through the hinge area, and offsetting the opposing fold limbs. One core hole shown on this section transects the hanging wall of the zero fault and now resides in the Rutgers core repository (table 1). The locations and lengths of other rock core hole from Sterling Hill and Franklin that are included in table 1 require confirmation. A second document of note is a 1947 internal report by John 'Jack' Baum and William Williams, geologists for Sterling, titled "The nature of ore occurrence and structure in the lower portion of the East vein at Sterling". Jack Baum was the NJZC chief geologist (1950 to 1981) before Bob Metsger (1981 to 1988) and was involved in exploration and mining there and elsewhere for decades. No other information was found about Mr. Williams from a cursory Internet search using his name and employer. This report includes structural and stratigraphic details of the sheared-out eastern limb of the regional syncline between the -1000 and -1500 levels and the 1000 to 1520 north stope sections (figs. 25 and 26). The maps are at 1 in: 100 ft scale and include some bulk zinc concentrations of specific ore layers that range from 8% to over 30%. Layers of dark gneiss labeled "black rock" were also mapped in drifts cutting the marble. The black rock is reported as having originated as siliceous and aluminous interbeds of clastic and possibly igneous origin within an impure limestone (fig. 25). The layers of black rock comprise less than half of the bulk of the Franklin Marble and are situated beneath the Median Gneisses, of which there are two (fig. 12). Ore mineralization is associated with the black rock where haloes occur around fragments floating within the marble, and in the marble adjacent to thick black-rock layers (fig. 25). They point out that the entire complex was folded during the process of ore emplacement, and then the beds were further distorted through faulting and drag folding resulting in the distortion of horizons favorable for ore. They illustrate the overall distortion of the ore body from late tectonic stretching. The stope sections show that the structure of the limestone and black layers form interlayered marble and gneissic lenses with favorable ore horizons developed in the carbonate-rich layers.

SHARED COMPUTER-MODEL FILES

The SUP and associated files used to build the Sterling Hill and Franklin models are available on the Internet as free downloads from the 2025 GANJ website at the URL www.ganj.org/2025/data/. The following list summarizes the respective shared files:

File (file size and date)

SketchUp Pro (SUP) files (rev. 2024)

2025-07NJZCSterlingMineR19.skp (377,789 KB 07-28-2025)

2025-06NJZCFranklinMineWODTM.skp (42,456 KB 06-07-2025)

2025-07NJZCSterlingMineBaumandWilliamsZeroFaultR19.skp (14,942 KB 07-06-2025)

Compressed ZIP files of level and stope raster imagery

NJZCSterlingMineLevelMaps.zip (170 MB, 07-13-2025)

NJZCSterlingMineStopeSections.zip (116 MB, 07-13-2025)

NJZCFranklinMineStopeSections.zip (138 MB, 07-13-2025)

Google Earth Pro KMZ file

2025GANJ41NJZCSterlingHill&FranklinMines.kmz (4,019 KB, 07-18-2025)

MS Excel file

SomeVerbeek&Grout2025StructuralDataGCH09-26-2025.xlsx (51 KB, 09-26-2025)

Using the SUP models requires a proficient level of familiarity with the software. Users assume all risks and responsibility for their access and use. It's advised to download the original file, copy it, and rename it before implementing any further changes. The associated sets of raster imagery that the models were built from are also shared as compressed ZIP files. The ZIP files must first be decompressed into their individual files before reinserting them into the SUP models using embedded image frames (fig. 19). File types for Sterling Hill include TIFF and PNG but only PNG files for Franklin.

A derivative GE KMZ file is also shared that includes selected elements for each model that were imported and georegistered in GE as Collada objects (DAE files; figs. 31 and 32). These models can be interactively displayed and manipulated by anyone using the program. As a reminder, the Franklin Mine model is only partly developed in comparison with the Sterling Mine model. The Sterling DAE derivative model includes only subsets of model objects including TIN surfaces, 2D level polygons, 3D shafts, and cross sections of the surface cuts. The objects can be manipulated in 3D space in GE by accessing the model after loading the KMZ file, and adjusting its elevation in the following manner:

Open the KMZ file listed above, expand the folder to access an embedded *.dae object (MineHillFranklinR19C.dae or 2025SterlingMineR19CTINS.dae). Then, using a computer mouse, touchpad, or control arrows and <Enter> keys,

- 1) Activate a DAE model by checking its box and select a DAE object. The background will be blue when selected and active.
- 2) Right-click <Properties> or left click <Edit><Properties>.
- 3) With the object active and highlighted by green handles, click on <Altitude> and adjust its height from <Clamped to ground> to <Relative to ground>, and then use the slider or enter a desired elevation to raise and lower the model vertically.

A METHOD FOR CONVERTING STERLING HILL MINE FEATURES HAVING NORTH AND WEST COORDINATES (FEET) INTO GEOGRAPHIC DECIMAL DEGREES (WGS84)

This section summarizes a method for accurately calculating geographic coordinates (WGS84 - decimal degrees) of point-based mine features using north and west coordinate feet and the Sterling Mine grid (figs. 6 and 19). The methodology uses directional sines and cosines programmed into a Microsoft Excel spreadsheet to convert mine coordinates based on a reference grid that's rotated about its origin point 19° clockwise relative to true north (fig. 33). The north and west offsets of a point location are first converted to longitude (LON) and latitude (LAT) decimal degrees and then added to the geographic coordinates of the model origin point to compute its rotated location. The methodology uses the four equations below:

$$\text{Equation 1. } \text{WEST}_r = \text{WEST} * 0.94551857 + \text{NORTH} * 0.32556815$$

$$\text{Equation 2. } \text{NORTH}_r = -\text{WEST} * 0.94551857 + \text{NORTH} * 0.32556815$$

$$\text{Equation 3. } \text{LON}_r = \text{LON}_0 + (\text{WEST}_r * 0.00000368)$$

$$\text{Equation 4. } \text{LAT}_r = \text{LAT}_0 + (\text{NORTH}_r * 0.00000276)$$

The coordinate transformation is thus completed in two steps: Equations 1 and 2 calculate the north and west offsets resulting from the 19° grid rotation (fig. 33). Equations 3 and 4 compute the rotated geographic coordinates (LON_r, LAT_r) by adding the results derived from the first two equations to the geographic origin of the mine grid (LON₀, LAT₀). The trigonometric method is diagramed in figure 33 together with the charted results of a methods test using the ground-level field stations of Verbeek and Grout (2025; chapter 3). A MS Excel workbook containing the mathematical solutions for deriving rotated mine coordinates is included in this year's data downloads page on the internet (see file details listed in the prior section). The impetus behind deriving these relationships was to visualize the Verbeek and Grout (2025) fault data (Chapter 3).

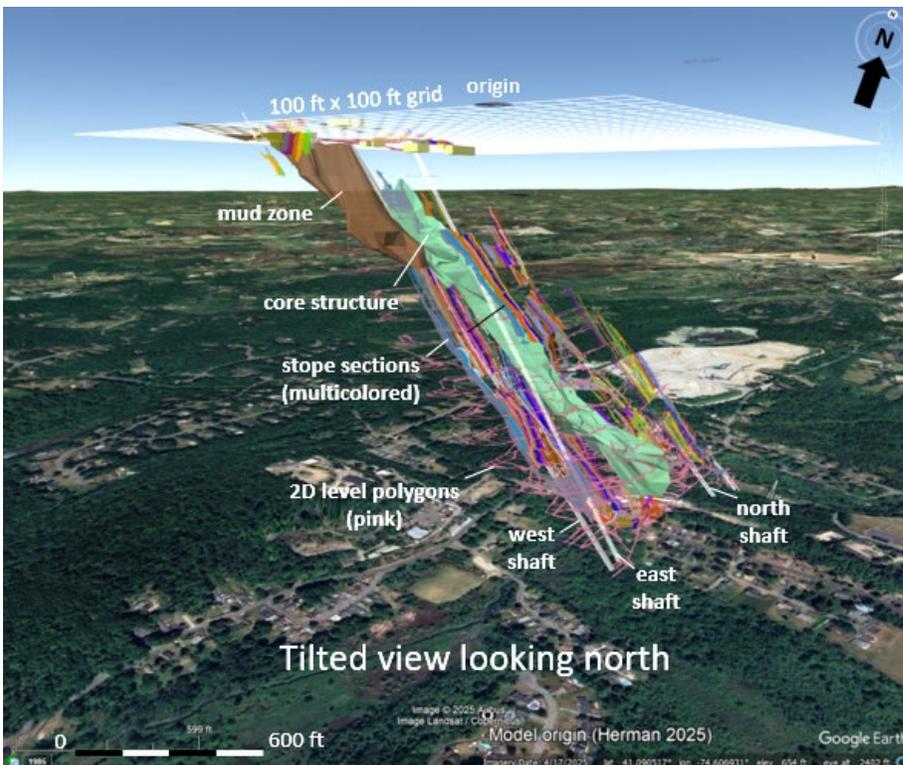
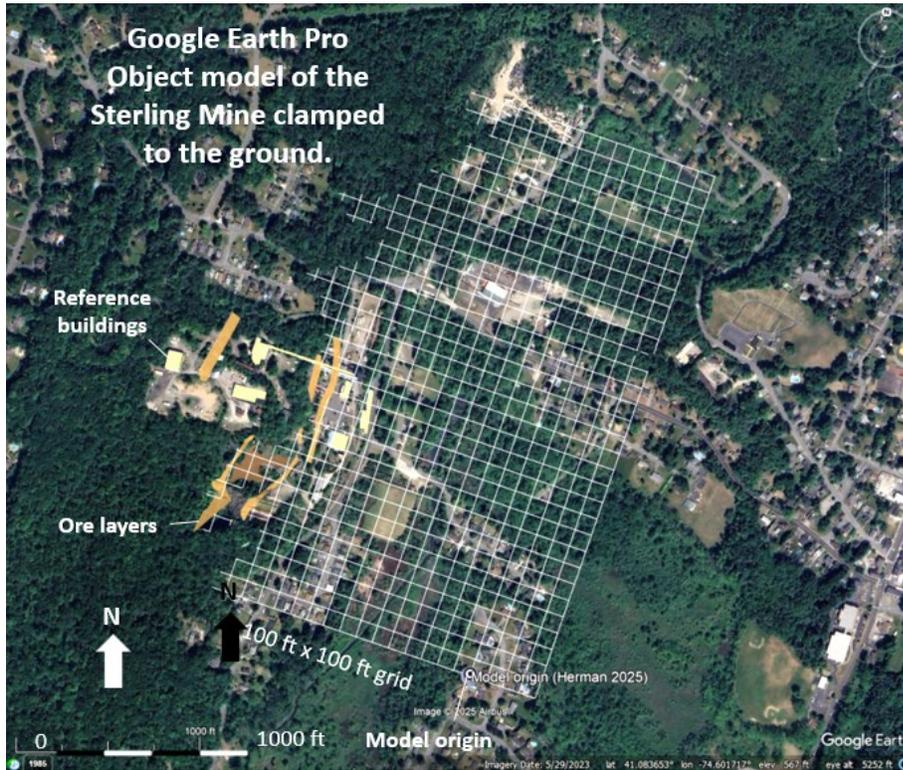


Figure 31. Map (top) and oblique, north view (bottom) of part of the Sterling Mine model that was added to a GE KMZ file as a Collada object (*.dae file). The map view has the model clamped to the ground. The bottom view shows the model raised 600 m (~1968 ft) vertically above ground. Only select components of the SUP model were exported as the DAE object model including the mine grid, reference buildings (yellow), and surface cuts in the ore body (multicolored). Ore layer surface traces appear as orange stripes in the map view. TIN surfaces of the structural core (green) and mud zone (brown) are shown below along with stope sections (multicolored), 3D shafts (white), and the twenty- six level polygons (pink).

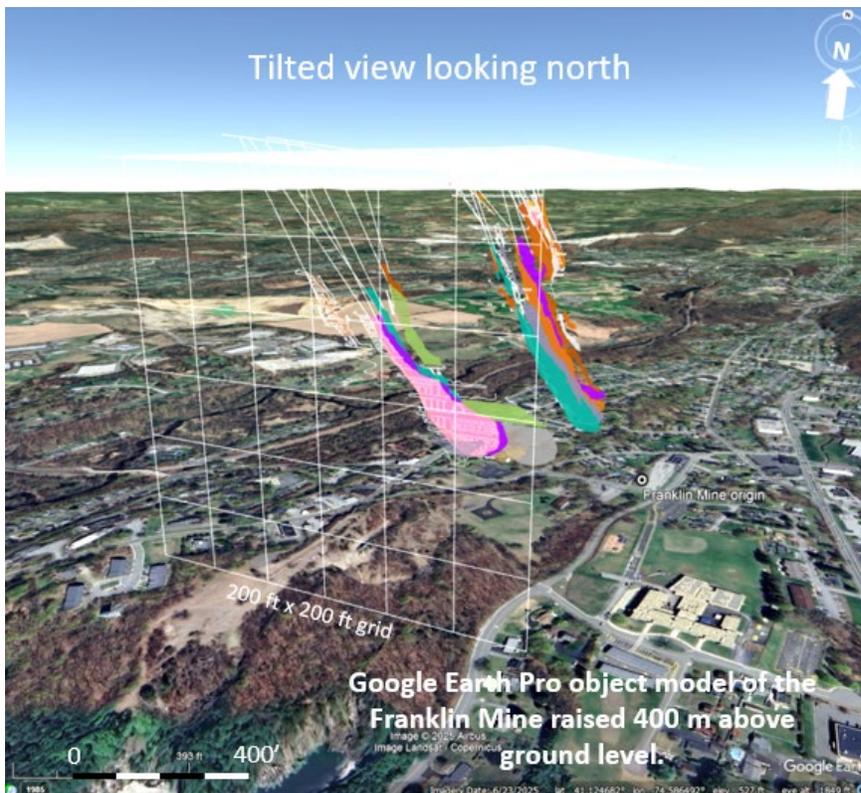


Figure 32. Map (top) and oblique, north view (bottom) of part of the Franklin Mine model that's was added to a GE KMZ file as a Collada object (dae file). The map view has the model clamped to the ground. The north view shows the model raised 400 meters (~1312 ft) vertically above ground. This object model includes the mine grid, some multicolored stope sections, and line projection of the ore body to the surface.

Their observations and measurements constrain the location of reverse and normal-fault systems that help shape the ore body as illustrated using the aforementioned 3D CAD models. Discreet representation of 3D faults is made possible with the GE Pro virtual globe that can display oriented, colored, and scaled geological symbols to portray their orientations in geographic space relative to geological contacts and other mapped features (fig. 31, 32, and 34). Figure 34 features a GE Pro KML file of 308 oriented and scaled red ellipses generated from the near-surface fault data by Verbeek and Grout (2025 and Chapter 3). The KML was generated using the online geology tool www.impacttectonics.org/GeoTools/exceltoKML.html. This KML is only a subset of their report that details the mineralogy and slip directions of 1362 faults measured in the mine levels from -1200 ft to the surface before the mine eventually filled with groundwater.

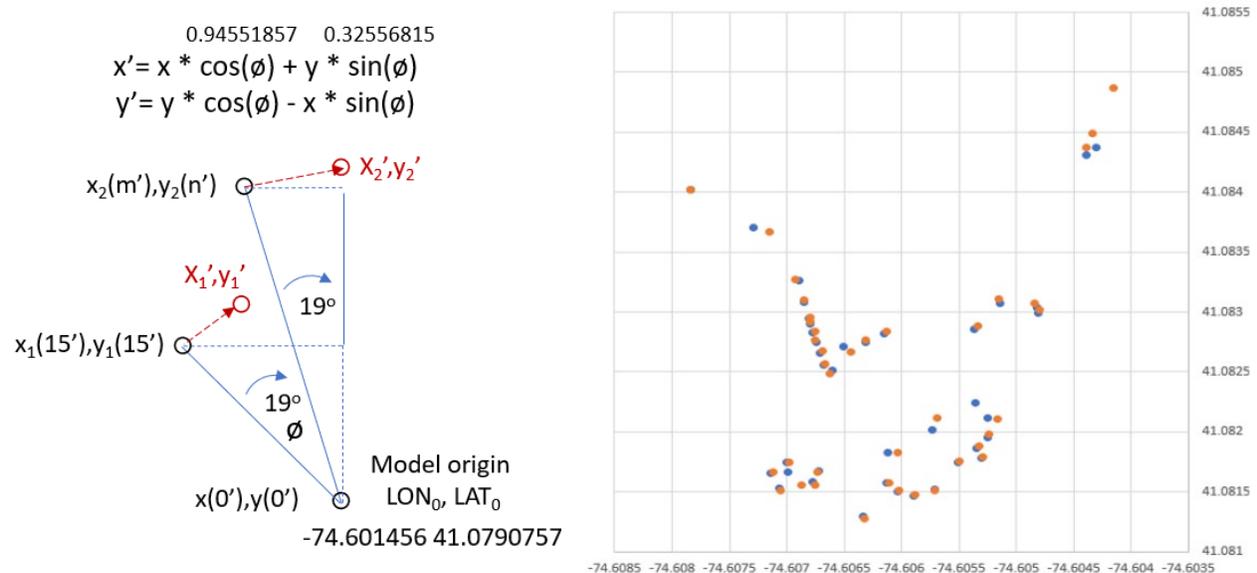


Figure 33. Left diagram illustrates the geometry of rotating 2D points 19° clockwise from the Sterling Mine model origin located at coordinates zero north and west, to the corresponding geographic coordinates. The scatter plot to the right compares the locations of thirty-nine, ground-level field stations recorded by Verbeek and Grout (2025) using the Kroth (1993) map (blue dots) in comparison to those derived using equations 1 to 4 to calculate geographic coordinates for each field station based on listed mine coordinates (orange dots). Local discrepancies arise from arbitrarily digitizing a point location for stations collected on a traverse having multiple fault readings. The MS-Excel spreadsheet included in this year’s data downloads contains the conversion formulae and graph above for some of the Verbeek and Grout (2025) faults mapped near ground surface.

SUMMARY COMMENTS

- 1) The ore could have originated as a metalliferous, magmatically spurred hydrothermal plume of Mesoproterozoic age that was discharged from a fault zone into the Franklin Marble protolith (fig. 16).

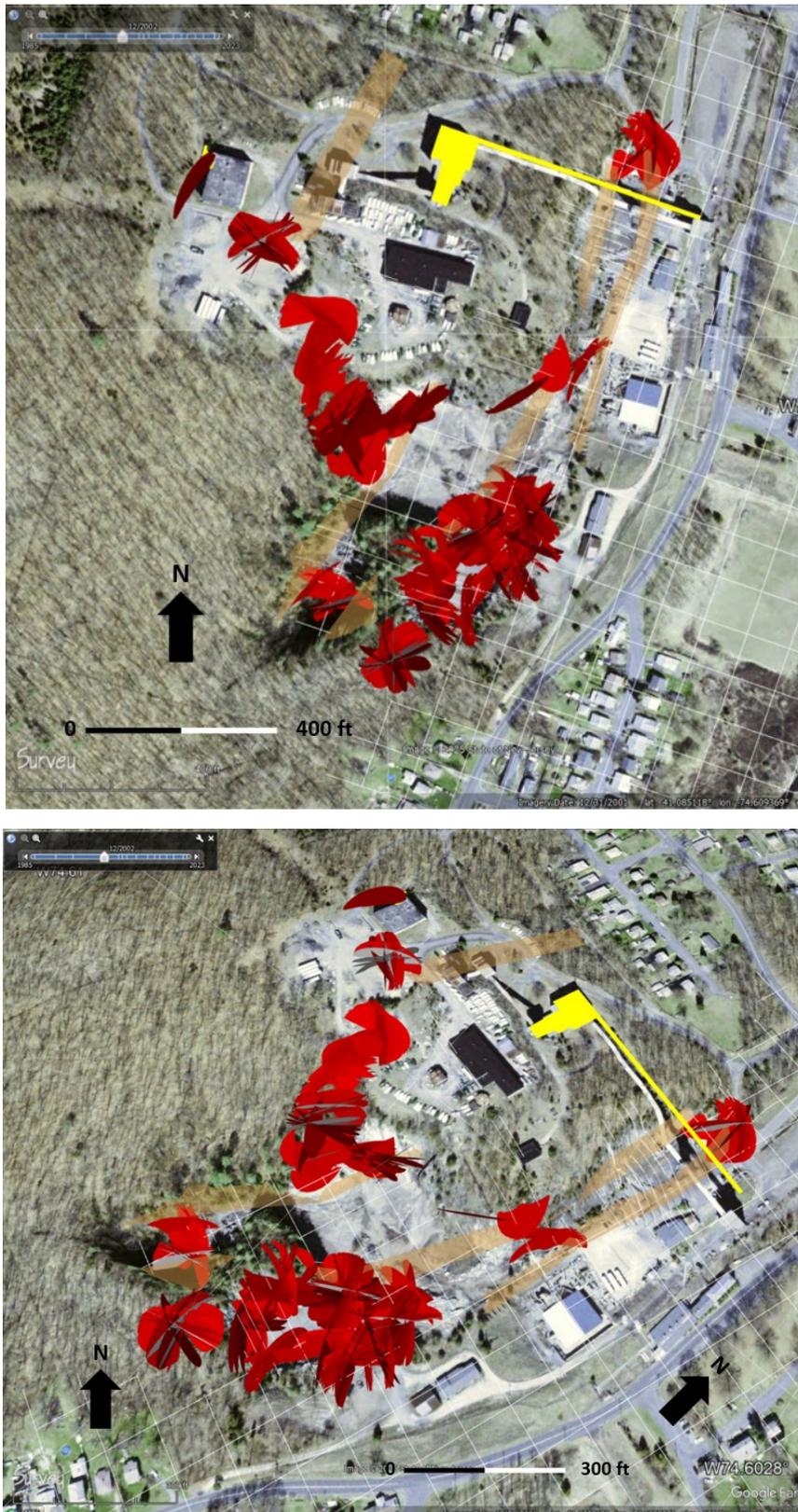


Figure 34. A 3D plot of 308 fault planes mapped at Sterling Hill near ground surface by Verbeek and Grout (Chapter 3) on a 2002 aerial image in GE Pro. Each red ellipse is scaled at 10-m strike and 6-m dip length (5:3 aspect ratio). The symbols were generated using WGS84 geographic latitude and longitude coordinates and structural dip /dip azimuth notation. The top diagram is a map whereas the bottom view is tilted and rotated clockwise. Further refinements can include variable scaling of smaller and larger faults. The yellow building is a reference building for aiding in geolocation of the associated 3D CAD model that was imported into GE as a Collada (*.dae) object model (fig. 32). The light orange stripes are the ore layers projected to ground surface.

Chapter 2. Structural, Tectonic, and Geospatial Aspects of the
Sterling and Franklin Zinc Mines, Sussex County, New Jersey

- 2) The Gerard and Beaver Lakes fault system mapped to the east is a candidate source for the ore fluids because it cuts across Mesoproterozoic protoliths in the Sterling Hill and Franklin areas (fig. 18).
- 3) The ore body has sill and dike-like segments including a thick, long, and internally complex core zone striking about N80E around which the mining efforts at Sterling Hill were focused (figs. 13 and 14).
- 4) The structural core thickens to the east where it butts up against the Zero fault in the N1600 to N1680 stopes where the east and west limbs nearly connect.
- 5) The structural core branches into mineralized layers lying above and below it.
- 6) The mineralized structural core strikes ~N80E, the adjacent, mineralized layers strike ~N20W to N20E and average ~ N-S, and the mineralized cross layers, or members, strike ~N20E to N50E.
- 7) The ore body in the Franklin Mine has a sill-like form with a fattened eastern termination and an upturned, curved shape similar to the northern ore body at the Sterling Mine (figs. 5, 10, 11, 31, and 32).
- 8) Crystallization of the ore minerals occurred after emplacement of the iron and zinc-rich fluids, but before ductile-brittle shearing and brittle stretching of the ore body, because there is no indication of preferred crystal alignment from dynamic movements accompanying crystallization (fig. 4).
- 9) Metal cations were fractionated and segregated upon emplacement before deep burial, compaction and crystallization of the ore bands because the three primary ore minerals occur in different strata, and there is lack of evidence for extensive fluid exchange accompanying regional metamorphism.
- 10) The franklinite and black willemite layer at the bottom of the Sterling Hill ore body is about 30 ft thick in the west high wall of the Passaic Pit (see field guide STOP 5).
- 11) The first layer above the mud zone and structural core at Sterling Hill is comparatively thin (~12 ft), with a basal franklinite layer a few feet thick underlying willemite and zincite layers in the rock pillar with the saw cuts in the Passaic Pit (see field guide STOP 3).

- 12) The uppermost, eastern ore layer at Sterling Hill no longer crops out and seems to have been thoroughly mined and/or sheared out near ground surface.
- 13) The early mining approaches at Franklin used systematic arrays of pillars to shore up level roofs. Ore was first extracting ore from many small, excavated chambers (fig. 35) before removing the pillars by top slicing before backfilling the excavations. Mining at Sterling benefited from the experience gained at Franklin as they were able to confidently open up larger stopes using the same mining methods (figs. 5, 9, 10, and 13).
- 14) The highest-grade ore lies in the structural core and adjacent, infiltrated layers away from areas that have been repeatedly sheared and faulted during successive tectonic events, especially in the footwall of the zero fault where ore is spotty and of lower grade.

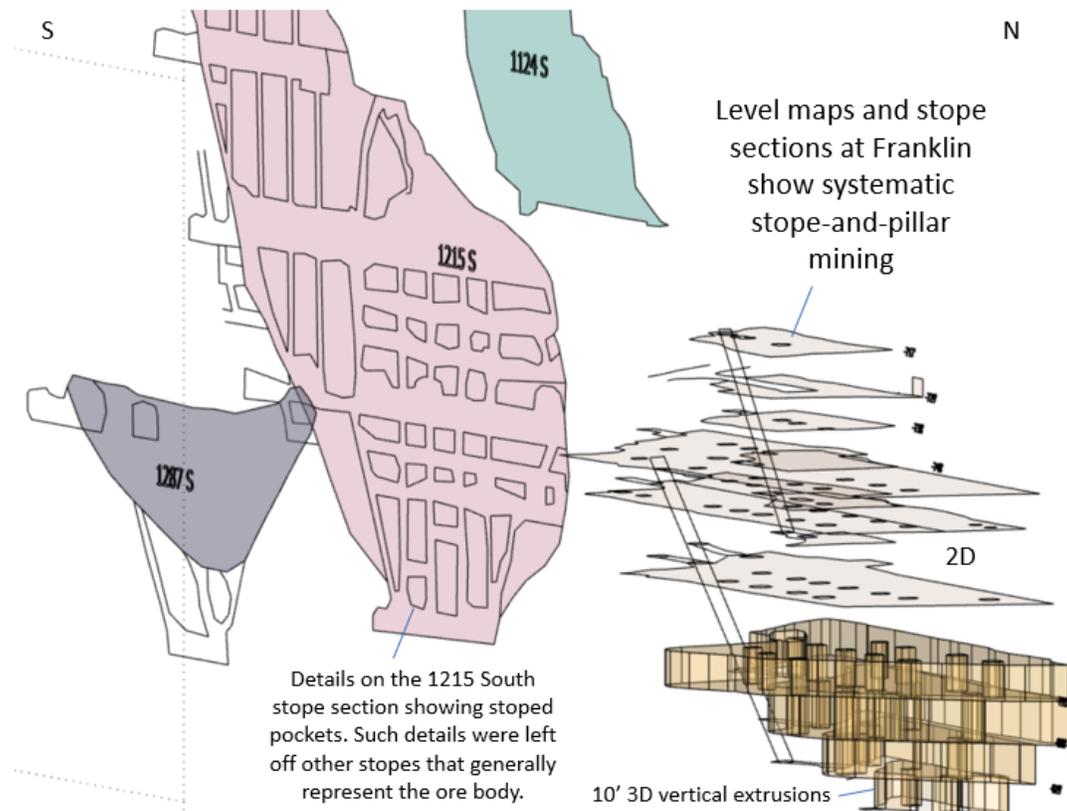


Figure 35. An oblique, WNW view of part of the Franklin Mine showing representative 2D and 3D polygonal elements including three 2D stope sections (left and top) and 12 level maps on the right, with four extruded 10 ft vertically to illustrate aspects of the shrinkage, stope-and-pillar mining method. The details captured on the stope sections are only shown for the 1215 South (S) stope section.

- 15) The ore body was compressed, structurally thickened, and thrust westward during Alleghanian orogenesis that imparted brittle-ductile structures striking about $\sim 040^\circ$ to 060° , at an acute angle to Mesoproterozoic ones striking about E-W (fig. 15).
- 16) The ore body was structurally segmented by normal faults and dropped downward during Triassic-Jurassic regional rifting (fig. 18). Old reverse faults may have been reactivated with normal and oblique movements during east-and north directed stretching. The ore body was compressed again, sheared northward, and uplifted to the surface during the Eocene that resulted in a regional, Oligocene unconformity (fig. 8). The orientation of fault identified by Verbeek and Grout (2025; chapter 3) as set 4 may stem from this tectonic pulse.
- 17) The ore body was compressed again, sheared northward, and uplifted to the surface during the Eocene that resulted in a regional, Oligocene unconformity (fig. 8). The orientation of fault identified by Verbeek and Grout (2025; chapter 3) as set 4 may stem from this tectonic pulse.

After digitizing the set of raster imagery for the Franklin stope sections and extracting vector-polygon representation of the respective mine components, and then upon returning the maps to the SHMM map room and appropriate drawer, I saw another map folder that held all of the level plans. Apparently, some of the level maps that I digitized from the stope-section folder had been used and then misplaced back into the wrong folder prior to this effort. The amount of information that remains to be added to the Franklin model is robust.

Upon learning that some of the diamond-drill-hole (DDH) rock core from the Franklin Mine is now curated by the Yale Peabody Museum, I emailed Dr. Stefan Nicolescu, Collection Manager of Mineralogy & Meteoritics. After further correspondence he sent some representative samples of the coring records in their collection (fig. 36). We requested a complete listing of core held by Yale but have yet to receive one.

We have recently learned that the NJSM holds many maps and reports detailing core-hole locations and records, including those in the aforementioned Baum and Willams (1947) report. But much work remains to be done in preserving the legacy of this historic, geological treasure. A worthwhile goal would be to add the diamond-drill-hole core traces into the model that have core samples preserved in the Peabody Museum, the Rutgers University core repository, or any of those held by the SHMM (table 1).

Some stope sections for the Sterling Mine include DDH locations but such aspects need further development in these mine models. Such efforts would be appreciated by many as these

K. STERNLOP LITHOLOGIC LOGGING SHEETS PAGE 1 OF 4

LOGGED BY 6/11/85 DATE DDH N.4 (24-A) HOLE LOGGED ?

INTERVAL	LITHOLOGIC DESCRIPTION	CORE QUALITY	SAMPLES TAKEN	REMARKS
0' - 2'4"	GARNET RICH ZONE -- GAR + WT AT TOP, GAR + ft + spwt IN CALCITE TO NEAR PURE MARBLE IN MIDDLE, ABUNDANT ft + GAR w/CALCITE + NO WT AT BOTTOM. CALCITE FLUORESCENT PINKISH (APPARENTLY GAR IS REALLY GARNITE)	RECOVERY IS SPOTTY HARD TO PINPOINT DEPTHS	F4(24A)-5": WHAT IS FLESH COLORED, TRANSLUCENT SPECIES? F4(24A)-2'3": (GARNITE, CALCITE, ft + WHAT IS NON-FLUR. LIT. LOOKING MINERAL)	BOXES DIVIDED INTO ZONES; DEPTHS WILL BE MEASURED FROM NEAREST BLOCK ABOVE, WITH LOST CORE ASSUMED TO OCCUR AT THE BOTTOM OF EACH BRACKETED ZONE
2'4" - 11'	RELATIVELY PURE MARBLE, PINKISH TO GRAY ON FRESH SURFACES. SCATTERED SMALL INCLUSIONS OF FT. A BOUND TO GREENISH PHYLLOSILICATE (BIOTITE), AND A VITREOUS, SEAGREEN SILICATE NOT SHOWING ANY GOOD CLEAVAGES	SMALL PIECES TO LARGE	F4(24A)-10'6": REPRESENTATIVE	
11' - 12'4"	HIGHLY ALTERED LOOKING, DARK GREENISH HUE, VERY FINE GRAINED. CONTAINS CALCITE IN MATRIX, BUT NOT PRE-DOMINANT. LOOKS LIKE FRACTURED ZONE, SOME EVIDENCE OF BRECCIATION, SOFT SERPENTINIZED(?), CHLORITE ALTERATION, SOME CUBES OF PYRITE SEEN. SOME CHUNKS OF K-SPAR + QUARTZ, ALL SiO ₂ AT BOTTOM.	CHUNK	F4(24A)-11'8": REPRESENTATIVE	
15' - 15'4"	MARBLE w/ INCLUSIONS OF BIOTITE(?) ft.	ONE PIECE	NONE	
15'4" - 18'11"	A MASSIVE, FLESH-PINK, LARGELY MONOMINERALIC ROCK EXHIBITING ONE GOOD CLEAVAGE -- RHODONITE. SEEMS ALTERED ALONG FRACTURES ROUGHLY PARALLEL TO CORE AXIS CONSISTING OF DARK GREEN (SERPENTINIZED?) CORE w/ LIGHT GREEN (ALTERED RHODONITE?) BOUNDARIES. SOME CUBES OF PYRITE PRESENT	GOOD, LONG PIECES	F4(24A)-18': REPRESENTATIVE	

4 Parker, Tooling = N^o 24 A Franklin

1100 level Elev. 152 N Bearing N 86°-36' E Dip 22° W Date: Dec 1903

Drilled into NW opposite first x-cut N from Parker Winze.

0 - 1/4	1/4	Gr. wt. G. sp. ft.
1/4 - 1 1/2	1	Calc. G. + ft. sp. wt.
1 1/2 - 10	7	WT + Pink LC. T. ft. + G. + ft. from 2-3/4. No wt. 2" G + fld at 7. Loc. ft. cdt.
10 - 11	1/4	Pt. + Q. Mass.
11 - 13	1/4	Wt. Non-ft.
13 - 14	1/4	Mass. Pt. Q.
14 - 15	1/4	Mass. G.
15 - 15 1/2	1/4	Wt. Pt. cdt.
15 1/2 - 19 1/2	4	Pt. Red fld. Pt. → Grn. M. Mass. Pt. at contact.
19 1/2 - 56	33	Gt. wt. w. Loc. cdt. + Pt. Loc. 13rd. Gt. wt. 50-56.
56 - 57	1	Wt. + abt. Mt.
57 - 93	18	Wt. sp. Loc. cdt. Gt. wt.
93 - 95	1 1/2	Mass. Pt. Pt. Mt. at contact.
95 - 103	7	Same as 57-93
103 - 105	2	Well bnd. Gt. wt.
105 - 117	3	Gt. wt. w. L.
117 - 160	30	Wt. Well bnd. Gt. wt. Bnd. at 50-55. Loc. Cr. by 134-135 + 136.
160 - 210	36	Lt. Gr. L. Bnd. Loc. sp. cdt. Loc. Amp. at 165. Loc. Cr. Pt. + Pt. at 188-189. Gt. wt.
210 - 245	35	Lt. Gr. L. Gt. wt. No Amp. cdt. abt.
245 - 258	8 1/2	Same
258 - 287	23 1/2	Same + Loc. cdt. + Pt. + Loc. bnd. Gt.

Figure 36. Two examples of mining records for the Franklin Mine held by the Yale Peabody Museum that accompany the curated rock core. The upper example dates from 6/11/1985 and the bottom record is from 9/20/1934.

mines warrant any efforts to preserve their legacy. Moreover, if the curated core can be placed into spatial context with the core and adjacent, infiltrated layers at Sterling Hill, then further insights into the mineralogy, petrology, and genesis would be forthcoming by employing modern geophysical instrumentation isotopic characterization and radiometric dating.

The surface expression of the ore bodies as mapped and modelled here also needs more work (fig. 6). The six half days spent photographing and mapping outcropping structures at Sterling Hill were enough to assemble a tentative representation of the surface expression of the ore body and generate material for a few-hour field trip, but this map rendition can be vastly improved with more surface mapping. Though it's worth noting here, that no large meso-scale folds were seen in any of the high walls or surface cuts in the Passaic or Noble pits. Only one recognizable, small-scale fold set was seen in the Passaic pit at STOP 1. A small rock bridge located in the roof of the ore excavation holds fault-propagation folds in the footwall of the slickensided fault plane of probable Paleozoic age (field STOP 1).

The tectonic nature of the Gerard and Beaver Lakes fault system is uncertain. The geometry is clear, but the tectonic impetus behind its occurrence is speculative. I collected fault and slip measurements on this fault system 40 years ago at the outset of my career with the NJGS along NJ Route 23 at about the time that the NJZC began closing the Sterling Hill mine. This crustal shear zone has both ductile and brittle features seen in outcrops along. Epidote and chlorite coat slickensided fault surfaces and a complex strain history is indicated by various, reverse, normal, and oblique-slip kinematic indicators. This Grenville-age fault system cuts across the highlands of New Jersey and exhibits ductile-shear geometry with a right-lateral reverse slip sense (fig. 37). Similar fault systems cut the Hudson Highlands of southern New York (Gates, Valentino, Gorrington, Chiarenzelli, and Hamilton, 2001). This raises the prospect that the core structure is a massive, old tension gash accompanying sudden, regional wrenching and shearing. The topographic expression of this old fault system is clear, and the resulting zinc deposits in the Highlands appear to only occur within the Franklin Marble where component faults of this old system cut across it (fig. 18). In summary, early, Mesoproterozoic faulting and folding in the area include reverse faulting with east-verging, upright folding of a layered sequence of carbonate and clastic that may include some volcanic layers. These ductile-brittle faults were originally moderate- to steeply northwest dipping with a component of right-lateral ductile shearing upon structural restoration involving clockwise rotation in profile, such that the overlying, northwest-dipping, Paleozoic dolomite beds are returned to horizontal.

This exquisite structure is the most complex one that I have studied and portrayed in such detail. To realize that its geological history spans a billion-plus years, and then to ponder its origin, deep burial and metamorphism, and subsequent uplift to the surface through time gives one pause. We see evidence for its fluid-driven genesis during early tectonism, then subsequent

brittle-ductile cataclasis and mylonitic faulting before brittle segmentation and offset. We also see evidence of episodic, hydrothermal alteration and modification of the original ore body (Verbeek and Grout, 2018). When one considers that the entire region was structurally elevated and unroofed during the Cenozoic period resulting in three to five kilometers of erosion, one can then suppose there may be a couple of more tectonic episodes represented (fig. 15). Much of the late uplift likely stems from crustal compaction and thickening from tectonic far-field strains occurring down range of the large-bolide impact crater buried beneath the mouth of Chesapeake Bay, Maryland, USA (Herman, 2015; Mathur and others, 2015). Also please note that current plate drift in this region invokes low-level, spotty seismicity that is temporally distributed throughout the region, so this ore deposit continues to be subject to neotectonic strains.

The mining techniques and operations utilized in identifying and retrieving the ore, and documenting the associated activities are impressive. I am also amazed how lucky the NJZC was in encountering the thickest and richest ore bodies at depth. They must have been thrilled upon prospecting below the 10 to 30 ft-thick ore layers mapped up top to discover unweathered core structures at depth that span several hundred feet in length and thickness. They must have been very pleased with the bounty of resources discovered beneath their feet. Sadly though, scores of miners perished executing their duties; Dunn (2002) verified at least 77 deaths prior to 1913, with an average of one per year based on records compiled from 1917 to 1984.

My interpretation of the ore genesis as fault-mediated, metalliferous fluids that infiltrated a siliciclastic sequence echoes the work of Palache (1937) who proposed metasomatic

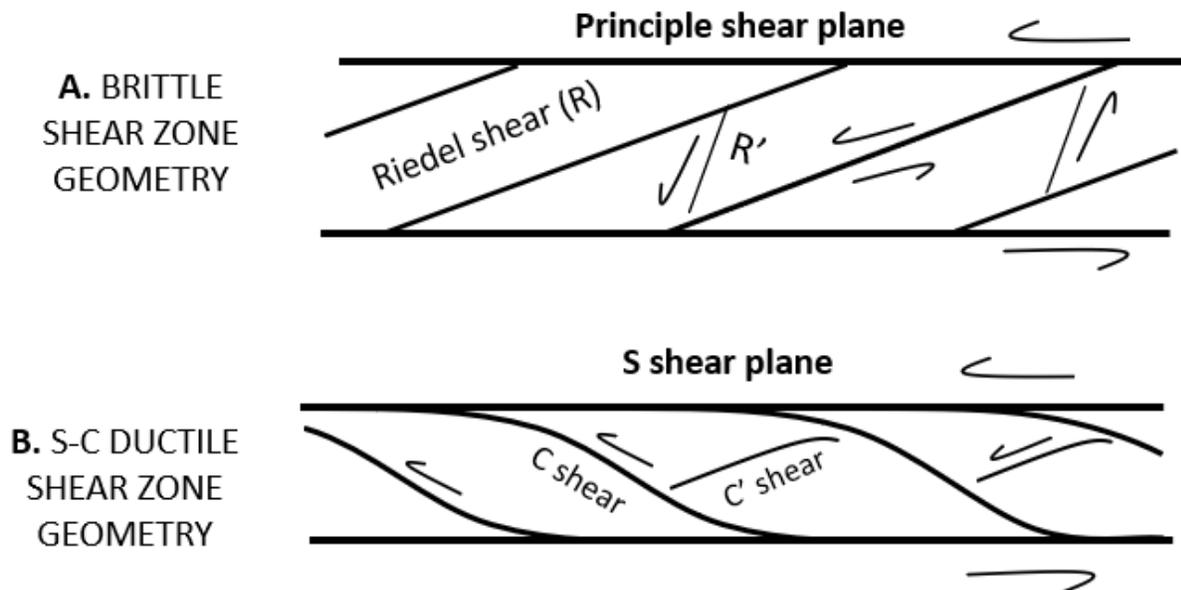


Figure 37. The contrasting geometry of brittle (A) and ductile (B) shear zones with left-lateral slip.

emplacement as the most probable explanation for the source fluids. He believed that they “were deposited near the surface under oxidizing conditions, and that they probably consisted largely of the hydrous zinc silicate, calamine, together with hydrous oxides of iron and manganese and perhaps carbonates of zinc and manganese.” He also considered the depositing solution to have derived its metallic contents from the products of oxidation of a previously existent mass of mixed sulphides. He provides analogous proof from a zinc deposit in Moresnet, Belgium where vast accumulations of sphalerite underwent profound oxidation, and the soluble products were transferred to the nearby dolomite where *they accumulated in synclinal folds that halted the circulation*. At Sterling Hill, the ferrous fluids appear to have been flushed into the Franklin Marble protolith along a cross-strike core structure and then gathered, or pooled along a steeply-dipping reverse fault, with some mineral fractionation and perhaps differentiation occurring in the upright fluidized column in the N1600 – N1660 stope area. Having the faulted, synclinal hinge as a hydraulic barrier to subsequent, cross-strike fluid migration helps explain why the zinc-lead-sulfide seen across the fault to the east within the same stratigraphic section as that on the west wasn’t subsequently oxidized. But the New Jersey mines extracted highly oxidized ore that was subsequently buried deep and subject to regional dynamothermal metamorphism, unlike that in their proper position with respect to the ore body so that geochemistry can be used to further interpret the ore petrogenesis. Palache (1937) also neglected to provide a mechanism for introducing the “depositing solutions”, which I suggest here to be fault-mediated flow during folding of the Mesoproterozoic rocks along the E-W striking shear zone and core structure where it pooled against the Zero fault on the western side, and likely along strike of the fault.

The structural core at Sterling Hill is probably more complex than portrayed here, or possibly larger than represented in the model because of what the Baum and Williams (1947) report shows. Their work includes mapped ore concentrations within stratiform layering based on exploratory drilling in the heart of the Sterling ore deposit. A cursory examination of the mapped chemical isograds shows that the highest ore grades occur along the margins of the structural core, and in parts of the bottom, synformal keel. Their report also shows that the zero fault has complex splays of reverse and normal displacements, both of which likely contribute to the down-warped, synformal shape of these ore bodies at depth. In other words, the upturned, synformal keel is also likely shaped by sagging into extensional grabens of probable Newark age.

Although much of the aforementioned is speculative, what this work provides with certainty is a virtual foundation upon which a more thorough understanding of these unusual ore bodies can be attained. The computer models reflect the assembly of unbiased data, and the only interpretations embedded in the Sterling Mine model are the TIN surfaces built to encompass the structural core and adjacent. Infiltrated layers. How the ore accumulated and was distributed in the fold hinge can be further explored now using the CAD models to place specific core holes into

To conclude, this has been a very interesting and fulfilling project that has resulted in new friendships and has laid a foundation for future research into this unique geological phenomenon. I hope that the computer models will be used by others in this scientific pursuit. I'm excited to see how the archived core fit into the model and how future efforts will continue to resolve this magnificent mineral deposit.

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A photograph showing solution weathering of the Franklin marble on the eastern wall of the Passaic Pit that was temporarily cleared of foliage during surface grooming conducted by the Sterling Hill Mining Museum in 2006. Photo by Earl Verbeek received in written communication of June 6, 2025.