Humphris, S.E., Herzig, P.M., Miller, D.J., et al., 1996.
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APPENDIX: THIN-SECTIONS SUMMARY[1]

Shipboard Scientific Party[2]

INTRODUCTION

This appendix contains general descriptions of polished thin sections prepared from sulfide/sulfate-rich rocks during Leg 158. These descriptions are grouped according to rock type, as defined in the "Sulfide Petrology and Geochemistry" section of the "Explanatory Notes" chapter (this volume).

Type 2: Chert

Sample 158-957A-3X-1, Piece 9, Thin Section #1
Sample 158-957B-4R-1, Piece 5, Thin Section #8
Sample 158-957J-1X-1, Piece 33, Thin Section #43
Sample 158-957A-3X-1, Piece 10, Thin Section #2
Sample 158-957N-1W-1, Piece 2, Thin Section #57

The dominant silica types in gray and red cherts are chalcedony and quartz. Amorphous silica is rare. The red color is caused by disseminated Fe-oxides, locally crystallized or recrystallized to hematite. A yellow fibrous clay mineral is locally associated with the red silica. Pyrite is abundant as disseminated euhedral crystals in the gray silica. Very rare traces of marcasite are observed. Chalcopyrite and sphalerite are the two other trace minerals that occur as individual grains in silica or associated with pyrite. Gray chert generally occurs together with red chert after replacing the red chert caused by reducing conditions. The Fe-oxide is then recrystallized into hematite or replaced by pyrite. Commonly, a rim of gray silica depleted in Fe-oxides is observed around pyrite grains disseminated in red chert.

Sample 158-957N-1W-1 (Piece 2) is a particularly dark gray chert with only traces of Fe-oxides (hematite). Euhedral pyrite grains and aggregates, associated with chalcopyrite, are in a matrix of fine-grained quartz-chalcedony. Most chalcopyrite is altered to a bornite-chalcocite-digenite-covellite assemblage.

Type 3: Gray Silica

Sample 158-957A-3X-1, Piece 8, Thin Section #4

Gray silica dominated by amorphous silica with minor disseminated pyrite and traces of chalcopyrite and sphalerite.

Type 5: Massive Sulfides

Type 5a: Massive Porous Pyrite

Sample 158-957A-3X-1, Piece 11, Thin Section #3
Sample 158-957E-2R-1, Piece 2, Thin Section #28
Sample 158-957I-1N-1, Piece 8, Thin Section #41
Sample 158-957K-1X-1, Piece 2, Thin Section #44
Sample 158-957K-1X-1, Piece 4, Thin Section #45
Sample 158-957N-1W-1, Piece 4, Thin Section #59

One of the general characteristics of these samples is the high porosity (up to 50 vol%; visual estimate from thin sections). In Samples 158-957A-3X-1 (Piece 11), 158-957I-1N-1 (Piece 8), 158-957K-1X-1 (Piece 4), and 158-957N-1W-1 (Piece 4), the dominant minerals are pyrite and marcasite often associated in banded and colloform textures. In some sections, marcasite is dominant over pyrite, but replacement of marcasite by pyrite is often observed. Amorphous silica is the major or dominant phase in two sections (Samples 158-957K-1X-1, Piece 2; and 158-957K-1X-1, Piece 4) and occurs as black silica clasts with numerous biogenic structures and filamentous textures, or as late colorless silica filling open spaces and lining clasts and sulfides. Chalcopyrite, when present, is generally a trace constituent occurring as small inclusions in pyrite or sphalerite; it may be locally altered to bornite and covellite. Sphalerite is a minor (<5 vol%) or trace mineral in all samples that occurs as small inclusions in marcasite or pyrite; however, it also forms individual layers in the colloform pyrite-marcasite bands. Less commonly, sphalerite occurs as late crystals in open spaces partly replaced by chalcopyrite.

Sample 158-957E-2R-1 (Piece 2) is distinct among these samples. Colloform textures and high porosity are observed in pyrite, which is the dominant mineral. Marcasite is absent, and chalcopyrite is abundant as a late mineral in interstices or filling small cracks in pyrite. Sphalerite occurs as a trace mineral. Anhydrite and chlorite are minor late minerals filling pore spaces. Quartz occurs as a trace mineral in small clasts. The mineralogy and textures observed in this section suggest that this sample may represent a massive porous pyrite that has partly recrystallized during a late high-temperature episode when chalcopyrite and anhydrite where formed.

Type 5b: Massive Porous Sphalerite

Sample 158-957B-1R-2, Piece 1, Thin Section #5

This sample is similar in texture and mineralogy to white smoker chimney samples collected at the surface of the mound. It is characterized by high porosity. Multiple generations of coarse sphalerite, overgrowing minor silica, colloform pyrite, and chalcopyrite, form a highly porous structure later coated by amorphous silica. The largest open spaces are conduits rimmed by chalcopyrite and coarse-grained pyrite. Euhedral pyrite without sphalerite inclusions are overgrowing sphalerite. A red clast of silica and shards of fresh glass are present in this sample.

Type 5c: Massive Granular Pyrite

Sample 158-957B-3R-1, Piece 1, Thin Section #6
Sample 158-957F-2N-1, Piece 5, Thin Section #29
Sample 158-957G-1N-1, Piece 3, Thin Section #31
Sample 158-957K-2N-1, Piece 9, Thin Section #46

The intergranular porosity (up to 35 vol%; visual estimate from thin section) is lower than for the porous massive samples. In Samples 158-957B-3R-1 (Piece 1), 158-957F-2N-1 (Piece 5), and 158-957G-1N-1 (Piece 3), the dominant mineral is coarse-grained pyrite, which forms polycrystalline, recrystallized assemblages where the porosity is particularly low. Colloform primary textures are locally preserved but no marcasite is observed. Chalcopyrite and sphalerite are rare or occur as minute inclusions (<50 μm) in pyrite. In some cas-

[1]Humphris, S.E., Herzig, P.M., Miller, D.J., et al., 1996. *Proc. ODP, Init. Repts.,* 158: College Station, TX (Ocean Drilling Program).
[2]Shipboard Scientific Party is as given in the list of participants in the contents.

es, sphalerite is distributed along former grain boundaries within pyrite. In one section (Sample 158-957F-2N-1, Piece 5), local enrichment of anhydrite in pore spaces is associated with some chalcopyrite and sphalerite. Anhydrite is normally rare or occurs in trace amounts only. Silica is present as minor chalcedony, quartz aggregates, and euhedral quartz crystals at the core of early pyrite overgrown by colloform recrystallized pyrite. Amorphous silica and smectites are late minerals filling pore spaces in pyrite. Hematite forms irregular aggregates and hexagonal crystals within the quartz.

Sample 158-957K-2N-1 (Piece 9) is different from those described above in that it is enriched in marcasite (20 vol%) and chalcopyrite (10 vol%). This rock type is best described as intermediate between Types 5a and 5c. Marcasite forms banded late overgrowths alternating with pyrite on recrystallized pyrite aggregates. Chalcopyrite fills void spaces and occurs as inclusions in early pyrite. Its local alteration to covellite, digenite, and bornite is more evident when the grains are in contact with marcasite. Sphalerite forms individual grains disseminated in pyrite. A more complex history is suggested by the mineralogy. During the first stage, pyrite precipitated with late chalcopyrite (equivalent to the first group of thin sections). During the second stage, after recrystallization of the early pyrite, alternating bands of marcasite and pyrite were formed, and chalcopyrite was partly oxidized.

Type 5a–5c: Massive Pyrite (Intermediate Between Types 5a and 5c)

Sample 158-957K-3X-1, Piece 6, Thin Section #47
Sample 158-957K-3X-1, Piece 7, Thin Section #48

The mineralogy is dominated by pyrite and marcasite with traces of disseminated chalcopyrite. Pyrite and marcasite form coarse- to very fine-grained polycrystalline aggregates and colloform bands. Sphalerite is common and forms intergrowths with pyrite and marcasite bands. Quartz and chalcedony are minor to rare, occur late in voids and fractures, and show multiple stages of precipitation and recrystallization. Amorphous silica occurs in trace amounts in open spaces. There is evidence of the inversion of marcasite to pyrite and the recrystallization of pyrite. These samples are generally very similar to the massive porous pyrite except for their porosity.

Type 5d: Massive Pyrite-Chalcopyrite Selvage

Sample 158-957C-14N-2, Piece 1D, Thin Section #24

This section does not show the chalcopyrite enrichment generally observed in the anhydrite vein selvages. Pyrite is the dominant mineral with concentric colloform growth. Along the anhydrite veinlets, pyrite is dense and shows almost no inclusions. Chalcopyrite occurs only as a minor interstitial phase overgrowing pyrite or as inclusions in pyrite. Sphalerite is a trace mineral in pyrite where it locally forms layers along the growth planes. Rare quartz fills pore spaces in pyrite. Anhydrite is abundant and interstitial to the pyrite nodules.

Type 6: Massive Pyrite Breccia

Type 6a: Nodular Pyrite Breccia

Sample 158-957F-1N-1, Piece 10C, Thin Section #30
Sample 158-957H-1N-1, Piece 13, 60–61 cm, Thin Section #36
Sample 158-957H-1N-1, Piece 13, 61–62 cm, Thin Section #37
Sample 158-957H-3N-1, Piece 1, Thin Section #38

Samples are dominantly composed of pyrite, which occurs as nodular clasts (up to 1 cm) locally replaced by quartz and containing quartz crystals. Three types of pyrite nodules and clasts are present: (1) rounded with porous cores (partly dissolved?), (2) rounded with porous cores with later nonporous pyrite precipitates at their outer rims, and (3) clasts with outer portions comprised of euhedral pyrite. The latter are less porous and do not contain quartz inclusions. Chalcopyrite is rare to abundant as small inclusions in pyrite, but generally enriched in the matrix. In chalcopyrite-rich aggregates (Sample 158-957H-1N-1, Piece 13, 61–62 cm), two generations of pyrite are observed. One is euhedral at the center of the clasts and surrounded by chalcopyrite; the second generation occurs as euhedral crystals forming an outer rim around the clast. Sphalerite occurs as small rare inclusions in the early pyrite. Anhydrite with disseminated pyrite is the major mineral in the matrix among the pyrite clasts. Minor polycrystalline quartz zones are observed in the anhydrite matrix, but there is no evidence of mutual replacement. Some large pyrite clasts show clear replacement of pyrite by quartz. This appears to progressively isolate pyrite domains surrounded by quartz. Hematite occurs in trace amounts, but numerous very tiny (<5 μm) inclusions are found in early pyrite (Sample 158-957H-1N-1, Piece 13, 61–62 cm). Some samples contain millimeter-sized basalt clasts altered to quartz, clay minerals, and pyrite; locally, however, they retain relics of igneous textures.

Thin Section #36 (Sample 158-957H-1N-1, Piece 13, 60–61 cm) consists of a clast of massive pyrite (Type 5) from a nodular pyrite breccia; it is not representative of this type, therefore. Sample 158-957H-3N-1 (Piece 1) is an unusual type in which a clast of massive pyrite (see Type 5c) is overgrown by a matrix of porous massive pyrite (see Type 5a).

Type 7: Pyrite-Anhydrite Breccia

Type 7a: Massive Pyrite-Anhydrite Breccia

Sample 158-957C-5N-1, Piece 2, Thin Section #11
Sample 158-957C-5N-1, Piece 6, Thin Section #12
Sample 158-957C-5N-1, Piece 7, Thin Section #13
Sample 158-957O-2R-1, Piece 5, Thin Section #60

Recrystallized pyrite is the dominant mineral occurring as aggregates in a matrix of anhydrite and chalcopyrite. The clasts show several generations of pyrite growth. Euhedral dense pyrite at the center is mantled by a more porous pyrite with abundant chalcopyrite and rare sphalerite inclusions. Most of the clasts are rimmed by euhedral pyrite grains. Some euhedral to subhedral quartz inclusions occur in the pyrite. The anhydrite matrix contains aggregates of pyrite and chalcopyrite. Some anhedral quartz grains predate the formation of anhydrite and locally replace pyrite. Traces of clay are observed filling voids in pyrite.

Type 7b: Nodular Siliceous Pyrite-Anhydrite Breccia

Sample 158-957C-7N-1, Piece 6F, Thin Section #14
Sample 158-957C-7N-1, Piece 6G, Thin Section #27
Sample 158-957C-7N-1, Piece 8D, Thin Section #15
Sample 158-957C-7N-2, Piece 1E, Thin Section #16

The nodular clasts are polycrystalline aggregates of pyrite with interstitial chalcopyrite, which may comprise as much as 40 vol% of the clast. Chalcopyrite also forms as rims around clasts. Some remnants of colloform texture indicates recrystallization. The outer part of some clasts is rimmed by euhedral, chalcopyrite-free pyrite. Quartz is generally rare but occurs in voids within the clasts. A second type of clast contains corroded pyrite in a quartz matrix. Recrystallization of pyrite and quartz results in irregular grain boundaries within clasts. The matrix is dominantly anhydrite with disseminated euhedral pyrite and chalcopyrite as large aggregates (10 mm). Isolated quartz crystals are rare in the matrix, but they are more abundant near the siliceous clasts. Rare sphalerite inclusions are commonly distributed along grain boundaries in pyrite fragments.

Type 8: Pyrite-Silica-Anhydrite Breccia

Sample 158-957C-12N-2, Piece 12, Thin Section #20
Sample 158-957N-1W-1, Piece 4, Thin Section #58

The dominant minerals are aggregates of euhedral pyrite (up to 8 mm) and quartz with complex, and probably multistage, intergrown relationships. Anhydrite is less abundant and interstitial to quartz, but it increases toward anhydrite veins where coarse chalcopyrite is enriched as interstitial crystals between the pyrite grains. Some smectites are observed within the pyrite clasts or as aggregates in the quartz. Anhydrite contains euhedral quartz, but no mutual replacement is observed.

Type 9: Pyrite-Silica Breccia

Type 9a: Pyrite-Silica Breccia

Sample 158-957C-11N-1, Piece 3A, Thin Section #18
Sample 158-957C-14N-1, Piece 2, Thin Section #23
Sample 158-957E-11R-1, Piece 9, Thin Section #33
Sample 158-957H-8N-1, Piece 14, Thin Section #40
Sample 158-957I-1N-1, Piece 12, Thin Section #42
Sample 158-957M-1R-2, Piece 30, Thin Section #50
Sample 158-957M-3R-1, Piece 30, Thin Section #51

Dominant minerals are pyrite and quartz or chalcedony. Pyrite (15–40 vol%) occurs as millimeter-sized grains and recrystallized aggregates in a quartz matrix. Some aggregates are enclosed in anhydrite; others are overgrown by late euhedral pyrite. Quartz occurs as fine- to coarse-grained aggregates. Coarser grains typically occur in voids and at pyrite boundaries. These contacts are irregularly shaped because of quartz replacement, but the contact with anhydrite grains is sharp. Anhydrite forms veins and rims around some pyrite grains. Chalcopyrite occurs as trace or rare inclusions in pyrite; locally, it is enriched in the interstices between quartz in grains or close to anhydrite. Sphalerite, pyrrhotite, and hematite are found as trace inclusions in pyrite. Pyrite-silica breccia and chloritized basalt (Type 10b) samples are the only sample types in which pyrrhotite is observed. Clay minerals are rare in the interstices between pyrite grains. Some pyrite, fine-grained quartz, and clay assemblages are interpreted as silicified and pyritized basalt clasts.

Type 9b: Nodular Pyrite Silica Breccia

Sample 158-957C-15N-4, Piece 4, Thin Section #21

This type is very similar to Type 9a. Polycrystalline grains of pyrite are found disseminated in silica. Chalcopyrite occurs disseminated in pyrite and interstitial between quartz grains. Quartz forms regular concentric aggregates. Commonly pyrite grains show a 20-µm-thick rim of euhedral quartz with quartz tips "growing" toward the pyrite. Quartz commonly exhibits concentric layering, which is then overgrown by euhedral quartz. Some of the concentric aggregates display a brownish center, which could be smectite. Clay minerals are also present in microporous cores of pyrite.

Type 10: Silicified Wallrock Breccia

Type 10a: Silicified Wallrock Breccia

Sample 158-957C-15N-2, Piece 1B, Thin Section #22
Sample 158-957C-16N-2, Piece 3C, Thin Section #25
Sample 158-957C-16N-2, Piece 1B, Thin Section #26
Sample 158-957E-4R-1, Piece 3, Thin Section #32
Sample 158-957H-5N-2, Piece 3A, Thin Section #39

Pyrite and quartz are the dominant minerals with minor clays related to basalt alteration. Chalcopyrite and sphalerite are very rare as isolated small grains in pyrite. The matrix cementing the altered basalt clasts is comprised of pyrite nodules (<1 cm) in white and gray quartz. Basalt clasts are totally recrystallized and replaced by quartz and pyrite, but some areas retain igneous textures. In many places, previous basalt clasts are identified by the presence of tan clay minerals and quartz pseudomorphs of olivine. The less altered basalts are cut by a network of quartz-pyrite veins, and the sharp angular outlines of the clasts are not always seen. Chlorite occurs locally in fine knots adjacent to the altered clasts. Anhydrite is rare as euhedral grains filling late millimeter-scale fractures or in open spaces. Pyrite in the recrystallized matrix often has corroded grain boundaries.

Type 10b: Chloritized Basalt Breccia

Sample 158-957E-18R-1, Piece 5, Thin Section #34
Sample 158-957E-14R-1, Piece 11, Thin Section #35

Pyrite is disseminated in chloritized basalt clasts; however, commonly it occurs as large grains (2 mm) in the quartz veins and as discontinuous rims around the clasts. Abundant green and brown chlorite replaces crystalline and glassy basalt. Colorless clays replace olivine and plagioclase. Quartz occurs in veins and partly replaces basalt. Chalcopyrite is interstitial to pyrite crystals and locally enriched in veins. Rare inclusions of pyrrhotite are observed in euhedral pyrite adjacent to chalcopyrite. Sphalerite occurs as rare disseminated grains in pyrite related to veins.

Type 11: Massive Anhydrite Vein

Sample 158-957C-11N-2, Piece 9, Thin Section #19

Massive anhydrite veins have rare pyrite inclusions and traces of chalcopyrite. Some anhydrite grains contain large fluid inclusions with vapor bubbles.

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