The following appendices B to D accompany Verbeek and Grout, 2025, Chapter 3. Fault History of the Sterling Zinc Mine, Ogdensburg, Sussex County, New Jersey, with Appendices: *in* Di Maio, M.P, Herman, G.C. and Verbeek, E.R., eds., Geological Association of New Jersey Annual Meeting 41, Ogdensburg, NJ., p. 117-140.

Appendix B. Minerals lining fault surfaces in various rock types and along individual faults

In this appendix we describe the relative abundance of various fault-lining minerals in relation to rock type. We begin with a summary listing and on subsequent pages record observations for individual faults from our field notes. During our work at Sterling Hill we noted, in many places, a close correlation between the nature of the hydrothermal vein minerals and the lithology of the wallrock. At some localities, where ore-marble contacts were exposed, the minerals lining individual faults changed completely over distances of only a few centimeters at the contact. Our observations were summarized in the following paper:

Verbeek, E.R. and Grout, M.A., 2018, *Hydrothermal mineral deposition in a rock-dominated fluid system at Sterling Hill, New Jersey.* The Picking Table (Journal of the Franklin-Ogdensburg Mineralogical Society), vol. 59, no. 2, p. 15-22.

The minerals listed here were identified by visual means only. Readers should realize that minerals appear much different under the comparatively weak and yellowish light from a miner's cap lamp (pre-LED versions) than they do in daylight, though this becomes less of a factor with experience. "Mine mud" coating the rocks in old workings imposed its own set of difficulties. In many places it was necessary to wipe away most of this mud with one's shirt sleeve or a handkerchief to reveal the minerals beneath. Nevertheless, the most common minerals were readily recognizable in almost all instances, with two exceptions. One concerns the fairly numerous instances, especially along faults in ore and in marble, of a white to buff, fibrous mineral, which upon visual inspection could be one of several different species, among them sussexite, fluoborite, chrysotile, willemite, and tremolite. Given the uncertainties, these minerals, excepting willemite, are not listed here. The willemite, of course, could be recognized by its fluorescence and was recorded as such for faults in the mine, but the bright glare of daylight precluded this simple test for faults at the surface. The second exception is the mineral we recorded simply as "chlorite," which in most places appeared only as a dark green to bluish-green film on fault surfaces. We list this mineral but did not attempt to characterize it further.

SUMMARY LIST OF FAULT-LINING MINERALS

In Marble:

Common: Calcite, Fluorite (violet), Serpentine (commonly green)

Fairly common: Chlorite (in some cases a mistake for serpentine?), Copper minerals, secondary (but generally only near ore)

Uncommon: Hematite "stains" (generally near ore)

Rare: Hydrozincite (only near ore), Sphalerite, Talc, Willemite (one example only, adjacent to ore)

In Ore:

Common: Calcite, Serpentine (commonly brown), Zincite (inc. "calcozincite"), Willemite

Fairly common: Copper minerals (secondary)

Rare: Magnussonite, Mcgovernite, Pyrochroite, Chlorite, Greenockite (? greenish-yellow films), Hemimorphite

In Gneiss:

Common: Calcite, Epidote

Rare: Axinite-(Mn), Chlorite, Fluorite, Galena, Serpentine, Sphalerite, Zeolites

In "Black Rock":

Common: Calcite, Chlorite

OBSERVATIONS OF MINERALS ALONG INDIVIDUAL FAULTS

Axinite-Mn is rare at Sterling Hill but is known as small crystals in solution pockets along faults in gneiss, as in the sole example mentioned here.

Fault 1154: Small pockets containing well-crystallized axinite, heulandite, and fluorite are present within a zone 1-6 cm thick of white, coarse-grained, blocky calcite parallel to compositional layering in the adjacent gneisses. Presumably this zone represents a layer-parallel fault along which hydrothermal fluids altered the original minerals to create open space for deposition of later, lower-temperature phases.

Chlorite in this paper refers to a dark green to bluish-green to nearly black coating on fault surfaces in "black rock" in the few places where large masses of this rock were exposed. A mineral resembling chlorite was also recorded on faults in marble, though some of this is probably serpentine instead, and some in mylonitic marble is possibly an alteration product of highly deformed flakes of original mica. Coatings resembling chlorite were also noted, but only rarely, on faults in ore and calc-silicate gneisses. The chlorite ID for these coatings is based purely on appearance; we did not investigate the nature of this mineral further.

Fault 499: A medium bluish-green mineral that appears as streaked films on the mylonitic foliation surfaces in the marble near the ore is possibly chlorite.

Fault 602: Streaks of a mineral resembling a mica altered to chlorite or serpentine are present within mylonite developed in marble along the Nason fault.

Fault 622: A fault within a sinuous, anastomosing Set 2 fault zone is coated with a dark green to bluish-green mineral, possibly chlorite. The fault places fine-grained feldspathic gneiss on the footwall against pyroxene-bearing marble on the hanging wall.

Faults 626-636: Fault 626 in fine-grained “black rock” is coated with fibrous accretionary calcite and chlorite (or serpentine). Faults 627 through 636, also in “black rock,” are similarly coated with chlorite (described as “deep blackish green” on fault 627).

Note following fault 636: Wallrock control on the nature of the minerals coating these faults is quite evident here. Epidote, for example, is found almost exclusively in the feldspathic gneisses, where many fault surfaces are bright yellowish-green. Dark bluish-green chlorite, in contrast, is confined almost wholly to faults cutting “black rock.” A further difference is that the accretionary material on faults in feldspathic gneiss ranges widely in thickness, from a bare film to 2 cm, whereas in the “black rock” it is invariably thin.

Fault 637-640: Faults in “black rock” are coated with chlorite and calcite.

Fault 656: Medium- to dark-green films, probably serpentine but possibly chlorite, are present with calcite as accretionary material on a fault in medium-grained graphitic marble bearing grains of sulfide minerals.

Fault 665: Calcite and serpentine (or chlorite) coat a fault in impure marble bearing sparse grains of a dark green pyroxene.

Fault 669: Calcite and chlorite line a fault surface through medium-grained impure marble containing (in different horizons) graphite, chalcopyrite, pyroxenes, etc.

Faults 677-678: Patchy grayish-blue chlorite(?) films fault surfaces in coarse-grained marble containing grains of pyroxene and scales of mica.

Fault 692: Fault in fine-grained “black rock” is heavily coated with white accretionary calcite, layers of which are separated by thin films of dark green to nearly black chlorite.

Fault 699: Minor Set 2 slip surface in coarse-grained, garnet-feldspar-quartz-minor calcite rock, at south edge of the “black rock” zone, is coated with accretionary calcite and chlorite.

Faults 701-702: Lengthy Set 3 faults in “black rock,” traceable for perhaps 10 m across the back and down both ribs, have accretionary calcite and chlorite on their surfaces.

Faults 703-712: Chlorite and patchy calcite coat fault surfaces through “black rock.” All but two of these are Set 3 faults.

Faults 720-721: Chlorite coats Set 2 fault surfaces in lean franklinite-calcite ore.

Fault 724: Fault in franklinite-calcite ore bears abrasion slickenlines and is coated with chlorite.

Fault 736: Chlorite-coated fault surface in fault zone. Rock type not recorded, but this is the Nason fault, which in this area places ore in the hanging wall against marble in the footwall.

Faults 787-789: Mylonitic marble contains abundant dark greenish-blue scales of chlorite(?) oriented parallel to the mylonitic foliation. Possibly altered mica.

Fault 866: An olive-green mineral coating the fault surface was tentatively identified as chlorite. Rock type not mentioned, but this fault is in the west limb haulage drift, so is probably in a marble host rock.

Fault 1085: Fault in graphitic marble is coated with fibrous accretionary calcite and an olive-green mineral, possibly chlorite.

Fault 1135: Set 4 fault in marble is coated with accretionary calcite and possible chlorite, but no particulars were given.

Copper minerals (secondary) are moderately common on faults in the mine, especially on faults cutting marble and ore. In marble, the wallrock commonly contains copper as well, generally as disseminated sulfides such as chalcocite or, more rarely, chalcopyrite. In ore, however, discrete copper minerals are not often seen adjacent to faults bearing secondary copper species.

Fault 88: Azurite in radiating, bladed crystal rosettes as much as 1 cm across encrusts a probable Set 4 fault through medium- to high-grade franklinite-calcite ore along footwall of East limb.

Fault 118: Malachite in places is intergrown with fibrous accretionary calcite on a Set 2 fault in high-grade, medium- to coarse-grained franklinite-calcite ore along footwall of the East limb.

Fault 120: Secondary malachite and azurite (derived from wallrock chalcocite) are present on a Set 2 fault in moderate- to high-grade, medium-grained franklinite-willemite-calcite ore along footwall of the East limb.

Fault 542: Azurite and probable aurichalcite locally coat a Set 2 fault in medium- to coarse-grained, blocky, sparsely micaceous marble with disseminated sulfide minerals (chalcocite?).

Fault 543: Films of a secondary copper mineral are present on this Set 2 fault. Fault cuts medium- to coarse-grained, blocky marble containing abundant, steely gray grains 1-5 mm across of a sulfide mineral (chalcocite?) and scales of phlogopite.

Note following fault 640: A fault of orientation N84E/76-80NW contains abundant, elongate stringers of chalcopyrite(?) 0.5-2 mm thick within highly sheared rock (resembling a protomylonite) along the fault.

Fault 669: Spots of secondary copper minerals are present on a Set 2 fault surface in medium-grained impure marble containing (in different horizons) graphite, chalcopyrite, pyroxenes, etc.

Note following fault 670: At and near the entry to 1270 subdrift on 340 level, secondary copper minerals are conspicuous on Set 2 fault surfaces within the marble, where disseminated sulfide minerals are common. The secondary copper minerals disappear abruptly where these faults instead cut lean franklinite ore near the footwall of the East limb.

Fault 677: Greenish-blue secondary copper minerals are present locally on a reactivated segment of the Nason fault in coarse-grained marble containing grains of pyroxene and scales of mica.

Fault 739: Much fine-grained, altered, seemingly post-faulting chalcocite and secondary green to blue copper alteration minerals line a probable Set 5 fault surface in high-grade franklinite-willemite ore with only minor calcite. This same fault cuts through a layer of apparently primary (and fresh) chalcocite in a layered succession of marble and generally lean ore.

Fault 905: A Set 3 fault cutting the contact between moderate-grade franklinite-zincite-willemite-tephroite(?)-calcite ore and medium- to coarse-grained marble is coated with abundant secondary copper minerals of turquoise color, but only where the fault cuts marble. The copper minerals become sparse near the marble-ore contact and, with the sole exception of a small patch 25 cm from the contact, are absent where the fault cuts ore.

Fault 907: A Set 3 fault in medium-grained marble is coated with much black material, probably a mix of chalcocite and sphalerite, and their blue to green copper alteration products. Also present along this fault is a lenticular mass of chalcopyrite measuring 18 x 4 cm in cross-sectional area.

Fault 910: An iridescent blue mineral (tarnished bornite, chalcopyrite, or sphalerite) is present along the irregular, anastomosing strands of this fault.

Note following fault 949: Many faults in this area strike about N30W, dip steeply SW, and are probably Set 4 faults. Where present in ore, these are commonly lined with streaked veins of sphalerite, embedded in which are small grains, 1-2 mm across, of chalcopyrite. Nearby, along one of these same faults, additional sulfides sight-identified as fine-grained bornite and chalcocite are also present. All of these minerals disappear within one inch of the footwall contact of the ore with marble.

Fault 950: A probable Set 4 fault in high-grade willemite-franklinite-calcite ore is coated with calcite, sphalerite, and chalcocite.

Note following fault 1061: Along a braided Set 2 fault zone at this locality, chalcopyrite, bornite(?), and their green and blue alteration products line the fault surfaces, but only where the faults cut coarse-grained marble, not where these same faults pass into ore. The mineralogy of the veins, then, is highly dependent on host-rock lithology.

Epidote coats numerous faults cutting the local calc-silicate gneisses. Epidote similarly occurs as a hydrothermal alteration product of feldspar along faults cutting the later pegmatites at Franklin.

Fault 348: Local epidote coats this fault, but rock type was not recorded.

Fault 352: Epidote with calcite coats a Set 3 fault in pyroxene gneiss.

Fault 511: Minor epidote locally coats a Set 3 fault surface that places fine-grained garnet-pyroxene(?) rock over micaceous marble.

Faults 610-613: Set 2 and Set 3 faults through fine-grained feldspar-pyroxene gneiss are coated with epidote and locally also calcite.

Fault 618: Where this Set 2 fault cuts garnet-pyroxene gneiss, the fault contains lensoidal masses 0.5-1.5 cm thick of white accretionary calcite streaked with epidote.

Fault 619: A sinuous, anastomosing Set 2 fault zone through fine-grained feldspathic gneiss on the footwall and pyroxene-bearing marble on the hanging wall contains a lenticular mass 2 cm thick of white accretionary calcite with epidote, beautifully developed. Faults 620-622 are similar.

Faults 623-624: Fault 623 is in feldspathic gneiss. The fault surface is finely scored, polished almost mirror-smooth and bright, and covered with epidote 2-4 mm thick. Fault 624 is similar, but fault surface is not as highly polished. Both are probably Set 3 faults.

Fault 625: Epidote and calcite coat a Set 3 fault surface in feldspathic gneiss.

Note following fault 636: Wallrock control on the nature of the minerals coating these faults (most of them Set 3 faults) is evident here. Epidote, for example, is present almost exclusively in the feldspathic gneisses, where many fault surfaces are bright yellowish-green. Dark bluish-green chlorite, in contrast, is confined almost wholly to faults cutting “black rock.” A further difference is that the accretionary material on faults in feldspathic gneiss ranges widely in thickness, from a bare film to 2 cm, whereas in the "black rock" it is everywhere thin.

Note following fault 640: In this area, a large epidote-coated fault surface, source of specimens of mirror-polished slickensides in fine-grained feldspathic gneiss, is exposed on the west rib from mine coordinates 639N to 646N.

Faults 846-853: Epidote-coated, polished fault surfaces of Sets 3 and 5 cut through granular pyroxene-calcite and pyroxene-garnet-calcite gneisses.

Fault 854: Epidote coats a Set 2 fault surface in pyroxene-calcite-feldspar gneiss.

Fault 959: Smooth, almost polished Set 3 fault surface in pyroxene gneiss is coated with epidote.

Fault 963: A Set 3 fault in epidotized pyroxene(?)-feldspar gneiss is lined with fibrous accretionary calcite and epidote.

Faults 964-965: Faults of Sets 2 and 4 in fine-grained pyroxene-feldspar gneiss are lined with fibrous accretionary calcite and epidote.

Fault 966: Set 2 fault in garnet amphibolite(?) is lined with fibrous accretionary calcite and epidote.

Fault 973: Set 4 fault in garnet amphibolite is locally coated with epidote.

Fault 974: Fault in fine-grained, feldspathic amphibole(?)-garnet gneiss is coated with epidote.

Fault 976: Set 3 fault in feldspathic gneiss (probable host rock; not specified as such) is coated with epidote.

Faults 977-979: Faults in coarse-grained garnet amphibolite are locally coated with epidote.

Fluorite at Sterling Hill is quite common on faults in marble but was rarely documented on faults in any other lithology. Almost invariably the fluorite is some shade of violet.

Fault 32: Violet fluorite coats part of fault surface in marble.

Fault 39: Minor amounts of violet fluorite coat fault in fine-grained graphitic marble.

Fault 64: Minor amounts of violet fluorite coat fault in graphitic marble.

Fault 75: Small amounts of violet fluorite coat a Set 4 fault in graphitic marble.

Fault 85: Minor amounts of violet fluorite coat a Set 2 fault in marble.

Fault 251: Violet fluorite sparsely coats a Set 2 fault in micaceous, tremolitic marble.

Fault 252: Violet fluorite, locally abundant, coats a Set 2 fault in medium-grained graphitic marble.

Fault 258: Minor violet fluorite coats a Set 3 fault in graphitic, micaceous marble.

Faults 260-263: Minor violet fluorite coats Set 3 faults in medium-grained graphitic marble.

Faults 265-266: Minor violet fluorite coats Set 3 faults in graphitic marble.

Fault 291: Small amounts of violet fluorite and green serpentine coat a fault in norbergite-bearing marble.

Fault 380: Calcite and violet fluorite in minor amounts coat a Set 3 fault in graphitic marble.

Fault 388: Fluorite and calcite coat a Set 4 fault. Rock type not recorded, but others here are in marble.

Fault 391: Minor violet fluorite, calcite, and pale green serpentine line a Set 5 fault in medium-grained, graphitic, norbergite-bearing marble.

Fault 392: Fluorite coats a minor Set 3 fault in marble.

Fault 396: Minor violet fluorite coats a fault in marble.

Fault 473: Minor violet fluorite coats a Set 3 fault in graphitic marble with local norbergite and sulfides.

Fault 480: Violet fluorite in small amounts is part of the accretionary material on a Set 5 fault in graphitic marble, along with serpentine where the marble contains norbergite.

Fault 482: Small amounts of fluorite are present as thin films on or within calcite-serpentine accretionary material on a Set 5 fault in graphitic, tremolitic marble containing a layer rich in norbergite.

Fault 486: Minor violet fluorite, with calcite and serpentine, coats a Set 3 fault in graphitic marble with norbergite.

Faults 532-534: Films of violet fluorite, locally abundant, are part of the accretionary material (with calcite) on Set 3 faults in marble.

Fault 558: Violet fluorite, sparse, is present within the accretionary calcite on this fault.

Fault 713: Violet fluorite and calcite coat a fault surface in impure marble containing graphite and norbergite.

Fault 823: Minor violet fluorite coats a fault surface in medium- to coarse-grained marble.

Fault 825: Small amounts of fluorite coat a fault surface in graphitic marble containing a little norbergite.

Fault 931: A Set 3 fault surface here, in impure marble, appears to be patchily coated with fibrous accretionary calcite, lime-green serpentine, and violet fluorite.

Faults 933-934: Violet fluorite lightly coats fault surfaces of Sets 2 and 3 in graphitic marble.

Fault 937: Violet fluorite coats a Set 3 fault surface in graphitic marble.

Fault 971: Set 2 fault in marble is coated with fibrous accretionary calcite and sparse violet fluorite in streaks parallel to the calcite fibers.

Fault 1019: Trace amounts of violet fluorite coat a Set 2 fault in graphitic marble.

Fault 1021: Violet fluorite is present on a Set 3 fault surface in graphitic marble, but it is granular and appears to postdate the fibrous, accretionary calcite on the same surface.

Fault 1092: Minor fluorite coats a Set 4 fault surface in graphitic marble.

Fault 1109-1110: Minor violet fluorite coats Set 5 fault surfaces in marble.

Galena is a widely distributed mineral at Sterling Hill, but generally in only small amounts, often as a replacement product of other minerals or as small crystals lining solution pockets. Only rarely, it seems, is it present as a fault-lining mineral.

Fault 854: An epidote-coated Set 2 fault in pyroxene-calcite-feldspar(?) gneisses contain sphalerite, minor galena, calcite, and zeolites in open spaces between the fault strands, where minor brecciation occurred.

Greenockite is a difficult species to sight-identify at Sterling Hill, and genuine examples are probably rare.

Fault 739: A fault in high-grade franklinite-willemite ore with only minor calcite (“brown ore”) is lined with much fine-grained chalcocite and secondary green to blue copper alteration minerals. In addition are local films of a greenish-yellow mineral, as yet unidentified. Greenockite is one of several possibilities.

Hematite is commonly present as a red stain on fault surfaces in ore, where it probably formed from the partial hydrothermal alteration of franklinite. Faults in marble, in contrast, most commonly are stained by limonite rather than hematite. Most of the exceptions are for localities either close to an ore-marble contact or are in marble containing scattered grains of ore minerals. Hematite is also known on faults cutting the local gneisses, but is not common.

Fault 599: Hematite-stained accretionary calcite is present on a Set 5 fault surface in franklinite-willemite-calcite ore.

Fault 605: Fault surface in micaceous marble is light stained reddish-brown (= hematite?), perhaps from breakdown of the mica. Probably a Set 3 fault.

Fault 606: Fault surface in moderate- to high-grade franklinite-calcite ore is hematite-stained.

Fault 609: Highly polished fault surface in high-grade franklinite-willemite-calcite ore is hematite-stained.

Fault 645: Set 2 fault surface in medium-grained marble is hematite-stained.

Fault 648: Hematite-stained, Set 2 fault surface cuts medium-grained marble.

Faults 659-661: Hematite-stained accretionary calcite lines faults in impure, medium-grained marble containing scattered grains of dark green diopside and sparse franklinite. Two of these are Set 2 faults.

Fault 662: This is a hematite-stained, Set 5 fault that juxtaposes impure marble against lean franklinite-calcite ore.

Faults 663-664: Faults in lean franklinite ore are coated with hematite-stained, fibrous accretionary calcite. Fault 664 is a Set 2 fault.

Note following fault 669: Fault surfaces at the entry to 1270 subdrift on 340 level are hematite-stained in low-grade franklinite ore, but the hematite stain disappears abruptly as the faults pass into marble along the footwall of the East limb. Most of the faults here are members of Set 2.

Fault 783: Light iron (hematite?) stains coat a probable Set 5 fault in marble. Locality is in 935 stope, so is near ore.

Fault 785: Surface of this fault is locally stained red to brown by hematite; the fault is in coarse-grained marble containing sparse grains of willemite. Locality is in 935 stope, so is near ore.

Fault 790: Exposed foliation surfaces in mylonitic marble of a Set 1 fault in marble are heavily stained medium reddish-brown by hematite and/or limonite. Fault is near ore.

Note following fault 800: Mylonite derived from biotite gneisses is now a highly schistose rock containing lensoidal streaks of calcite and is locally stained brownish red by thin films of hematite, a probable decomposition product of the biotite.

Fault 910: The wallrock of a fault in medium- to coarse-grained marble with accessory phlogopite is stained red in areas where sulfide minerals lining the fault have been altered.

Fault 911: A fault in medium-grained, willemite-bearing marble is hematite-stained close to the hanging-wall contact of ore.

Fault 963: Set 3 Fault in epidotized pyroxene(?)-feldspar gneiss is lined with fibrous accretionary calcite, epidote, and in places by hematite (dark red streaks on fault surface).

Hemimorphite is most common near and at the surface, as in this example, and is a late-stage mineral genetically unrelated to the faults along which it locally occurs.

Fault 2: Preserved in open spaces along this fault is a 1-3 mm thick coating of post-movement hemimorphite(?) in tightly intergrown, bladed crystals perpendicular to the fault surface. The fault, a member of Set 2, is in low- to medium-grade ore consisting of coarse-grained, manganoan calcite with abundant disseminated grains of franklinite.

Hydrozincite is a late-stage product of weathering of previously deposited minerals and bears no genetic relation to the faults along which it locally occurs.

Note following fault 670: Hydrozincite lines Set 2 fault surfaces here and is quite abundant (and beautifully fluorescent) at the entrance to the 1270 subdrift (340 level), in and within about 0.5 m of the lean ore. Hydrozincite on the faults then disappears abruptly as the faults pass into marble.

Note following fault 905: Fault 905 is a Set 3 fault that offsets the contact of moderate-grade, franklinite-zincite-willemite-tephroite(?)-calcite ore with medium- to coarse-grained marble. The fault surface is coated with abundant sphalerite, other associated sulfides, and secondary copper minerals only where it cuts marble. In ore, it is coated with calcite, secondary willemite, and “calcozincite” instead. This abrupt change in mineralogy is also reflected in minerals developed later, upon weathering: Hydrozincite, an alteration product of sphalerite, is common here in the marble but was not seen in ore. The combination of the bright blue-fluorescent hydrozincite against a matrix of bright red-fluorescing calcite is quite attractive.

Limonite (mostly goethite). Limonite is fairly common on faults in marble, where it reflects breakdown of disseminated sulfide minerals within the weathering zone in the shallow subsurface, and wherever faults allow oxygenated water to descend to greater depth. Limonite stains are also sometimes found on faults in gneiss, due to weathering of iron-bearing pyroxenes and micas. However, such stains are considerably less common on faults in ore, probably because franklinite is quite resistant to weathering and remains in place long after other components of the ore have been removed.

Fault 47: A Set 5 fault in medium- to coarse-grained graphitic marble with local norberite is lightly limonite-stained.

Fault 456: Iron-stained fault cuts through medium-grained graphitic marble containing tiny grains of a black, submetallic to metallic mineral resembling magnetite.

Note following fault 494: Graphitic marble adjacent to numerous faults in this area is weathered and limonite-stained; this is an area of mud-filled solution channels and much water leakage along these faults. The faults are probably members of Set 5.

Fault 604: Probable Set 5 fault with limonite-stained surface cuts graphitic marble.

Fault 781: Nason fault. Parts of this fault are heavily limonite-stained. The adjacent wallrock is highly altered, locally to clay, and large solution channels are visible along the general trend of the fault. The largest solution channels are in marble along its fault contact with ore. Some of the altered rock and clay are of identical texture to that of moderate-grade ore containing 25-40% franklinite in calcite in the footwall and probably were originally that same lithology.

Fault 782: Local iron stains are present on a fault surface in coarse-grained marble. Probably a Set 5 fault.

Fault 790: Mylonitic marble; exposed foliation surfaces are heavily stained medium reddish-brown by hematite and/or limonite. Numerous Set 5 faults that formed by slip along the earlier Set 1 foliation surfaces are present in this area and are the probable conduits for water entering the mine here and weathering the rock.

Magnussonite is known from several occurrences in the Sterling mine but was recovered in quantity at only one of them; it remains a rare mineral locally.

Note following fault 1052: A fault of orientation N09E/65SE at this locality contains a brown, nonfluorescent mineral, possibly magnussonite but not yet tested, plus tiny, angular bits of brecciated calcite. The locality is 970 stope, 1000 level, in East limb ore along the east side of the stope, near mine coordinates 1080N, 420W.

Fault 1155: This is the fault, a member of Set 2, that furnished the magnussonite specimens collected by John Kolic and that were widely distributed to collectors. The locality is 1020 stope, about 20 ft above 1200 level, at mine coordinates 1075N, 750W.

Mcgovernite. Three localities for mcgovernite are listed here, but all are close to one another and are downdip extensions of the same volume of rock. The localities extend over a vertical range of roughly 175 ft. Mcgovernite to date has been found nowhere else in the mine.

Fault 839: Gently curved fault surface is coated with white calcite and scaly mcgovernite. Fault is in moderate-grade, franklinite-willemite-calcite ore. The locality is a raise between 800 and 700 levels, at approximate mine coordinates 735N, 1140W, at a depth of about 725 ft.

Fault 842: Minor fault in franklinite-willemite-zincite-calcite ore is lined with calcite (lavender, gray, and white), zincite, and minor mcgovernite. Same locality as fault 839.

Fault 897: Much secondary zincite is present on this fault, along with calcite (fluorescent red), fine-granular fault gouge (locally fluorescent green due to secondary willemite), and mcgovernite. Secondary zincite on the fault, as usual, occurs only where the ore is zincite-bearing; the same fault upon entering franklinite-willemite-calcite ore abruptly loses the secondary zincite and is filled instead with much red-fluorescent secondary calcite and local mcgovernite, the whole locally as much as 3” thick.

Fault 953: The main strand of this Set 3 fault is in disseminated franklinite-willemite-calcite ore and is lined with beautiful cream-colored accretionary calcite which is quite splintery, mostly 0.5-1 cm thick but locally up to 2 cm thick, and fluoresces bright red. Secondary willemite is also present along the main strand, as is much post-faulting mcgovernite.

Fault 954 (same locality as fault 953): This is an extensive Set 2 fault, traceable across the entire width of the stope, and is the fault from which numerous mcgovernite specimens were recovered in 1990. Much accretionary calcite (1-3 cm thick) and secondary willemite line the fault surface, the calcite in coarse splintery masses and the willemite as local druses of pale green acicular crystals in narrow open vugs. The fault cuts moderate-grade franklinite-willemite-calcite ore.

Pyrochroite is widely distributed in the Sterling mine but is most abundant in the North Ore Body, far below where our faults were measured. We noted only two instances of pyrochroite lining the faults we observed.

Fault 766: “Calcozincite” fibers and possible pyrochroite coat a minor Set 3 fault in high-grade franklinite-willemite ore locally containing abundant zincite.

Fault 1074: Set 3 fault in franklinite-willemite-zincite-calcite ore is filled with fibrous accretionary “calcozincite” and pyrochroite 1-4 cm thick over an exposed length of 5 m.

Serpentine (in marble) is quite common, particularly where the marble contains norbergite. Almost invariably the serpentine is some shade of green, as opposed to its generally brown color in ore.

Fault 128: Probable serpentine with calcite is part of the fibrous accretionary material on this Set 4 fault.

Fault 291: Fibrous olive-green serpentine coats a fault in norbergite-bearing marble.

Faults 364-365: Serpentine and calcite coat Set 4 faults in medium- to coarse-grained marble; color of serpentine not recorded.

Fault 391: Pale green serpentine is in patchy films on a Set 5 fault in medium-grained marble. Where serpentine is present on the fault, so is chondrodite or norbergite in the host marble.

Fault 473: Within the wallrock, a fine-grained brown mineral, possibly spinel, is a major component of a layer that also contains norbergite and phlogopite in graphitic marble. The spinel is prominently altered within 2-3 cm of the fault and is now pistachio green (thus serpentine?). This is a Set 3 fault.

Fault 476: Probable grayish-green serpentine is present in films on a Set 3 fault where it cuts a marble layer rich in norbergite, spinel, and sulfides below graphitic marble.

Fault 477: This Set 3 fault surface is mineral-streaked where it cuts graphitic marble but is coated with accretionary calcite and serpentine where it cuts a norbergite-rich layer.

Fault 480: Calcite-serpentine-fluorite accretionary material coats this Set 5 fault only where it cuts layers rich in norbergite (i.e., those rich in magnesium). Serpentine is white to apple green.

Fault 482: Serpentine coats fault in marble; color not mentioned.

Fault 486: Minor green serpentine coats a Set 3 fault in graphitic marble, but only where it cuts a norbergite-bearing layer.

Fault 537: Probable serpentine within accretionary calcite is locally exposed on a Set 3 fault surface in diopside-bearing marble. The magnesium to form serpentine on this fault was derived from diopside rather than norbergite.

Fault 602: Streaks of a mineral resembling a mica altered to chlorite or serpentine are present on a Set 5 fault developed within marble mylonite along the Nason fault.

Faults 617-618: Pale green serpentine and accretionary calcite film a Set 2 fault in impure, pyroxene-rich marble. The pyroxene is dark green and is probably diopside.

Fault 653: Minor pale green serpentine coats a Set 2 fault in medium-grained graphitic marble.

Fault 655: Pale- to medium-green serpentine lightly films a Set 2 fault in medium-grained, graphitic marble bearing grains of sulfide minerals.

Fault 656: Medium- to dark-green films, serpentine or possibly chlorite, are present with calcite as accretionary material on a probable Set 2 fault in medium-grained graphitic marble bearing grains of sulfide minerals.

Faults 665-667: Calcite and serpentine (or possibly chlorite) coat Set 2 faults in impure marble bearing sparse grains of a dark green pyroxene.

Fault 678: Patchy coatings of serpentine or chlorite line fault surfaces in coarse-grained marble containing grains of pyroxene and scales of mica.

Fault 684: Possible serpentine coats a Set 5 fault in coarse-grained marble containing pale green grains of diopside and a medium-brown mica.

Fault 687: Finely scratched Set 3 fault surface in medium-grained marble is lightly and patchily coated with fibrous serpentine. The marble contains sparse phlogopite and a green, bladed amphibole.

Fault 688: A Set 3 fault through impure marble is coated with fibrous accretionary calcite and serpentine. Some of the marble layers are rich in norbergite, and others contain pale green, fine-grained pyroxene or amphibole. Serpentine fibers appear only on those parts of the fault that cut layers of norbergite-bearing marble; elsewhere the fault is coated with accretionary calcite. The change from serpentine to calcite on the fault surface occurs within 1 cm.

Fault 689: Fibrous accretionary calcite and serpentine line a Set 3 fault surface in impure marble containing dark brown chondrodite or norbergite plus a pale green amphibole or pyroxene.

Fault 693: Set 3 fault in impure marble is encrusted with white accretionary calcite and apple-green serpentine. The marble contains norbergite, much pale olive-green diopside(?), and disseminated chalcopyrite in different layers, about 20-30 cm from the south contact with the “black rock” zone.

Faults 695-696: Set 2 faults in norbergite-bearing marble are coated with calcite and pale apple-green serpentine.

Fault 698: Minor Set 3 fault through norbergite-bearing marble is coated with accretionary calcite and serpentine.

Fault 823: Minor dark emerald-green serpentine lines a fault surface in medium- to coarse-grained marble.

Fault 882: Fibrous, dark green serpentine lines a fault in medium-grained marble.

Fault 888: Surface of a Set 3 fault is pale green due to a thin coating of presumed serpentine; host rock is coarse-grained, medium-orange marble.

Fault 931: Set 3 fault surface here, in impure marble, appears to be patchily coated with fibrous accretionary calcite, lime-green serpentine, and violet fluorite.

Fault 932: A beautifully striated Set 3 fault cutting norbergite-graphite-phlogopite marble is coated with bright green serpentine.

Faults 935-936: Set 3 faults in graphitic, norbergite-bearing marble are encrusted with fibrous accretionary calcite and bright green serpentine, locally as much as 1.5 cm thick on fault 935. The green serpentine fibers have formed only on those parts of the fault surface that cut norbergite-bearing marble; they stop abruptly at the top of the norbergite layer. Above that, in a zone two inches thick where the wallrock is graphitic marble, the fault surface is graphite-streaked. Above the graphitic marble the wallrock is pure saccharoidal marble, and there the fault surface is coated only with a bit of powdery gouge. Very clear, tight relation between composition of wallrock and the character of the material coating the fault surface here: no Mg (norbergite) in the wallrock, no serpentine on the fault.

Fault 1011: Minor fault (probably Set 5) in marble with accessory norbergite, fluoborite, and arsenopyrite is prominently streaked emerald green and white from fibrous accretionary calcite intergrown with (probable) serpentine.

Fault 1012: Set 5 fault in marble is coated with white to grass-green fibrous accretionary material, dominantly calcite but probably with intergrown serpentine, the whole measuring 1-10 mm thick.

Fault 1090: Set 4 fault in graphitic marble is coated with fibrous accretionary calcite and a dark green film that possibly is serpentine.

Fault 1137: Set 4 fault surface in marble is coated with fibrous accretionary calcite and a pale green mineral, probably serpentine.

Fault 1147: Set 2 fault in marble is coated with a pale green, fibrous to splintery mineral, probably serpentine.

Serpentine (in ore) as a fault-lining mineral is just as common in ore as in marble. In ore it is generally some shade of brown and forms translucent coatings, some of them >1 cm thick, as opposed to the green and generally much thinner coatings in marble. Green serpentine on faults in ore is limited mostly to calcic ore of only low to moderate grade.

Fault 114: A mineral resembling brown serpentine is present with willemite and calcite on a Set 4 fault in moderate- to high-grade franklinite-calcite ore.

Fault 119: Translucent, honey-brown serpentine is part of accretionary material on a Set 4 fault in high-grade, medium- to coarse-grained franklinite-calcite ore.

Fault 314: Minor green serpentine lines a Set 3 fault in medium-grade franklinite-calcite ore.

Fault 539: Translucent brown serpentine with willemite and calcite coat a Set 2 fault in high-grade franklinite-brown willemite-zincite-calcite ore.

Fault 680: Reddish-brown serpentine(?) forms lenticular masses along a fault in medium- to high-grade franklinite-calcite ore with minor willemite.

Fault 739: A Set 5 fault surface in high-grade franklinite-willemite ore appears to have been serpentinized.

Fault 744: Fibrous accretionary calcite with stringers of serpentine and secondary willemite, the whole up to 2 cm thick, line a Set 3 fault surface in moderate-grade franklinite-willemite-zincite-calcite ore.

Fault 751: Translucent brown serpentine is present on a fault in moderate-grade franklinite-willemite-calcite ore.

Faults 752-754: Serpentine, calcite, and willemite are present on Set 3 and Set 4 fault surfaces in moderate-grade franklinite-willemite-calcite ore. The color of the serpentine of fault 753 was specified as brown, as is common in ore.

Fault 755: Greenish-brown to brown serpentine 1-6 mm thick lines fault surface in moderate-grade franklinite-willemite-calcite ore.

Fault 757: Fibrous calcite with stringers of serpentine and some willemite line a Set 3 fault surface in moderate-grade franklinite-willemite-calcite ore.

Fault 760: A fairly large, low-angle, reactivated Set 2 fault is exposed here over a distance of at least 5 m. Abundant fibrous accretionary calcite and brown serpentine line the fault, along with a trace of secondary willemite.

Fault 761: Dark brown serpentine, with abundant stringers of willemite and dolomite, line fault in calcite-willemite ore.

Fault 762: A set 5 fault in moderate-grade franklinite-willemite ore is lined with fibrous, cream-colored accretionary calcite; translucent to transparent, toffee-brown serpentine; and secondary willemite, the whole having a prominently layered appearance.

Fault 767: A set 4 fault in medium- to coarse-grained, high-grade franklinite-willemite ore with local lenses rich in zincite is lined with serpentine, calcite, abundant willemite, and probable secondary zincite as well.

Fault 768: A minor Set 4 fault through high-grade franklinite-calcite ore is lined with secondary calcite, serpentine, and willemite in seams 2-4 mm thick.

Fault 774: A Set 5 fault in high-grade franklinite-calcite ore with minor willemite is heavily coated with translucent brown serpentine and calcite, along with local seams of secondary willemite.

Fault 776: This fault, in moderate-grade franklinite-willemite-calcite ore, is probably a member of Set 5 and is coated with 1-2.5 cm of serpentine, pale tan willemite in stringers as much as 1 cm thick, and minor calcite. The serpentine is nearly transparent through a thickness of several millimeters, appearing much like amber.

Faults 778-779: Faults in moderate-grade franklinite-willemite-calcite ore are lined with well-developed fibrous accretionary calcite with minor serpentine.

Fault 909: Set 3 fault in moderate-grade franklinite-willemite-calcite ore is coated with calcite and a translucent, caramel-colored mineral with waxy luster (probably serpentine).

Fault 958: A fault in lean franklinite-calcite ore (thus mostly calcite) is coated with pale green accretionary fibers, probably serpentine.

Sphalerite is about equally abundant on faults in ore and in marble but was rarely noted in other lithologies. Some of the sphalerite in ore (e.g., note following fault 1061) represents hydrothermal dissolution of zincite and reprecipitation of the zinc so freed as sphalerite. Other occurrences of sphalerite on faults in marble probably resulted from widespread Mississippi Valley-type mineralization that affected much of the region in Paleozoic time.

Note following fault 591: Lensoidal masses of honey-brown, fine-grained sphalerite are present along parts of this fault, in marble containing sparse grains of willemite and franklinite in red-fl. calcite.

Fault 905: Set 3 fault cutting the contact of moderate-grade franklinite-zincite-willemite-tephroite(?)-calcite ore with medium- to coarse-grained marble is coated with abundant sphalerite, other associated sulfides, and secondary copper minerals only where this fault cuts marble. In ore, it is coated with calcite, secondary willemite, and “calcozincite” instead.

Fault 907: Set 3 fault in medium-grained marble is coated with much black material, probably a mix of chalcocite and sphalerite.

Fault 910: Fault in medium- to coarse-grained marble with accessory phlogopite contains much sphalerite, principally as a cement of fault breccia.

Fault 940: Wallrock on both sides of fault in granular willemite-franklinite-calcite ore is coated with orange to reddish-tan, sheared calcite and sphalerite; between them, in middle of vein, is apparently undeformed, olive-brown, cryptocrystalline sphalerite.

Note following fault 949: Where faults similar to no. 940 cross from the ore into the marble beneath, sphalerite that lines faults in the ore ends abruptly within one inch of the footwall contact, and no sphalerite lines faults within the marble.

Fault 950: Fault in high-grade willemite-franklinite-calcite ore is coated with calcite and red sphalerite.

Note following fault 1061: Much of the fault breccia along and between Set 2 faults in hydrothermally altered ore in 970 stope (1000 level) is cemented by sphalerite.

Fault 1080: A Set 2 fault in ore (component minerals not specified) is coated with a carbonate mineral and very fine-grained sphalerite 3-20 mm thick.

Talc. Only three examples of a talcose mineral coating faults were noted during our study. None was definitely identified as talc, though that mineral is fairly well known at Sterling Hill (most often as a hydrothermal alteration/replacement product of willemite).

Fault 872: An unidentified soft, platy, nearly white mineral with pearly luster (talc?) accompanies fibrous accretionary calcite on this Set 3 fault surface.

Faults 946 and 947: The surfaces of these faults, probably members of Set 4, are lightly coated with an unidentified, greenish-brown fibrous mineral that scratches easily and has a talcose feel.

Note following fault 949: Faults at this locality, probably members of Set 4, are coated with a talcose mineral where they cut marble, but in ore they are commonly lined with streaked veins of sphalerite instead.

Willemite. All but one documented occurrence of secondary willemite as a fault-lining mineral were on faults in ore. The sole exception was in marble containing sparse grains of franklinite near the main orebody. Much of the willemite is fibrous, but some occurs in thin layers interlaminated with serpentine, or as well-formed microcrystals either lining residual voids or embedded in calcite.

Fault 111: Fibrous white accretionary material on a Set 4 fault surface in lean to moderate-grade franklinite-calcite ore shows only a weak reaction to dilute HCl and is possibly willemite mixed with calcite.

Fault 112: Same as fault 111. Our notes state the finely fibrous, secondary willemite is present on many fault surfaces in ore within the mined-out interior of the ore pillar along the western wall of the fill quarry, but elsewhere, in the glare of daylight, willemite is difficult to identify (it resembles other white, fibrous minerals such as sussexite, amphiboles, fluoborite, etc.).

Fault 114: A white, fibrous mineral on a Set 4 fault in moderate- to high-grade franklinite-calcite ore likely is willemite.

Fault 135: A white, finely fibrous mineral thought to be willemite, along with secondary zincite, coat a Set 2 fault surface in very high-grade zincite-franklinite-calcite ore.

Faults 501-503: Willemite and calcite are present as fibrous accretionary minerals on fault surfaces in "black ore." Two of these faults are members of Set 3.

Fault 539: Lensoidal openings along this Set 2 fault are filled with calcite, translucent brown serpentine, and phosphorescent willemite. Rock type is high-grade franklinite-willemite-zincite-calcite ore.

Fault 540: Secondary willemite is present along a Set 3 fault in high-grade, franklinite-willemite-zincite-calcite ore.

Fault 601: Splintery accretionary calcite is intergrown with willemite on a brittle fault that developed during reactivation of a mylonite zone in high-grade franklinite-willemite ore containing only minor amounts of calcite.

Fault 661: Secondary willemite is present along with hematite-stained accretionary calcite on a Set 2 fault in impure, medium-grained marble containing scattered grains of dark green diopside and sparse franklinite.

Faults 740-741: Minor secondary willemite is present on faults in moderate-grade, medium-grained franklinite-calcite ore. Fault 740 is a Set 3 fault.

Faults 743-749: Minor willemite is present on some of these fault surfaces, and on others it is quite abundant. Most of these are Set 3 faults.

Faults 752-753: Secondary willemite, calcite, and serpentine line faults in moderate-grade franklinite-willemite-calcite ore. Fault 752 is a member of Set 4 and fault 753 is a member of Set 3.

Fault 756: Finely fibrous willemite and calcite line a fault in moderate-grade franklinite-willemite-calcite ore.

Fault 757: Fibrous calcite with stringers of serpentine and some willemite line a Set 3 fault surface in moderate-grade franklinite-willemite-calcite ore.

Fault 759: Set 3 fault in moderate- to high-grade franklinite-willemite-calcite ore is lined with fibrous accretionary calcite with minor secondary willemite.

Fault 760: A fairly large, low-angle, reactivated Set 2 fault, exposed over a distance of at least 5 m, is lined with abundant fibrous accretionary calcite and brown serpentine, along with a trace of secondary willemite.

Fault 761: Dark brown serpentine, with abundant stringers of willemite and dolomite, line fault in calcite-willemite ore.

Fault 762: A fault in moderate-grade franklinite-willemite ore is lined with fibrous, cream-colored accretionary calcite; translucent to transparent, toffee-brown serpentine; and secondary willemite, the whole having a prominently layered appearance.

Fault 767: Set 4 fault in medium- to coarse-grained, high-grade franklinite-willemite ore, with local zincite-rich lenses, is lined with serpentine, calcite, abundant willemite, and probable secondary zincite as well.

Fault 768: A minor Set 4 fault through high-grade franklinite-calcite ore is lined with secondary calcite, serpentine, and willemite in seams 2-4 mm thick.

Faults 771-772: Fibrous accretionary calcite 1-2 mm thick with minor secondary willemite line Set 3 fault surfaces in high-grade willemite-franklinite ore.

Fault 773: A Set 3 fault through high-grade franklinite-willemite ore locally rich in zincite is lined with fibrous accretionary calcite and secondary willemite, locally to at least 6 mm thick.

Fault 774: A probable Set 5 fault in high-grade franklinite-calcite ore with minor willemite is heavily coated with translucent brown serpentine and calcite, along with local seams of secondary willemite.

Fault 776: A probable Set 5 fault in moderate-grade franklinite-willemite-calcite ore is coated with 1-2.5 cm of serpentine, pale tan willemite in stringers as much as 1 cm thick, and minor calcite.

Faults 837-838: Secondary willemite as dispersed grains within a white to pale lavender carbonate occurs with brilliant red-orange zincite in lenticular masses 1-4 mm thick on fault surfaces. The carbonate fluoresces red in most places, but green where the willemite is present.

Fault 897: Tiny grains of willemite cause green fluorescence in fine-grained fault gouge along a probable Set 3 fault in high-grade franklinite-willemite-zincite-calcite ore.

Fault 905: Set 3 fault in moderate-grade franklinite-zincite-willemite-tephroite(?)-calcite ore is coated with abundant calcite and secondary willemite (as indicated by fluorescent green streaks parallel to the calcite fibers). Where this same fault cuts marble, no trace of willemite was seen.

Fault 906: Set 3 fault in high-grade franklinite-willemite-zincite-calcite ore is coated with 1-5 mm of fibrous to splintery accretionary calcite with secondary willemite and "calcozincite."

Fault 951: Set 3 fault in ore is coated with secondary, powdery willemite that renders the fault trace strongly phosphorescent.

Fault 953: Set 3 fault in franklinite-willemite-calcite disseminated ore is lined with highly fluorescent and phosphorescent secondary willemite. The fault is bordered by numerous subsidiary fractures in an anastomosing network; these too are lined with willemite.

Fault 954: Set 2 fault in moderate-grade franklinite-willemite-calcite ore is coated with much accretionary calcite and secondary willemite, the calcite in coarse splintery masses and the willemite as local druses of pale green acicular crystals in narrow open vugs.

Fault 955: Set 2 fault in willemite-franklinite-calcite ore locally containing zincite is lined with accretionary calcite, secondary willemite, and secondary zincite (as "calcozincite").

Fault 1073: A Set 2 fault in ore is coated with 3-15 mm of fibrous accretionary calcite and secondary willemite.

Zeolites (heulandite, stilbite, chabazite) are found almost exclusively in gneissic rocks where hydrothermal alteration along faults created the open space for their development. These are low-temperature, late-stage minerals and are generally the last minerals to form in those areas.

Fault 854: A multistranded, epidote-coated Set 2 fault in pyroxene-calcite-feldspar(?) gneiss contains sphalerite, minor galena, calcite, and zeolites in open spaces between the fault strands, where minor brecciation occurred. This is the fault that produced most of the zeolite specimens collected in late 1990 by John Kolic. The zeolites encrust the calcite and are probably the latest minerals to be deposited there.

Fault 958: A fault in dark, gneissic, pyroxene-rich rock provided the permeability conduit for the deposition of zeolites (stilbite, chabazite) lining solution pockets along the fault trace. The zeolites were heavily collected.

Zincite, "calcozincite." Whether present alone or as a component of "calcozincite," zincite was documented only on faults in ore. In nearly all cases, the immediately adjacent wallrock contains primary metamorphic zincite as well.

Fault 135: Some secondary zincite with a white, fibrous mineral (willemite?) coats a Set 2 fault in very high-grade zincite-franklinite-calcite ore.

Note following Fault 539: This Set 2 fault, in ore, is coated with calcite, brown serpentine, and willemite. The absence of secondary zincite along this fault is probably because the fault cuts through the ore at a low angle and does not intersect the zincite-rich parts of it. Other, smaller faults related to this one, but only 20 cm away and within zincite-rich ore, do contain secondary orange zincite.

Fault 540: Set 3 fault through high-grade, franklinite-brown willemite-zincite-calcite ore is coated with abundant "calcozincite" where the faults cuts ore containing primary zincite.

Fault 766: "Calcozincite" fibers coat a Set 3 fault surface in high-grade franklinite-willemite ore.

Fault 767: This Set 4 fault cuts medium- to coarse-grained, high-grade franklinite-willemite ore with local lenses rich in zincite. The fault is lined with serpentine, calcite, abundant willemite, and probable secondary zincite as well.

Faults 837-839: Faults 837 and 838 are in zincite-rich ore and are coated with lenticular masses 1-4 mm thick of brilliant red-orange zincite interlayered with a white to pale lavender carbonate. Fault 839, in contrast, cuts franklinite-willemite-calcite ore, and zincite is absent on the fault surface. These faults are only 0.5 m apart, but zincite on their surfaces is abundant only where the ore contains primary zincite and is totally absent from all faults where it does not.

Fault 842: Splintery "calcozincite" lines a fault, probably a member of Set 3, in franklinite-willemite-zincite-calcite ore.

Fault 845: "Calcozincite" is present on this fault, but only where zincite is present in the wallrock. The fault is probably a member of Set 3.

Faults 892-893: Secondary zincite and a white to lavender calcite coat Set 3 faults in high-grade franklinite-willemite-zincite-calcite ore.

Fault 897: Secondary zincite on the fault occurs only where the ore is zincite-bearing; the same fault upon entering franklinite-willemite-calcite ore abruptly loses the secondary zincite and is filled instead with much red-fluorescent secondary calcite and local mcgovernite, the whole locally as much as 3" thick.

Fault 898: Lenticular voids along this fault are filled with secondary calcite where zincite is absent in the wallrock; "calcozincite," zincite, and calcite where zincite is present in the wallrock; and locally with a fine-grained, lavender to pale brown material that is in part fault gouge and probably in large part a carbonate mineral, as yet unstudied. The fault is probably a member of Set 3.

Fault 905: This Set 3 fault in moderate-grade franklinite-zincite-willemite-tephroite(?)-calcite ore is coated with “calcozincite” where the wallrock contains zincite.

Fault 906: A Set 3 fault in high-grade franklinite-willemite-zincite-calcite ore is coated with 1-5 mm of fibrous to splintery accretionary calcite, secondary willemite, and “calcozincite.”

Faults 955-956: Faults 955 (Set 2) and 956 in willemite-franklinite-calcite ore locally containing zincite are lined with accretionary calcite, secondary willemite, and secondary zincite (as “calcozincite”). Typically, the “calcozincite” is present on the fault surfaces only where there is zincite in the adjacent ore; along most of the faults it is absent. In this area we have observed repeated instances of this effect, where alternating layers of ore contain zincite, and the faults cutting them are lined with “calcozincite” only in those areas.

Fault 967: Secondary zincite is present on the fault surface in ore but is lacking where the fault passes into marble.

Faults 981-982: Faults in franklinite-zincite-calcite ore are lined with accretionary “calcozincite.”

Fault 1041: Set 3 fault through high-grade franklinite-willemite-zincite-calcite ore is lined with 1-10 mm of fibrous accretionary calcite with sheared-out franklinite and zincite (“calcozincite”).

Faults 1042-1044: Set 3 faults in high-grade franklinite-willemite-zincite ore are lined with fibrous accretionary calcite and zincite (“calcozincite”).

Fault 1046: “Calcozincite” (fibrous calcite and zincite) lines fault surface in franklinite-calcite-willemite-zincite ore and in most places is 3-4 mm thick, locally as much as 5 mm.

Fault 1049: Set 3 fault in willemite-calcite-franklinite ore with minor zincite is coated with fibrous calcite and zincite (“calcozincite”) 0.5-1 cm thick.

Fault 1055: Minor Set 3 fault in franklinite-willemite-calcite ore with minor zincite is lined with fibrous accretionary calcite and zincite (“calcozincite”).

Fault 1056: Rock type not recorded, but doubtless is ore. Set 2 fault surface is coated with fibrous accretionary calcite and zincite (“calcozincite”) 1-15 mm thick.

Fault 1059: Set 3 fault surface is coated with 1-2 mm of fibrous accretionary calcite and zincite (“calcozincite”). Rock type not recorded, but all else in this area is ore.

Faults 1060-1061: Faults in franklinite-zincite-calcite ore with minor willemite are lined with fibrous accretionary calcite, locally accompanied by zincite (“calcozincite”). Fault 1061 is a member of Set 2; fault 1060 is probably a reactivated Set 2 fault.

Faults 1062-1072: Minor faults in franklinite-zincite-calcite ore with minor willemite are lined with fibrous accretionary calcite with zincite (“calcozincite”). Most of these faults are members of Set 3.

Fault 1074: This Set 3 fault in franklinite-willemite-zincite-calcite ore is filled with fibrous accretionary calcite and zincite (“calcozincite”) and pyrochroite 1-4 cm thick.

Faults 1075-1076: Set 3 faults in franklinite-zincite-calcite ore with minor willemite are coated with fibrous accretionary calcite and secondary zincite (“calcozincite”).

Fault 1078: Fault in zincite-franklinite-calcite ore is filled with 0.5-1.5 cm of a fine-grained white carbonate, locally with some secondary zincite.

Fault 1079: Fault in zincite-franklinite-calcite ore is coated with 1-5 mm of “calcozincite” (fibrous accretionary calcite with secondary zincite).

Appendix C. Notes on selected mineral localities in the Sterling mine

The localities described here are listed in order of increasing depth in the mine. Note that collecting and documenting minerals in the mine, except for those that formed along faults, was not a featured part of this study, though selected mineral localities were documented in passing.

150 LEVEL

Gahnite, "biotite", 150 level, along a 15-ft stretch centered on mine coordinates 960N, 1205W.

Specimens from this locality, which was worked by John Kolic, contain abundant, dark green gahnite and a black mica along the footwall contact of the East limb. An upward extension of this zone was well exposed within 50-60 ft of the surface, in stopes above the 150 level, south of the Log Cabin shaft. The mica-gahnite zone extended to the surface, where in August 1992 it was present within the southern one-third of the "genthelvite trench," near the northeast end of the Passaic pit. This area, too, is along the footwall of the East limb of ore. Though the "genthelvite trench" was later modified and partially backfilled, remnant masses of the mica were still visible as of late 2021.

180 LEVEL

Sphalerite-willemite-calcite veins, 180 level, footwall of West limb, at mine coordinates 850N, 1570W.

Several calcite veins 1-4 mm thick cut the ore and the footwall marble at this locality between 845N and 870N. The veins contain calcite, sphalerite, and willemite, and are beautifully laminated; Bob Jenkins will describe these in detail at a later date [notes here were made August 31, 1992]. The calcite fluoresces golden yellow LW, followed by an enduring phosphorescence, where the veins cut the zincite layer near the footwall contact of ore. Calcite in these same veins instead fluoresces red, with typical fleeting phosphorescence, where the veins pass into granular willemite-franklinite ore. The abrupt change in fluorescence correlates perfectly with the change in character of the wallrock, though visually there is no discernible difference in the vein contents. The ore here contains fairly abundant sphalerite in grains 1-2 mm across. Orientations of the veins: N83W/88SW, N79E/84NW, N76W/85SW, N87W/82SW, N80W/86NE, N85W/89NE, N88W/87NE, (7 readings on 4 veins), Median: N83W/88SW

The veins are somewhat irregular along both strike and dip. Four principal veins are present, along with at least five shorter and thinner ones. Two of the veins can be traced from the W rib across the back to the E rib; the largest can be traced at least 5 m laterally and 4 m vertically.

Duftite, Gravity Tram in East limb at mine coordinates 1055N, 1172W

Fault no. 543 (orientation N01W/32NE) at this locality is one of the early, low-dipping thrust faults of Set 2 in the mine. It is a minor fault through medium- to coarse-grained, blocky marble containing abundant, steely gray grains 1-5 mm across of a sulfide mineral (chalcocite?) and scales of phlogopite. This is the fault that Robert Jenkins reported as bearing patchy coatings of duftite, a Pb-Cu arsenate hydroxide, and from which about 50 specimens were recovered. Dr. Jenkins discovered duftite at this locality in 1992 while doing geologic mapping in the mine. The mineral was originally thought to be conichalcite but upon further work was found to be duftite-β, a variety of duftite and a compositional intermediate in the duftite-conichalcite series (see discussion on the Mindat website, at https://www.mindat.org/min-10745.html).

Reference: Jenkins, R.E., II (1993), β-duftite from the Sterling mine, Ogdensburg, New Jersey: The Picking Table, vol. 34, no. 2, p. 6-11.

Fluorite, Gravity Tram at mine coordinates 1050N, 1525W

Specimens rich in colorless granular fluorite in white marble matrix were produced from this area. All came from the north rib and back between stations 130 and 136 of Steve Misiur; most came from near his station 135. These were produced from the westmost of the two layers of fluorite in this area. The fluorite fluoresces white to bluish white under shortwave ultraviolet light and is sometimes referred to by collectors as “poor man’s barite.” Note: Most fluorite at Sterling Hill occurs as late-stage, low-temperature, violet films with calcite on fault surfaces, but it is also known as a local component of the Franklin Marble, as in this occurrence.

340 LEVEL

Zinkenite and guérinite, 340 level, near entry to 1270 subdrift, centered around approximate mine coordinates 745N, 1225W.

This area is notable mineralogically for a probable occurrence of zinkenite, previously known only from the 800 and 900 levels at Sterling Hill. Disseminated sulfide minerals, particularly chalcopyrite, are abundant within coarse-grained marble in this general area, but here, within a zone about 3.5 m thick, dark gray lenses are present that much resemble those of zinkenite and fine-grained quartz from the lower levels. The lenses, best visible along a newly exposed portion of the north rib, are commonly 3-20 cm long, 1-6 cm thick, and have their long dimensions parallel to compositional layering in the marble. The two largest masses in cross section measure 34 x 11 cm and 38 x 11 cm; these are on the south rib. Both appear to be boudins, part of the same, once-continuous layer. Visually there is not the slightest evidence for structural control of the sulfides here; they appear to represent original compositional layers in the marble. Specimens were taken of these dark lenses for later optical and X-ray study. It should be noted that these lenses are in a different position relative to the orebody than the 800- and 900-level occurrences, but as noted above, they are of visually identical character and should be studied to determine their mineralogic makeup.

This same part of the subdrift has long been known as a locality for post-mining guérinite, a hydrous calcium arsenate. If the zinkenite lenses also contain arsenopyrite, like those on 800 and 900 level, that mineral may have been the source of arsenic for the guérinite.

430 LEVEL

"Dead-zone" willemite, 430 level, East limb haulage drift, west rib, between 70 and 120 ft north of the safety exit, centered on mine coordinates 1030N, 980W.

This is the area from which the specimens of "dead-zone" willemite were collected. These are characterized by centimeter-thick veins of solid willemite in granular, brightly fluorescent calcite-willemite ore. Adjacent to each vein, for a distance of 2-4 cm, the calcite and willemite grains in the ore are "dead" – that is, they show no fluorescence, so under shortwave ultraviolet light one sees a prominent slash of green (the willemite vein) bordered by two strips of black, these in turn bordered by red-and-green-fluorescent ore. Such specimens (fig. C1) are visually dramatic and highly prized by collectors. They came from a group of Set 3 faults that strike at low angles to the drift here and dip westward, into the west rib. The most prominent members of this set are beautifully exposed on the west rib from about 60 ft to 100 ft north of the safety exit. As indicated

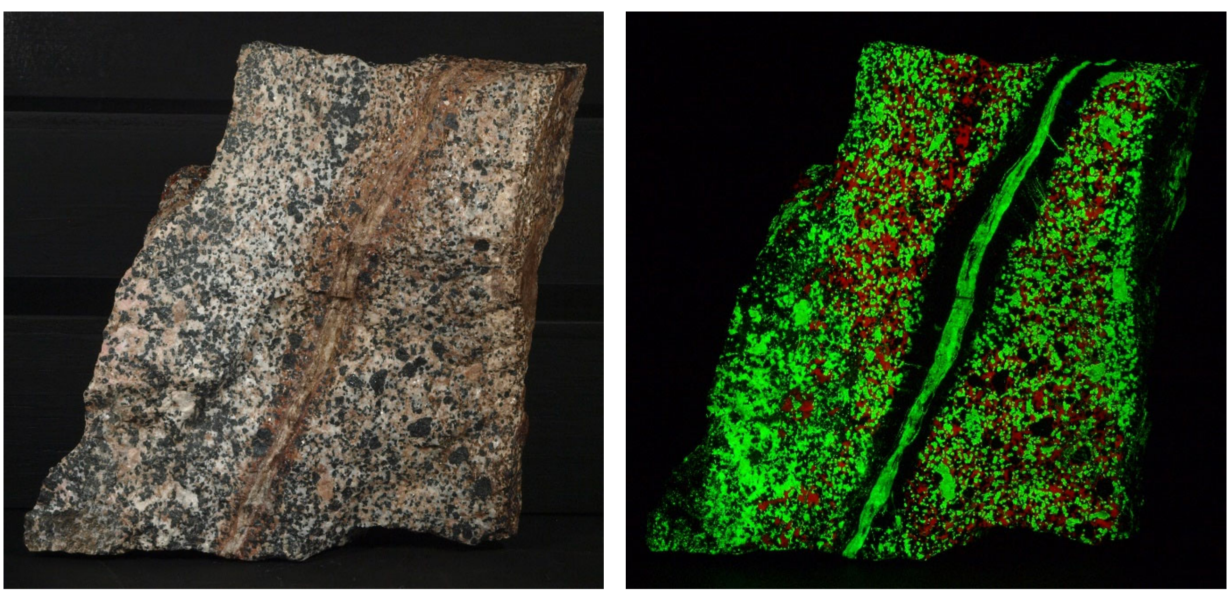

Figure C1. A large display specimen of "dead zone" willemite from 430 level of the Sterling mine. Ex Mark Leger collection, 29 x 25 x 9 cm. Left, appearance under normal light. Right, same specimen under shortwave ultraviolet light.

by the faults documented here and at nearby station 6 (see Verbeek and Grout, 2025 Appendix A), members of this fault set are quite abundant in this part of the mine. These are reverse faults, with common orientations of N30-60E/50-60NW. Faults 763-766 and 769-773 are members of this set of faults.

What is probably the best specimen collected at this locality, a slab containing two "dead zone" willemite veins (fig. 18 of chapter 3), was retained by Robert Hauck, one of the founders of the Sterling Hill Mining Museum. This specimen was eventually acquired by Earl R. Verbeek on behalf of the Franklin Mineral Museum and is now (2021) on public display in the main fluorescent exhibit of that museum.

700 LEVEL

Barite, 700 level, East limb, just north of keel, at mine coordinates 850N, 840W and 870N, 820W

The best and most prolific find of barite from the Sterling mine was on 700 level, in late 1990, in the hanging wall of the East limb, in the southern part of the mine. This area was reached through a raise from 800 level, which led to the west end of 740 crosscut. One then walked eastward along the crosscut to its end, turned left, and proceeded northeastward along the stoped-out portions of the East limb to the barite locality.

The barite from this occurrence was in two finds. The earlier of the two was at mine coordinates 850N, 840W, and comprised about 20% of the total number of specimens recovered. Nearly all of this material had been sold by the time these notes were made (January 8, 1991).

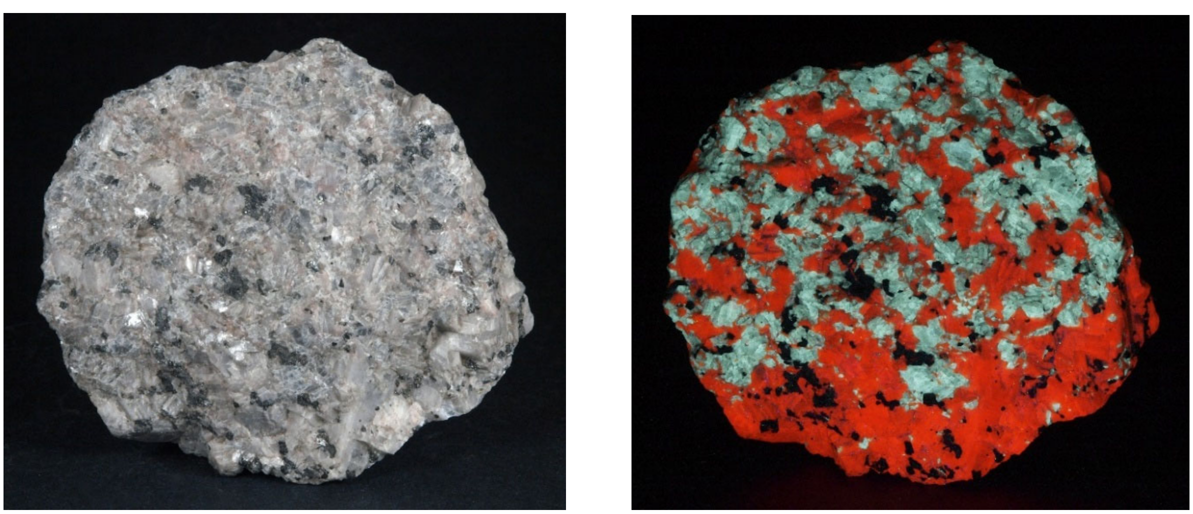

Figure C2. Barite from the 700-level occurrence of the Sterling mine. The barite is visually inconspicuous in its calcite matrix in daylight (left) but fluoresces white to cream (right) under shortwave ultraviolet light. Richard Bostwick specimen, 10.5 x 9.5 x 4 cm.

The second find was far more prolific and produced the best and largest specimens. This find was about 40 feet northeast of the earlier one, at mine coordinates 870N, 820W. Specimens from the second find filled about 15 powder boxes and three five-gallon buckets; in addition to these were 10 additional and generally larger specimens 15-30 cm across. As a wild guess this material totaled about 200 large (15 cm or larger) specimens and numerous smaller ones down to miniature size.

The rock from this locality tended to split along the barite seams, which in general were 1-2 cm thick, so the display faces on many specimens are flat and rich in barite. In a few places the barite layer is as much as 4 cm thick. Most of the barite grains are fairly coarse, 0.5-1.5 cm across, with some as much as 2.5 cm across. The fluorescence of the barite ranges from bright to very bright creamy white, and the calcite matrix from moderate deep red to bright orange-red (fig. C2). The fluorescence of one seems not to correlate with fluorescence in the other in terms of brightness; there are duller barites in bright calcite and vice versa, and also bright barites in bright calcite. The barite fluoresces as brightly as the best Franklin material and in the best specimens is in pleasing balance with the fluorescence of the calcite matrix. Unlike much of the Franklin material, barite from the 700-level Sterling mine occurrence is inconspicuous in daylight, occurring as off-white grains in a pale gray, medium-grained calcite matrix. Accessory minerals include a dark green pyroxene in scattered grains 2-5 mm across and a black metallic mineral, not yet examined but possibly franklinite.

The largest and best specimen recovered from this find is a huge slab measuring 96 x 60 cm across the display face; of this, an area of about 73 x 55 cm is about 35% covered with brightly fluorescent barite. It was mined by John Kolic and Steve Misiur on Friday, December 21, 1990. After a blast, a large area of barite was observed high on the east rib of the haulage drift parallel to the East limb of ore. Steve had wanted a large barite specimen to display in the Rainbow room along with the large calcite-willemite and wollastonite specimens already there, so he and John attempted to extract this one intact. John drilled a hole 1.5-2.0 feet deep behind the barite and hammered in a wedge, but strenuous hammering yielded no result. A second hole was drilled, a second wedge inserted, and some small fractures in the calcite were produced. A third wedge produced much more cracking, but still no separation of the specimen. John then inserted a small chisel into the most prominent crack, and after 15-20 blows the piece separated completely and fell off the wall, coming to rest, unbroken, on edge, on the sill of the drift. John and Steve then roped the specimen to a 9-foot length of drill steel and attempted to carry it to the raise down to 800 level, but got only about 30 ft before deciding it was more than a two-man job. They descended to 800 level, recruited Bob Hauck and Charlie Puzio to help, and then returned to 700 level to the barite locality. With two men on each end of the pole they then carried the barite specimen—in Steve Misiur's words, "like a stuck pig"—to the top of the raise. There it remained until the next day (12-22-90), when John Onder announced he would get the thing out. He, Steve, and Bob returned to the top of the raise, wrapped the specimen in several gunny sacks, attached it to a rope, and lowered it down the raise—a half-hour process. From there it was loaded on an Eimco, driven to the shaft station, placed on the cage, and brought to the surface. For years it was on display, as intended, in the Rainbow Room in the mine, but it was slowly weathering in place, the calcite turning brown and the fluorescence of both minerals gradually dimming. Around 2010 it was removed from the mine by Pete Gillis, successfully cleaned to its former appearance, and moved to a display case in the Thomas S. Warren Museum of Fluorescence, where it remains. The smaller, opposing face of this same mass was purchased by Earl R. Verbeek and is currently (2015) on display in the Franklin Mineral Museum.

The barite on 700 level was exposed in both places where the rock was blasted for specimen recovery; its presence had already been known from previous lamping of the area. This contrasts with the earlier occurrence on 900 level, where the discovery of barite was a stroke of luck. That area had been drilled and blasted to recover orange calcite for the tourist trade, but no barite was visible until the muck pile was lamped.

Wollastonite, 740 crosscut, 700 level. Mine coordinates for this area are 735N, 1000W.

This part of the 740 crosscut is dominated by gneissic rock and was drilled and blasted in a search for zeolites. Wollastonite was not at first exposed. After the first blast no zeolites were found (though they did eventually turn up nearby, only 30 feet farther west, at station 4), but a UV lamp was on hand, and out of curiosity the blasted rib and muck pile were searched. A tiny area of wollastonite was visible on the rib. This area was drilled and blasted about five times, during which the exposed size of the wollastonite mass successively increased through the first few blasts but then decreased again. An estimated 80% of the wollastonite thought to be in place was recovered. Around the wollastonite mass, close to it and locally within one-half inch from it, was abundant granular galena. During blasting the rock always broke through the galena, so no specimen showing the transition from the galena-bearing rock into the wollastonite could be preserved.

The amount of material recovered, mostly as hand-sized or larger pieces, filled about 50 powder boxes. The largest specimens, blocks 20-50 cm across, were placed on the floor to form a pile about 12 feet long, 2 feet wide, and 1.5 feet high, numbering (as a pure guess) perhaps 60-80 pieces. Assuming each powder box held about 15 specimens, these, in addition to those on the floor, totaled about 830 specimens – an impressive amount. Most are of granular wollastonite thickly dispersed in calcite, attractive but not otherwise notable. Some, particularly the larger specimens, are more interesting in that they show, through variation in the abundance of wollastonite, the prominent layering of the rock. Among these are some that show, as well, a good color change in the fluorescence of the wollastonite, either gradually across the face of the specimen or (rarely) rather abruptly from one layer to another (fig. C3). The associated calcite ranges from nonfluorescent to weakly red-fluorescent SW; the intensity of the calcite fluorescence generally increases with increasing richness of color of the associated wollastonite. That is, wollastonite fluorescing pale yellow is generally in a matrix of nonfluorescent calcite (low-Mn rock), and wollastonite fluorescing orange is generally in a matrix of red-fluorescing calcite (higher Mn content).

In the Richard Hauck collection is a singular piece from this occurrence, measuring 22 x 18 x 8 cm, and containing a mass of wollastonite as densely packed grains within an area of 17 x 10 cm, consisting of 90-95% wollastonite. The wollastonite shows a dramatic variation in color of fluorescence within single grains. The bulk of this material fluoresces bright, rich orange, much like Franklin "first find" wollastonite, but the cores of some grains fluoresce moderately bright pale lime green to yellowish green. The color of fluorescence in wollastonite depends on its content of manganese, an impurity element that substitutes for calcium. The fluorescence ranges from pale green or greenish gray at low levels of Mn through yellow to orange and deep orange at higher levels. The green response is rarely seen in natural material, but here it is well developed. The change from green to bright orange fluorescence in most grains is fairly abrupt, rather than going through the green → yellow → orange transition. Here there is only green and orange with, minimally, only a little yellowish-orange to deep yellow-fluorescing material. In daylight the wollastonite is ivory to pale tan in color and is in a matrix of pale gray calcite containing grains of a greenish-black pyroxene. The calcite is so fine-grained as to resemble chert and shows a weak to moderate red fluorescence SW. The coarsest wollastonite grains are 1.0-2.5 cm in length; it is these that show the zoned fluorescence. Most of the grains, however, are so

Figure C3. Wollastonite from the 700 level of the Sterling mine, viewed under normal light (left) and shortwave ultraviolet light (right). Note the sharp change from yellow-fluorescent wollastonite in the lower part of the specimen to orange-fluorescent wollastonite above. Sterling Hill Mining Museum specimen, 26 x 17 x 10 cm.

tightly packed that their size is difficult to determine. Another notable aspect of this specimen is that it was recovered from the muck pile after the first blast into the wollastonite zone. Little wollastonite was produced during that first blast; in addition to the Hauck specimen was one other about 1/3 the size (which entered the Kozykowski collection) and a few small fragments. The bulk of the wollastonite was recovered during later blasts.

The specimen described above is one of the few from this occurrence to show a mass of densely packed wollastonite grains. Also notable is the mass known as the "Aztec sun," one-half of which is in the Bostwick collection and the other half in the Verbeek collection. Both show a large, roughly circular area of densely packed wollastonite grains that fluoresce pale yellow, in a matrix of nonfluorescent calcite. The vast majority of specimens from this occurrence are attractive and richly fluorescent pieces, but of small wollastonite grains densely scattered in calcite matrix, most with considerably less than 50% wollastonite.

Four of the wollastonite specimens contain thin, discontinuous veinlets of a mineral that fluoresces and phosphoresces bright green. These resemble, and may be, tiny willemite-filled tension gashes; they are 2-10 mm long and range in thickness from a hairline crack to 0.5 mm, rarely as much as 0.8 mm. Their planar surfaces are nearly parallel to the compositional layering in the rock or cut it at a low angle.

The notes above were made on January 7, 1991, after about 5-10% of the wollastonite specimens, mostly the larger pieces, had been sold. Since then, the Hauck specimen became, upon incorporation of the Sterling Hill Mining Museum as a nonprofit institution, part of the collection of that museum. It was later sold to Mark Leger, thereby removing the prime specimen from this occurrence from a public museum to a private collection, and still later was sold to Dick Bostwick, in whose collection it remains (as of October 2015). Though still belonging to Mr. Bostwick, it has long been on display in the fluorescent room in Zobel Hall of the Sterling Hill Mining Museum, so once more is viewable by the public.

Zeolites, 700 level, 740 crosscut at 735N, 1030W.

The fault that produced most of the zeolite specimens collected in late 1990 by John Kolic is no. 854, a Set 2 fault oriented N50E/36NW. The fault cuts pyroxene-calcite-feldspar gneisses of highly variable grain size (0.1-3 cm). Epidote lines the fault surfaces. Sphalerite, minor galena, calcite, and zeolites occupy open spaces in the areas between the fault strands, where minor brecciation occurred. The zeolites encrust the calcite and are probably the latest minerals to be deposited. The upper plate of this fault moved N85W, though no sense of slip was determined here.

800 LEVEL

Mcgovernite. Three localities for mcgovernite are listed in this appendix, two here and the other (on 900 level) later, but all are close to one another and are downdip extensions of the same volume of rock. The localities extend over a vertical range of roughly 175 ft. Mcgovernite to date has been found nowhere else in the mine.

● 1130W raise between 800 and 700 levels, at approximate mine coordinates 735N, 1140W, about 25 ft below 700 level. The axis of this raise is about 45/S40E as measured downward. Mcgovernite in the raise occurs as scaly masses in irregular, discontinuous veinlets within a Set 3 fault of orientation N40E/75NW and others related to it; also, within another fault of orientation N60W/53NE. Most of the mcgovernite scales are only 1-2 mm across, but some measure fully 1 cm, these occurring in one wide vein where the mcgovernite grew as coarse plates nearly perpendicular to the vein walls. Slip along multiple, interconnected minor faults, along with brecciation along some of them, created the void space within which the mcgovernite grew. Some hand specimens, then, show an interesting network of mcgovernite-cemented, broken rock (fig. C4). Associated minerals lining faults in this area include bright orange-red zincite, "calcozincite" (fibrous mixture of zincite and calcite), and a pale lavender carbonate which is composed in part of fault gouge. Some of this material fluoresces red, but most fluoresces green due to admixed secondary willemite. Mcgovernite is most prevalent in faults cutting ore that lacks zincite but is not restricted to such places; its lesser abundance in faults cutting zincite-rich ore possibly is attributable to closure of most available void space by secondary zincite and calcite. Mcgovernite appears to have been the last phase to form. Grains of it are commonly implanted directly on the fault surfaces or on the calcite that coats them.

Figure C4. Brown mcgovernite and a fine-grained, pale lavender carbonate mineral cementing clasts of mildly brecciated ore from 1130W raise, 25 ft below 700 level, Sterling mine. Franklin Mineral Museum specimen FMM-3093, 12 x 10 x 3.5 cm.

● 800 level, 740 crosscut in West limb of ore just north of the keel, at mine coordinates 740N, 1080W. Much secondary zincite and "calcozincite" are present on a fault of orientation N25E/80NW (fault no. 897) here, along with calcite (fluorescent red), fine-grained fault gouge (locally fluorescent green due to secondary willemite), and mcgovernite (coating those portions of the fault lacking zincite). The net slip on this fault appears to be in a reverse sense. This movement, probably the second episode of slip, opened lenticular voids that are now filled with zincite, locally 0.5-1 cm thick. Secondary zincite on the fault, as usual, occurs only where the ore is zincite-bearing; the same fault upon entering franklinite-willemite-calcite ore abruptly loses the secondary zincite and is filled instead with much red-fluorescent secondary calcite and local mcgovernite, the whole locally as much as 3" thick.

Sphalerite, 800 level, stope along East limb of ore about 20 ft above 800 level. Approximate mine coordinates at south end of stope, at raise entry, are 1220N, 690W.

Axis of raise leading up to stope from 800 level is about 58/S80E as measured downward. This is a mineralogically noteworthy stope from which numerous specimens of sphalerite and associated sulfides were recovered. The stope is elongated in a N-S direction and is about 120 ft long by 20-25 ft wide, with a fill fence on the north and a raise on the south. Most of the faults containing the sulfides strike NNE and have moderate (50°-65°) NW dips; these are Set 3 reverse faults, reactivated as right-lateral faults in places. Notes on three of these:

<u>Fault 905</u>- This fault contains much sphalerite. Where measured, it is at the hanging-wall contact of ore against marble in the stope. Where the fault cuts ore it is plastered with abundant calcite and secondary willemite (as indicated by fluorescent green streaks parallel to the calcite fibers), local "calcozincite" where the wallrock contains zincite, and sparse secondary copper minerals of turquoise color. The copper minerals are generally at or near the ore-marble contact, with the sole exception of a single small patch 25 cm from the contact. The same fault where it cuts the medium- to coarse-grained marble above the ore, however, contains abundant sphalerite, other associated sulfides, abundant rather than sparse secondary copper minerals, and no zincite. In addition, secondary willemite intergrown with the accretionary calcite, so common where the fault is in ore, is nowhere to be seen where the fault cuts marble. This, as in 970 Stope on 1000 level, is a dramatic example of how the character of the wallrock influenced the mineralogy of secondary minerals precipitated along a fault. The change in mineralogy occurs precisely at the hanging wall contact of the ore and is quite abrupt. The change in mineralogy is reflected in minerals developed later, upon weathering, as well: Hydrozincite, an alteration product of sphalerite, is common here in the marble but was not seen in ore. The combination of the bright

blue-fluorescent hydrozincite against a matrix of bright red-fluorescent calcite is quite a beautiful one.

Fault 907- A fault in medium-grained marble 1-2 ft above hanging-wall contact of ore. Fibrous accretionary calcite lines parts of this fault, but its sense of slip is unknown. Multiple interconnected fault strands are present here, this being one of them, with abundant sulfides forming irregular veins along them. Visible here along the fault is a mass of chalcopyrite, lenticular in shape, and measuring 18 x 4 cm in cross-sectional area. Also present is much black material, probably chalcocite and sphalerite, with blue to green alteration products. This fault is about 30 ft north of the raise and is probably where most of the black sulfide specimens were recovered shortly before (early January 1990).

Fault 910- This is one of the principal faults controlling the sphalerite mineralization here. It is an irregular, branching, multiple-stranded fault in medium- to coarse-grained marble with accessory phlogopite, 0.5-1 m above the hanging wall contact of ore, at approximate mine coordinates 1280N, 690W. The fault strands are quite irregular and form anastomosing surfaces; fault breccia cemented by sphalerite is locally developed where the strands are closely spaced. Also present are an iridescent blue mineral (tarnished bornite or chalcopyrite?), probable hematite (rock stained red in areas of alteration), and hydrozincite (alteration product of sphalerite). The fault strands occupy a zone 0.5-0.7 m thick. This is the area from which Robert Hauck recovered numerous specimens of sulfide minerals during the second week of January 1990.

Zinkenite, realgar, monohydrocalcite, 800 level, western part of 1040 crosscut at mine coordinates 1040N, 975W.

The western part of this crosscut is an area of great mineralogic interest. Prominent layers rich in zinkenite and realgar (fig. C5) occur within the marble here, particularly on the north rib. Both above and below the zinkenite-realgar zone are occurrences of wollastonite. Following is a very slightly edited version of our field notes at this locality.

The zinkenite-realgar zone measures 2.4 m thick and is prominently banded in black and white. Most of the zinkenite-rich layers are < 5 cm thick; many are 1-3 cm. All are enclosed in coarse-grained (about 1 cm), white to pale gray marble. The zinkenite layers are discontinuous and of uneven thickness due to boudinage (marble more ductile); individual layers pinch and swell, and commonly pinch out entirely. Few are traceable in continuity for more than 1 m on the rib face. Within the zinkenite zone are irregular, lenticular (flattened parallel to compositional layering) masses of nearly pure, coarse-grained quartz, 1-3 cm thick and 5-10 cm long, and of pale grayish-brown color. These appear to be part of the same layer, perhaps once continuous and now boudinaged. The quartz is immediately underlain by, or rather forms the topmost part of, another prominently boudinaged layer containing much fine-grained, medium-green pyroxene(?) and local scales of a beautiful, rich mahogany-brown mica, as well as coarse grains (4-7 mm) of a bright tin-white mineral, probably arsenopyrite.

The base of the zinkenite-rich zone is marked by a 7-10 cm thick layer of coarse-grained, pale brownish yellow calcite nearly devoid of other minerals. Below this, sulfides still occur, but only in minor amounts, distributed in thin, wispy stringers throughout the marble. Zinkenite, if present at all in this zone, is inconspicuous; this is “typical” Franklin Marble with scales of graphite, green pyroxene(?), etc. distributed in layers. At 1.5 m stratigraphically below (west of) the base of the zinkenite zone, a layer rich in fine-grained, pale orange-fluorescent wollastonite occurs. This layer is 6-7 cm thick at its thickest part but is discontinuous and local; it is the only such layer here. The same layer in the same position was better developed on 900 level; the wollastonite there had identical appearance and fluorescence. Fluorescent calcite first appears 65 cm lower. From here on down (west) is marble, locally very pyroxene-rich, to the stoped-out portions of the West limb. Most of the marble is nonfluorescent or only very weakly fluorescent until 2-3 m from the ore.

Figure C5. A large specimen of zinkenite (dark gray) and realgar (brownish-red) in pale gray calcite marble. Additional minerals in the zinkenite-realgar layer include fine-grained quartz, sphalerite, pyrite, and arsenopyrite. This sample was collected on 900 level, from a downdip continuation of the 800-level zone described here. Franklin Mineral Museum specimen FMM-2639, 31 x 14 x 7 cm.

The top of the zinkenite zone is gradational as zinkenite becomes less abundant and then disappears. Above this is marble and calc-silicate rock defined by variable proportions of calcite, dark green pyroxene, orange-brown garnet, and wollastonite, the latter quite rich in some layers and in coarse (4-7 cm) bladed grains. Wollastonite first occurs 60 cm above the top of the zinkenite-realgar zone, the top of which is here regarded as the highest occurrence of realgar (in the absence of zinkenite).

Wollastonite samples were collected from a zone about 2.4 m above the top of the zinkenite-realgar zone. The compositional layering in the marble at this locality is oriented N55E/65SE, N33E/77SE (in zinkenite zone), N54E/73SE (best reading for this area; average strike sighted along the back). A thin, green-fluorescing vein cuts the wollastonite here. The vein is nearly parallel to the compositional layering. Samples of this green-fluorescent vein mineral were taken by Dick Bostwick. He later sent one to Bob Jenkins, who identified it as monohydrocalcite.

900 LEVEL

Fluoborite, 900 level, main haulage drift along West limb, from mine coordinates 870N, 1095W to 900N, 1080W.

This area is an updip extension of the locality where fluoborite as a primary metamorphic mineral of the Franklin Marble was first found underground at Sterling Hill, as opposed to area quarries. Fluoborite from Sterling Hill had previously been known only as a fibrous secondary mineral on slip surfaces in ore. The marble at this location is pale gray and shows prominent compositional layering, defined mostly by layers of orange-brown norbergite and phlogopite 5-20 cm thick. The layers thicken and thin laterally but are mostly continuous along their exposed extent. One layer of mixed phlogopite with an unidentified black mineral (probably spinel) and subordinate calcite is prominently boudinaged, with boudins 30-70 cm long, 15-25 cm thick at their midpoints, and 1-10 cm thick at the necks. Norbergite appears in the outermost 1-1.5 cm of these boudins at the expense of phlogopite; this is succeeded inward by a 1-2 cm zone of white calcite (depleted reaction rim?) and then by normal norbergite marble. Compositional layering in the marble here has orientation N25E/48SE and is especially prominent in norbergite-graphite-fluoborite marble with disseminated sulfides.

Mcgovernite, 900 level, West limb near keel, in 780 pillar just south of 800 crosscut, at mine coordinates 785N, 990W.

Two faults at this locality contain abundant post-faulting mcgovernite. One (fault no. 953) is a Set 3 reverse fault (N45E/70NW) in disseminated franklinite-willemite-calcite ore. The fault is lined with splintery, cream-colored accretionary calcite, mostly 0.5-1 cm thick but locally increasing to 2 cm, fluorescent bright red SW. Secondary willemite is also present along the main strand, as is mcgovernite. Fault no. 954 nearby is a low-angle, Set 2 thrust fault along which the upper plate was transported NW. This is an extensive fault, traceable across the entire width of the stope, and was the source of numerous mcgovernite specimens recovered in 1990. Much accretionary calcite (1-3 cm thick) and secondary willemite line the fault surface, the calcite in coarse splintery masses and the willemite as local druses of pale green acicular crystals in narrow, open vugs. The mcgovernite in the best specimens occurs as flat, circular groups of bronzy brown, radiating crystals 1.5-2.5 cm across (fig. C6).

Figure C6. Intergrown circular groups of radiating, post-faulting mcgovernite crystals encrusting a Set 2 fault surface from 780 pillar on 900 level of the Sterling mine. Note slickenlines on fault. Sterling Hill Mining Museum specimen SHMM-1365, 16 x 15 x 12 cm.

Molybdenite, powellite, chabazite, 900 level, 800 crosscut, in gneissic core near the keel of the orebody at approximate mine coordinates 804N, 975-1000W.

The dominant rock types here are massive, coarse-grained (1-3 cm) amphibolites interlayered with (a) fine-grained (1-2 mm), highly feldspathic garnet-amphibole(?) gneisses in which the feldspar is locally highly altered to epidote, and (b) local, highly irregular masses of very coarse-grained, gray to pale brown to cream-colored calcite. Embedded in the calcite are irregular masses and stringers as much as 1 cm across of molybdenite, and also some specular hematite. Small solution vugs in the calcite contain druses of bright green epidote crystals and small, medium-brown, perfectly formed rhomboidal crystals of chabazite that fluoresce weak to moderate emerald-green SW. In addition, in the feldspathic gneisses and the amphibolite within 0.5 m of the molybdenite occurrences, are numerous tiny grains of powellite showing pale yellow fluorescence SW. Sphalerite of pale amber color also occurs in the same general area.

Sphalerite, 900 level, 820 Pillar, West limb near keel of orebody, near footwall contact of ore, at approximate mine coordinates 790N, 995W.

Many Set 4 faults in this pillar strike about N30W and dip steeply SW. These show several episodes of movement, and some can be followed from the ore into the calcite marble of the footwall. In marble the faults are generally single surfaces coated with a talcose mineral; most of these faults show little evidence of wallrock deformation adjacent to the fault. In ore, however, the faults become more irregular and curving, and many split and merge to enclose elongate lenses of rock. Several fault surfaces in a narrow zone are often present, as opposed to the single surfaces characteristic of the marble. Faults in ore are commonly lined with streaked veins of sphalerite, orange to reddish tan to brownish red, in irregular stringers 1-2 cm thick, locally as much as 3 cm, in some places accompanied by later, gray, apparently undeformed sphalerite. Embedded in these masses of gray sphalerite are small grains, 1-2 mm across, of chalcopyrite. Nearby, about 25 ft farther SE along one of these same faults, additional sulfides sight-identified as fine-grained bornite and chalcocite are also present. The wallrock within 1-2 cm of the fault surfaces is depleted in zincite wherever these faults cut zincite-rich ore (e.g., "The Squiggle," which is about 80% zincite and the rest franklinite with a little calcite). All of this changes where these same faults enter the marble -- sphalerite that lines faults in the ore ends abruptly within one inch of the footwall contact, and no sphalerite lines faults within the marble. Within the ore there is strong visual evidence of hydrothermal effects along and near the faults, but within the marble, along these same faults, such evidence is lacking.

Zeolites, 900 level, 800 crosscut, in gneissic core near the keel of the orebody at approximate mine coordinates 804N, 975-1000W.

Fault no. 958 juxtaposes franklinite-calcite ore on the SW against dark, gneissic, pyroxene-rich rock on the NE. This fault is well exposed across the back and along the north rib of the crosscut, and is the fault that provided the permeability conduit for the deposition of zeolites (stilbite, chabazite) in pockets here. The zeolites were heavily collected, but the top part of the main pocket remains in the back and is located directly on, and elongated parallel to, the fault. The lean ore on the SW side of the fault is very near the upper (hanging wall) part of the orebody and is here pyroxene-rich and franklinite-poor; a little higher and to the east this rock grades rather abruptly into the gneisses. At the location of the zeolite pocket the fault thus juxtaposes gneiss against gneiss. Where the lean ore is exposed, a black mineral is seen concentrated within 1 inch of the fault; probably this is hematite. The fault in this locality is locally coated with pale green accretionary fibers, probably serpentine and/or calcite. The slip sense is possibly left-lateral but is not known with certainty.

1000 LEVEL

Fluoborite, 1000 level, West limb haulage drift, between mine coordinates 875N, 995W and 894N, 1000W, mostly on west rib.

This is where fluoborite in the Franklin Marble underground at Sterling Hill was first discovered by Earl R. Verbeek and Marilyn A. Grout on May 22, 1990. Fluoborite was previously known as a secondary, fibrous to splintery mineral coating fault surfaces in ore, but here it was found as a primary metamorphic mineral in equant to squat prismatic grains in the marble host rock, identical to its appearance in some of the marble quarries of the area. Similar fluoborite was later found in modest abundance in the updip extension of this occurrence on 900 level.

Pyrochroite, 1000 level, 970 Stope, East limb.

Fault no. 1074 along the northwest wall of this stope is a Set 3 fault filled with fibrous accretionary calcite with zincite (“calcozincite”) and pyrochroite 1-4 cm thick over an exposed length of 5 m. Calcite in the wallrock immediately adjacent to the fault has a chalky luster and is locally so altered as to be scratched with a fingernail. The pyrochroite from this fault was pale lavender when first collected but darkened rapidly upon exposure. After one day it was dark violet-brown, after two days it was dark brown with little trace of any violet color, and ultimately it became totally black. The fault is oriented N56E/48NW, and although slip sense was not determined here, it is a reverse fault.

Sphalerite, 1000 level, 970 Stope, East limb, along east wall of stope, at approximate mine coordinates 1080N, 420W.

A braided Set 2 fault zone 2-3 feet thick was sketched in detail (see Verbeek and Grout, 2025; chapter 3, fig. 9) and photographed at this locality. The ore above and below the fault zone is prominently layered and consists of nearly pure zincite-franklinite layers (fig. C7, left) alternating with layers of the same two minerals, but with 20-50% calcite. The ore above and below the fault zone is zincite-dominant; that within it generally is not, and apparently has been removed by hydrothermal fluids flowing along that zone (fig. C7, right).

The fault strands as mapped in Figure 9 include both discrete surfaces, commonly veined with secondary hydrothermal minerals, and thin zones of fault breccia within which no throughgoing fractures can be seen. The breccia masses along the faults are lenticular and, in some places, occupy the entire space between two strands of the fault zone. Most are 1-3 cm thick, but locally, some are 7-8 cm thick. Much of the breccia is cemented by sphalerite. Most of the sphalerite is medium-grained and pale honey brown to gray (fig. C8), but locally this grades into cryptocrystalline, reddish-brown sphalerite of the type sometimes mistaken for friedelite. Where breccia is absent, many of the fault surfaces are lined with fine-grained, ivory-colored carbonate and secondary willemite to form veins generally ranging in thickness from 1 mm to 1 cm (as in right photo of fig. C7), but locally as much as 2 cm. The thickness of both the breccia zones and the hydrothermal mineral veins lining the faults varies markedly within short distances because of nonmatching walls of the veins after slip and because of variable degrees of interaction among adjacent and intersecting fault strands that were moving at the same time.

Figure C7. Left, high-grade zincite-franklinite ore from 970 stope, 1000 level of the Sterling mine. Right, similar ore from the thrust-fault zone, where the zincite has been removed by hydrothermal fluids and reprecipitated along the faults as secondary sphalerite and willemite. The granular black mineral in both specimens is franklinite.

Figure C8. A sample of faulted, hydrothermally altered, zincite-depleted ore cut by a fault lined with gray to tan sphalerite from 970 stope, 1000 level. The ore contains much secondary hydrothermal willemite in microscopic grains that fluoresce bright green SW. Specimen size is 14 x 9 x 3.5 cm.

1200 LEVEL

Axinite, heulandite, 1200 level.

1200 crosscut, at mine coordinates 1200N, 460W, opposite subdrift leading northward to stopes in Cross member.

Fault no. 1154 at this locality is parallel to well-developed compositional layering in gneiss and was later etched out by solution and mineralized. It is now represented by a zone 1-6 cm thick of white, coarse-grained, blocky calcite which opens locally into small pockets containing well-crystallized axinite, heulandite, and fluorite. No evidence of the original fault surface remains, and the orientation of the fault parallel to compositional layering prevented determination of slip amounts and sense.

Magnussonite, 1200 level, 1020 stope, about 20 ft above 1200 level. Mine coordinates for this locality, as given by Kolic and Sanford (1993), are 1075N, 750W.

The fault that contains magnussonite at this locality, fault no. 1155, is a planar to gently sinuous Set 2 fault, N69W/32NE, with a very smooth, almost polished surface. Slickenside striations on the fault are subtle and amount to little more than a subdued streaked appearance in colors of red, black, brown, and white on the fault surface. The fault here cuts moderate-grade, salt-and-pepper, franklinite-willemite-calcite ore. This is the largest fault in the local area and can be followed up both ribs and across the back of the stope. The fault offsets the steeply dipping ore-marble contact about 1.5 m, and the sense of offset suggests the upper plate of this fault moved to the NW. Mineral grains in the wallrock are very nearly undeformed right up to the fault surface; there is only a very narrow zone of deformation here. This is the fault that furnished the magnussonite specimens collected by John Kolic in 1990 and that were widely distributed to collectors (fig. C9).

Figure C9. A front-on view of a vein 2-7 mm thick of dark green to brown magnussonite cutting calcitic willemite-franklinite ore from 1200 level of the Sterling mine. The dark olive-green color of fresh magnussonite is seen along the right edge of the vein. Note the slickenlines on the brown surface of the vein where it was in contact with the wall rock. Ex Dave Wellbrock and Mark Leger collections; specimen size is 12 x 6 x 5.5 cm.

Appendix D. Joints Measured in the Sterling Mine

Nearly all of the fractures measured at Sterling Hill during our study are faults showing visible evidence of tangential movement (shear) along their surfaces. These were the focus of our study. Locally, however, groups of parallel fractures are present that appear to have originated as extension (Mode 1) fractures, i.e., sets of joints, and in some places, they are sufficiently numerous and well-defined that we documented them. Evidence of their Mode 1 origin includes:

a. The presence at two localities of possible twist hackle, a feature that forms only on extension fractures.

b. The joints either terminate against faults present in the same exposure or cut through them without visible offset.

c. The joints of one of our measured sets are parallel to a known and widespread joint set documented by Volkert and Monteverde (2013) in Mesoproterozoic rocks at the surface.

d. Another of the joint sets is parallel to a nearby set of undoubted tension gashes.

e. The joints show no evidence of shear, either on or adjacent to their surfaces. Slickenside striations and fibrous accretionary minerals are lacking, drag features are not present, mineral grains show no sign of shear distortion as the joint walls are approached, and no brecciation has occurred along them.

f. Although the joints in places are rough-textured, their surfaces are approximately planar. They are not multistranded, undulatory, or “feather out” by splitting into smaller, curved fractures near their terminations, as do many of the local faults.

Groups of fractures interpreted as sets of joints were documented at seven localities underground at Sterling Hill and by orientation fall into three groups:

GROUP 1

Locality 1a: 180 level, gravity tram, at 1050N, 1485W

A prominent set of joints cuts through the marble at this locality, specifically at station 195 of Steve Misiur. The joint surfaces are rough and unmineralized, and the adjacent wall rock is unaltered. The joints are about 20-80 cm high (these are true heights; both ends exposed) and have exposed (partial) lengths of 5-40 cm. No surface structures were seen on them except for possible crude twist hackle. A few orientation readings:

N60W/89NE, N59W/88NE, N58W/88NE, N53W/88NE, N66W/85NE, N65W/86NE, N62W/86NE, Median*:* N60W/88NE (n = 7)

Locality 1b: Surface exposures within the Franklin 7.5-minute quadrangle

Joints in surface rocks of the Franklin area were measured by personnel from the New Jersey Geological Survey during a lengthy study of the New Jersey Highlands. Volkert and Monteverde (2013) described the dominant joints as strongly clustered around WNW strikes and having steep to moderate dips to the southwest. Though their orientations were stated to be somewhat variable due to later folding, the average orientation of 957 joints was N59W/76SW, almost identical in strike but of somewhat lesser dip than the joints we documented on 180 level in the mine. A possibly correlative set of joints in the overlying Paleozoic rocks, documented by the same authors, strikes N66W on average, though so few joints were measured in those rocks that the average should be viewed with caution. The typically unmineralized surfaces of all these joints, noted by us in the mine and by Volkert and Monteverde in the surface rocks, likely indicate a young geologic age.

GROUP 2

Locality 2a: 180 level, footwall of West limb, at mine coordinates 850N, 1570W

Calcite veins, the largest of which are 1-4 mm thick, cut the ore and the footwall marble at this locality between 845N and 870N. The veins are somewhat irregular along both strike and dip. Four principal veins are present, along with at least five shorter and thinner ones. Two of the veins can be traced from the west rib across the back to the east rib; the largest can be traced at least 5 m laterally and 4 m vertically. Our notes include no indication of shear along these structures, and their parallelism to known joints at several other localities (see below) suggests they too originated as extension fractures.

The veins contain calcite, sphalerite, and willemite, and are beautifully laminated; Bob Jenkins will describe these in detail at a later date [notes here were made August 31, 1992]. The calcite fluoresces golden yellow LW, followed by an enduring phosphorescence, but only where the veins cut the zincite layer near the footwall contact of ore. Calcite in these same veins instead fluoresces red, with typical fleeting phosphorescence, where they pass into granular willemite-franklinite ore. The abrupt change in fluorescence correlates perfectly with the change in character of the wallrock, though visually there is no discernible difference in the vein contents. The ore here contains fairly abundant sphalerite in grains 1-2 mm across. Orientations of the veins: N83W/88SW, N79E/84NW, N76W/85SW, N87W/82SW, N80W/86NE, N85W/89NE, N88W/87NE (7 readings on 4 veins), <u>Median</u>: N83W/88SW (n = 7)

Locality 2b: 800 level, East limb haulage drift at 1230N, 705W

Present at this locality are numerous joints that cut across the faults in this area but do not offset them, even slightly. The joints are subplanar, gently sinuous along both strike and dip, have exposed lengths from a few centimeters to 2 m, exposed heights from 0.5 to 2 m, and are spaced 1-2 m apart generally, but 10-25 cm locally. No evidence of slip along these surfaces was seen; they are simple joints and are unmineralized. A few readings of their orientations: N88W/76NE, N78W/78NE, N79W/69NE, N83W/74NE, N73W/75NE, N84E/73NW, N85E/78NW, N78W/77NE, N90E/75N, Median*:* N83W/75NE (n = 9)

Locality 2c: 800 level, 1220 crosscut east of the cross member at 1220N, 770W

A set of joints at this station cuts through the mylonite of the Nason fault and is obviously the younger feature. Calcite films the joint surfaces; the calcite shows a dim red fluorescence (thus is manganoan) and weathers brown to nearly black where exposed. The fluorescence of the calcite probably is due to proximity to the orebody here; this station is quite close to the East limb of ore. Also present on these joints are films of a dark grayish-blue clay(?), but the joints are otherwise unmineralized. Readings: N82W/76NE, N75W/72NE, N77W/70NE, N83W/77NE, Median*:* N80W/74NE (n = 4)

Locality 2d: 900 level, 800 crosscut at about 804N, 975-1000W

This area is in the gneissic core of the orebody, near the keel. A well-developed set of joints is present at this locality. A few readings: N85W/81SW, N80W/84SW, N76W/86SW, N86W/84SW, N80W/89SW, Median*:* N80W/84SW (n = 5)

These joints are spaced 0.5-1 m apart and have rough, discolored surfaces, but other than bare films of calcite they are unmineralized: they contain no secondary zincite, no willemite, no mcgovernite. Many of them terminate against the low-dipping, Set 2 faults present here, those whose upper plates moved to the NW; the joints clearly are younger. A few joints cut through these faults without offset, and again are obviously younger than the faults. The joints also appear to be younger than the steeply dipping Set 3 faults here, though that relation is not as clearly expressed as for the low-dipping set of faults.

The similarity in orientation of these fractures at all four localities (median values: N83W/88SW, N83W/75NE, N80W/74NE, N80W/84SW) suggests they are correlative and constitute a widespread set of joints in the mine. Joints of similar orientation are present at the surface, both in the Mesoproterozoic metamorphic rocks and the Paleozoic sedimentary rocks overlying them (Volkert and Monteverde, 2013) but on the basis of orientation alone do not appear to constitute a set distinct from the WNW-striking joints of Group 1. Crosscutting relations and the simple mineralization history of the Group 2 joints suggest that they, too, are younger than most or all of the faults in the mine, as is particularly clear along 800 crosscut on 900 level, where many of the faults are lined with zincite, calcite, and mcgovernite, but the joints are either empty or contain only calcite. The mineralized veins on 180 level are an exception and may or may not be part of the Group 2 set of joints.

GROUP 3

Locality 3a: 340 level, southern part of 1270 subdrift, west of the East limb

Within the "black rock" on the east rib, between 650N and 660N, are numerous calcite-filled tension gashes. Several readings of their orientations: N58E/52NW, N50E/69NW, N46E/62NW, Median: N50E/62NW (n = 3)

These provide the σ_3 vector and define the local σ_1- σ_2 plane for one of the episodes of fracture in this area. Note the parallelism of these features to the joints of locality 3b, which were reactivated as faults at that locality.

Locality 3b: 340 level, in "black rock" zone centered on coordinates 1010N, 1090W

Numerous small faults in this area all have NE strikes, moderate NW dips, are lightly coated with chlorite and/or calcite, and appear to be related. Though evidence of the sense of slip along these faults is only suggestive at best, in all three places seen it suggests reverse movement, with the hanging wall having moved up and south to southeast. These are all minor faults and resemble a set of joints reactivated in shear. Their surfaces are nearly planar, and all appear as single rather than multiple surfaces—that is, none define a shear zone but are individual "clean" breaks. They are abundant (spacings are 8-90 cm), mutually parallel, and do not split, merge, or otherwise connect to one another. Amounts of slip on most are trivial, a centimeter or so. Tellingly, some of these surfaces display apparent twist hackle, a feature that forms only on extension fractures. Thus, these surfaces are here provisionally interpreted as reactivated joints. Orientations: N66E/42NW, N34E/58NW, N52E/47NW, N56E/47NW, N47E/51NW, N34E/63NW, N28E/62NW, Median: N47E/51NW (n = 7)

The parallelism between these fractures and the tension gashes on the same level reinforces their interpretation as a set of reactivated joints. Complicating this assertion, however, is that the most common faults in the mine—the Set 3 faults, more than 200 of which were measured—have similar orientations: NE strikes and moderate to fairly steep NW dips. These are reverse faults, some of which were later reactivated and show different slip directions. We suspect, however, that the parallelism between the Group 3 joints and the Set 3 reverse faults is fortuitous because the faults, orientation aside, are of wholly different character. Many of them are curved, irregular, and consist of multiple, interconnecting strands, whereas the Group 3 joints are single, nearly planar fractures. The faults show common evidence of ductile deformation in the form of distorted, flattened, and drag-rotated mineral grains adjacent to the fault walls, and thin zones with mylonitic fabric are present where some of these faults cut marble. The joints documented here, however, are wholly free of any evidence of a ductile response.

MINERALIZATION OF JOINTS AT STERLING HILL

The joints described above, with the possible exception of locality 2a, are typically either empty or are thinly coated with calcite, even in areas where faults cutting the same rocks are heavily mineralized with a variety of hydrothermal species. Volkert and Monteverde (2013) likewise noted that joints in the surface rocks nearby are typically unmineralized. The only other species noted on the Sterling Hill joints are possible chlorite, a claylike mineral, and in one place (locality 2a), willemite and sphalerite. All of these, too, are compatible with fairly low temperatures of formation (the willemite included; see Brugger et al., 2003). We thus suspect that most or all of these joints are geologically young and postdate faulting at Sterling Hill, so have had only low-temperature hydrothermal fluids and meteoric water circulating through them.

The relative paucity of joints in the Sterling mine is probably ascribable to the sheer abundance of faults that cut the local rocks. These faults, diversely oriented (see Verbeek and Grout, 2025; chapter 3, fig. 6) and present by the thousands, left little opportunity for new fractures to form under the low-stress conditions under which joints normally develop. Any new stresses imposed on the rocks could instead be relieved by minor adjustments on faults already present.

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