NASA/USGS Lunar Highland Regolith Simulant Development

Stephen Wilson and Douglas Stoeser
U.S. Geological Survey, Denver, CO

USGS

NASA/USGS Simulants

- Previous prototypes NU-LHT-1M & 1D
- Current prototypes NU-LHT-2M & 2C
- Summer 2009 NU-LHT-3M (~4 tons)

(NASA/USGS-Lunar Highlands Type-version, grain-size type)

USGS

Development progress

- Synthetic agglutinate production (patent pending) LHT-1M
- High quality glass production LHT-1M
- Optimized particle size distribution (grinding) LHT-1M
- Dust material LHT-1D
- Minor minerals LHT-2M
- Synthetic breccia LHT-2C
- Synthetic mineral preparation

USGS

Improved mineral composition

- Trace mineral additions to LHT-2M
  - Ilmenite ($Fe^{+2}Ti^{+4}O_3$) 0.44 %
  - Phosphates 0.12%
    - Fluorapatite ($Ca_5(PO4)_3F,Cl$)
    - Synthetic whitlockite/merrilite ($\beta\ Ca_3PO_4$)
  - Chromite ($Fe^{+2}Cr_2O_4$) 0.04 %
  - Pyrite (FeS) 0 .01 %

(amounts determined by SEM X-ray modal analysis)

USGS

Synthetic mineral production

- Plagioclase (Anorthite An95)
- Pyroxenes

  Clinopyroxene (Augite, $Ca_{0.4}Mg_{0.4}Fe_{0.2}SiO_3)_2$)

  Orthopyroxene (Enstatite $Mg_{0.75}Fe_{0.25}SiO_3)_2$)
- Olivine (Fo75)

USGS

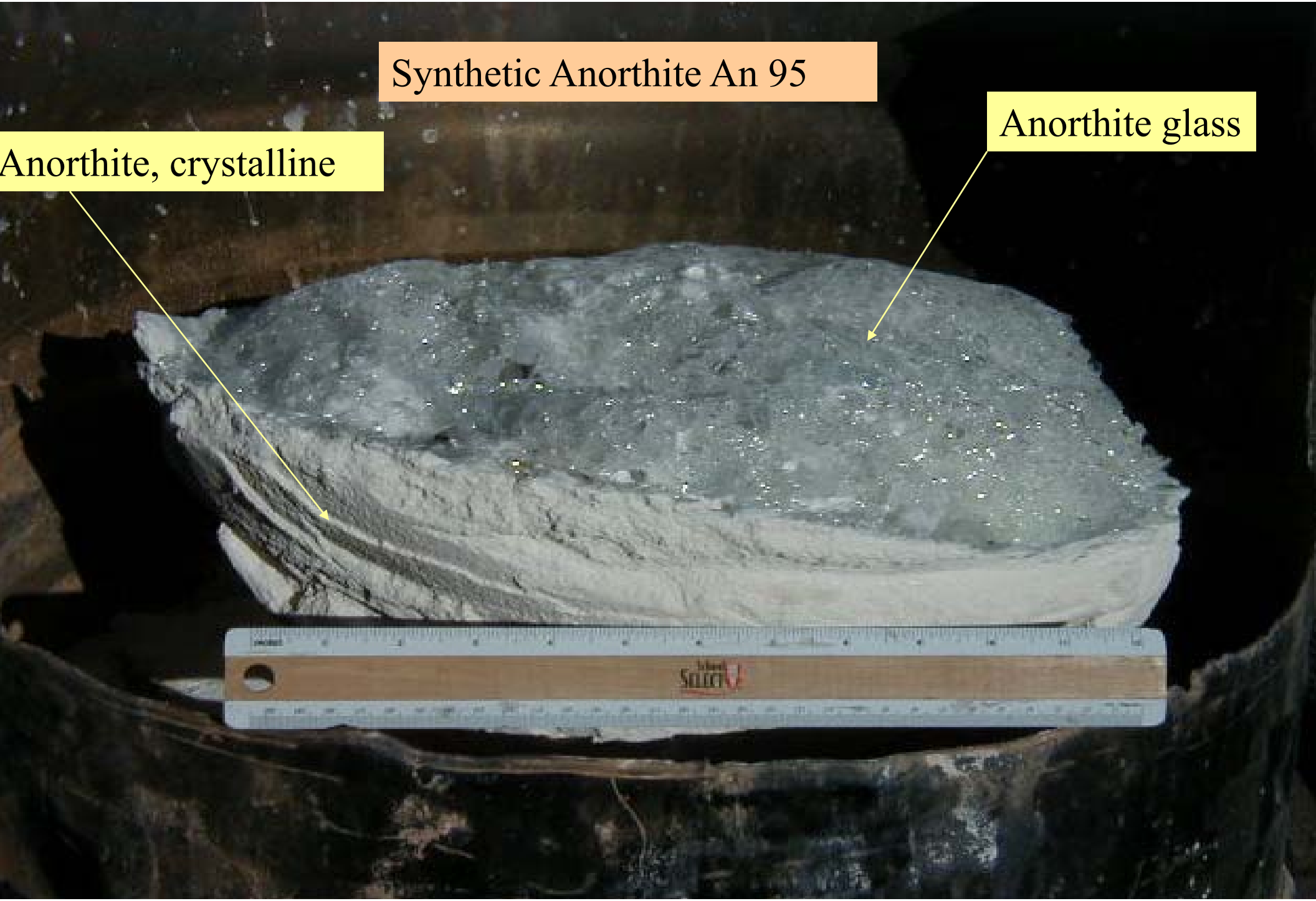
Synthetic mineral preparation

- Commercially available reagents

  Al_2O_3, SiO_2, CaO, MgO, Fe_2CO_3, Na_2CO_3
- Melt at Zybeck Advanced Products (1500-2000C)

  Batch mode, Continuous feed mode
- Crystallize during cooling
- Yield 20-60 lbs material

USGS


Synthetic Anorthite An 95
Anorthite, crystalline
Anorthite glass

Whole Pattern Fitting and Rietveld Refinement

FILE: [901002-02.raw] 1.2 u
SCAN: 5.0/65.0/0.02/2.1(sec), Cu, I(p)=7742, 01/09/09 10:26p
PROC: [WPF Control File]

- [x] K-alpha2 Peak Present
- [x] Allow Negative Isotropic B
- [x] Allow Negative Occupancy
- [x] Apply Anomalous Scattering
- [x] Use Isotropic B Value Only

[Diffractometer LP] Two-Theta Range of Fit = 5.0 - 65.0(deg)

- [x] Zero Offset of Goniometer - 2Theta = 0.759649
- [x] Specimen Displacement - Cos(Theta) = -0.675502
- [x] Axial Divergence - Cot(2Theta) = -0.005817
- [ ] Monochromator Correction for LP Factor = 1.0
- [x] K-alpha2/K-alpha1 Intensity Ratio = 0.506899

Profile Shape Function (PSF) for All Phases: pseudo-Voigt, Fixed-BG, Lambda=1.54059Å (Cu/K-alpha1)

Phase ID (2)	Source	I/Ic	Wt%	#L
Anorthite - $CaAl_2Si_2O_8$	PDF#01-070-0287	0.60(0%)	0.0 (0.0)	708
Anorthite - $(Ca_{0.96}Na_{0.04})(Al_{1.99}Si_{0.01})Si_2O_8$	PDF#01-089-1464	0.58(0%)	100.0 (0.0)	401

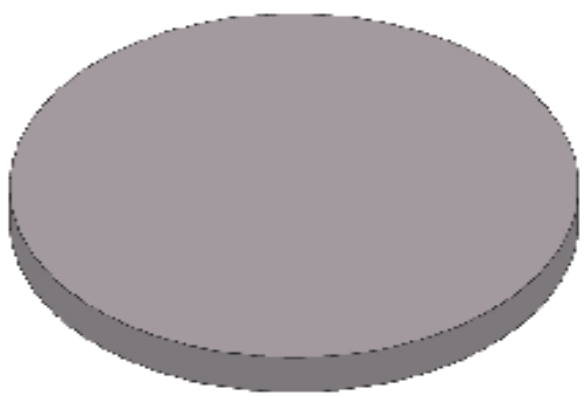
XRF(Wt%): CaO=19.3%, SiO2=44.2%, Al2O3=36.0%, Na2O=0.5%

NOTE: Fitting Halted at Iteration 0(1): R=35.37% (F=7.6%, R/F=4.65, P=29, FPS=0.5)

R=%

Anorthite An 95

100.0%



Whole Pattern Fitting and Rietveld Refinement

FILE: [809004-01 Wilson.raw] augite black
SCAN: 5.0/65.0/0.03/2(sec), Cu, I(p)=1867, 09/18/08 03:25a
PROC: [C:\Documents and Settings\wbenzel-pr\My Documents\Data Processing\809004-01 Wilson.wpf] [Crystallite Size & Strain]

- [x] K-alpha2 Peak Present
- [x] Allow Negative Isotropic B
- [x] Allow Negative Occupancy
- [x] Apply Anomalous Scattering
- [x] Use Isotropic B Value Only

[Diffractometer I P] Two-Theta Range of Fit = 5.0 - 65.0(deg)

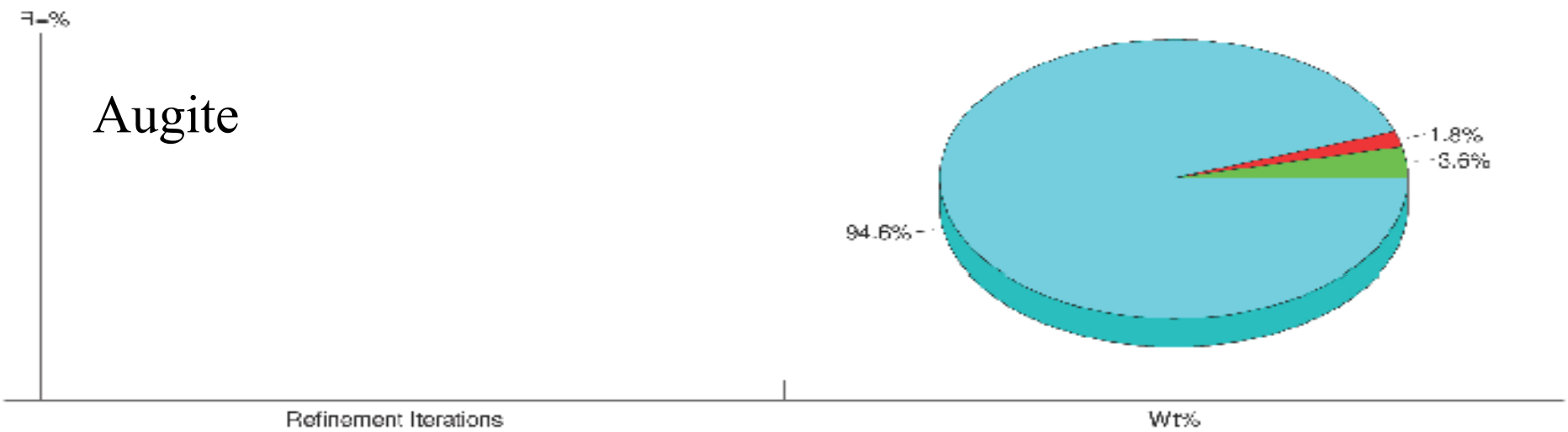
- [x] Zero Offset of Goniometer - 2Theta = 0.684686(0.66259)
- [x] Specimen Displacement - Cos(Theta) = -0.735412(0.59868)
- [x] Axial Divergence - Cot(2Theta) = -0.010646(0.01656)
- [ ] Monochromator Correction for LP Factor = 1.0
- [ ] K-alpha2/K-alpha1 Intensity Ratio = 0.5

Profile Shape Function (PSF) for All Phases: pseudo-Voigt, Fixed-BG, Lambda=1.54059Å (Cu/K-alpha1)

Phase ID (3)	Source	I/Ic	Wt%	#L
Cristobalite low - SiO_2	FIZ#30269	5.15(0%)	3.6 (0.2)	50
Quartz low - SiO_2	FIZ#41672	4.17(0%)	1.8 (0.2)	40
Augite - $(Mg_{0.72}Fe_{0.25}Al_{0.02}Ti_{0.01})(Ca_{0.78}Na_{0.02}Mg_{0.03}Fe_{0.16}Mn_{0.01})(Si_{1.95}Al_{0.05}O_6)$	FIZ#56929	1.21(0%)	94.6 (1.0)	80

XRF(Wt%): Fe2O3=13.7%, MnO2=0.4%, TiO2=0.3%, CaO=18.3%, SiO2=54.3%, Al2O3=1.5%, MgO=12.6%, Na2O=0.3%

NOTE: Fitting Halted at Iteration 0(1): R=14.27% (E=8.81%, R/E=1.62, P=22, EPS=0.5)



Synthetic Lunar Breccia

- Well over 90% of the rocks (>1cm) fragments at the Apollo 16 site are some form of impact breccia
- In order to produce a prototype simulant with large particles (1-20cm, i.e. LHT-2C) with physical properties more similar to those present in the highlands regolith we synthesized “impact melt breccia”, a material with various types of lithic. crystalline and glassy clasts in a glassy matrix.

USGS

ONE CENT
SIMULATED GLASS MATRIX
IMPACT BRECCIA
USGS-ZYBEK 3/24/08

Future directions

- Development of LHT-3M ~ 4 tons June 2009
- Development of mineral feedstocks

  Natural & synthetic
- Prototype simulant based on synthetic materials (plagioclase, pyroxene, olivine, agglutinate, glasses & trace minerals)

USGS

HOMER'S
BUCKET

Synthetic Breccia

Whole Pattern Fitting and Rietveld Refinement

FILE: [901002-02.raw] 1.2 u
SCAN: 5.0/65.0/0.02/2.1(sec), Cu, I(p)=7742, 01/09/09 10:26p
PROC: [WPF Control File]

- [x] K-alpha2 Peak Present
- [x] Allow Negative Isotropic B
- [x] Allow Negative Occupancy
- [x] Apply Anomalous Scattering
- [x] Use Isotropic B Value Only

[Diffractometer LP] Two-Theta Range of Fit = 5.0 - 65.0(deg)

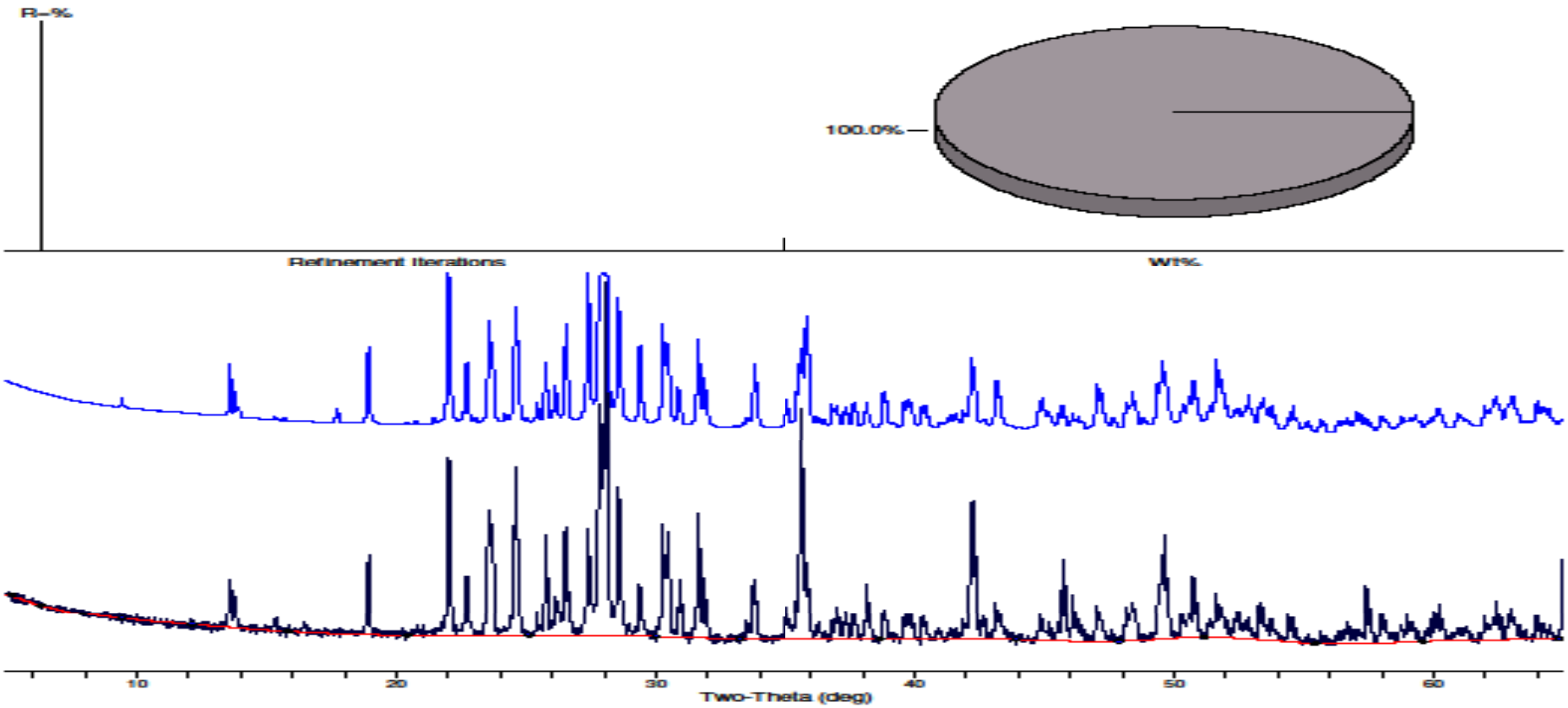
- [x] Zero Offset of Goniometer - 2Theta = 0.759649
- [x] Specimen Displacement - Cos(Theta) = -0.675502
- [x] Axial Divergence - Cot(2Theta) = -0.005817
- [ ] Monochromator Correction for LP Factor = 1.0
- [x] K-alpha2/K-alpha1 Intensity Ratio = 0.506899

Profile Shape Function (PSF) for All Phases: pseudo-Voigt, Fixed-BG, Lambda=1.54059Å (Cu/K-alpha1)

Phase ID (2)	Source	I/Ic	Wt%	#L
Anorthite - $CaAl_2Si_2O_8$	PDF#01-070-0287	0.60(0%)	0.0 (0.0)	708
Anorthite - $(Ca_{0.96}Na_{0.04})(Al_{1.96}Si_{0.04})Si_2O_8$	PDF#01-089-1464	0.58(0%)	100.0 (0.0)	401

XRF(Wt%): CaO=19.3%, SiO2=44.2%, Al2O3=36.0%, Na2O=0.5%

NOTE: Fitting Halted at Iteration 0(1): R=35.37% (E=7.6%, R/E=4.65, P=29, EPS=0.5)



Whole Pattern Fitting and Rietveld Refinement

FILE: [809004-01 Wilson.raw] augite black
SCAN: 5.0/65.0/0.03/2(sec), Cu, I(p)=1867, 09/18/08 03:25a
PROC: [C:\Documents and Settings\wbenzel-pr\My Documents\Data Processing\809004-01 Wilson.wpf] [Crystallite Size & Strain]

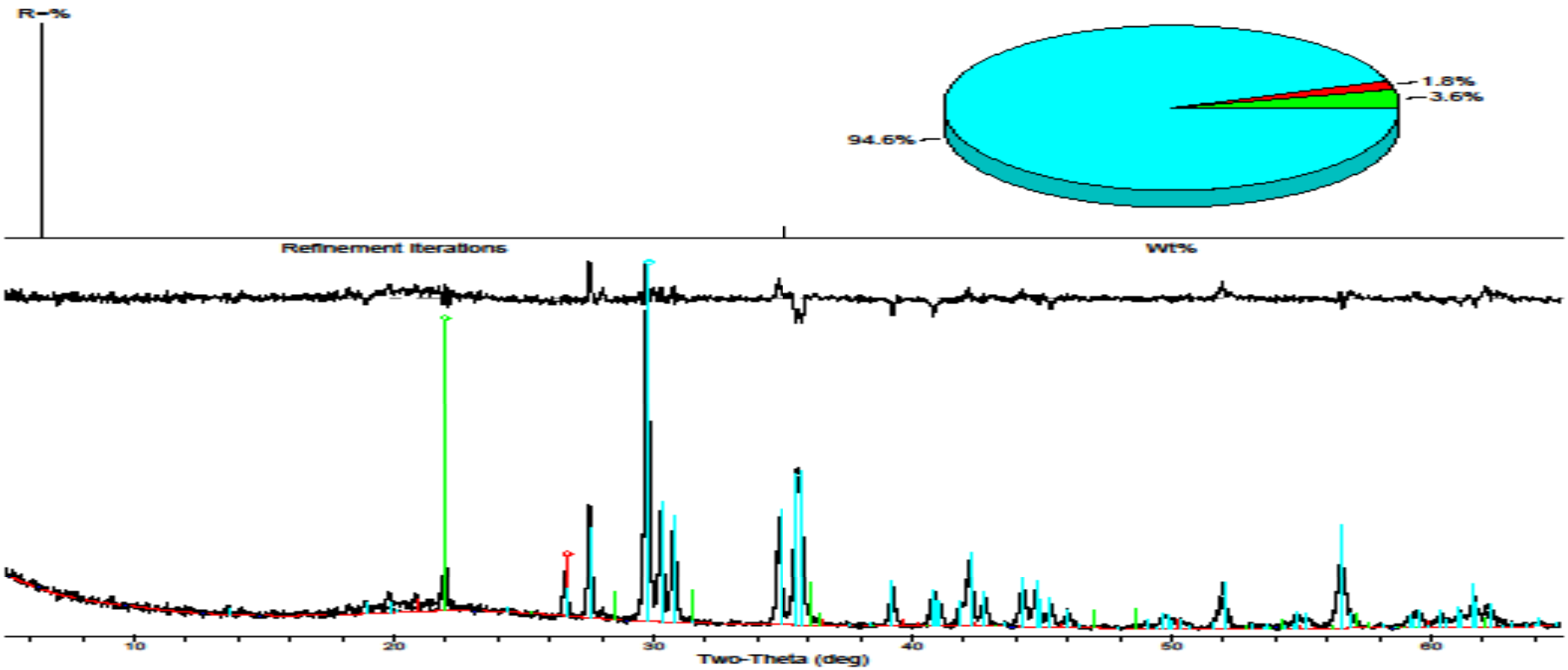
- [x] K-alpha2 Peak Present
- [x] Allow Negative Isotropic B
- [x] Allow Negative Occupancy
- [x] Apply Anomalous Scattering
- [x] Use Isotropic B Value Only

[Diffractometer LP] Two-Theta Range of Fit = 5.0 - 65.0(deg)

- [x] Zero Offset of Goniometer - 2Theta = 0.684686(0.66259)
- [x] Specimen Displacement - Cos(Theta) = -0.735412(0.59868)
- [x] Axial Divergence - Cot(2Theta) = -0.010646(0.01656)
- [ ] Monochromator Correction for LP Factor = 1.0
- [ ] K-alpha2/K-alpha1 Intensity Ratio = 0.5

Profile Shape Function (PSF) for All Phases: pseudo-Voigt, Fixed-BG, Lambda=1.54059Å (Cu/K-alpha1)

Phase ID (3)	Source	I/Ic	Wt%	#L
Cristobalite low - SiO_2	FIZ#30269	5.15(0%)	3.6 (0.2)	50
Quartz low - SiO_2	FIZ#41672	4.17(0%)	1.8 (0.2)	40
Augite - $(Mg_{0.72}Fe_{0.25}Al_{0.02}Ti_{0.01})(Ca_{0.78}Na_{0.02}Mg_{0.03}Fe_{0.16}Mn_{0.01})(Si_{1.95}Al_{0.05}O_6)$	FIZ#56929	1.21(0%)	94.6 (1.0)	80

XRF(Wt%): Fe=9.6%, Mn=0.2%, Ti=0.2%, Ca=13.1%, Si=25.4%, Al=0.8%, Mg=7.6%, Na=0.2%, O=43.0%

NOTE: Fitting Halted at Iteration 0(1): R=14.27% (E=8.81%, R/E=1.62, P=22, EPS=0.5)