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# Pre-Flight Characterization of Samples for the MISSE-7 Spacesuit Fabric Exposure Experiment

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## **Abstract**

A series of six sample spacesuit pressure garment assembly (PGA) fabric samples were prepared for the Materials International Space Station Experiment 7 (MISSE-7) flight experiment to test the effects of damage by lunar dust on the susceptibility of the fabrics to radiation damage. These included pristine Apollo-era fluorinated ethylene-propylene (FEP) fabric, Apollo-era FEP fabric that had been abraded with JSC-1A lunar simulant, and a piece of Alan Bean's Apollo 12 PGA sectioned from near the left knee. Also included was a sample of pristine orthofabric, and orthofabric that had been abraded to two different levels with JSC-1A. The samples were characterized using optical microscopy, field emission scanning electron microscopy, and atomic force microscopy. Two sets of six samples were then loaded in space environment exposure hardware, one of which was stored as control samples. The other set was affixed to the MISSE-7 experiment package, and will be mounted on the International Space Station, and exposed to the wake-side low Earth orbit environment. It will be retrieved after an exposure of approximately 12 months, and returned for post flight analysis.

## **1.0 Introduction**

The International Space Station (ISS) is a laboratory orbiting about 350 km (280 to 460 km) above the surface of the Earth, traveling at a speed of about 28,000 km/hr. It is a joint project among the space agency's of the United States (NASA), Russia (RKA), Japan (JAXA), Canada (CSA) and 11 European countries (ESA). The ISS has been continuously staffed since November 2, 2000. Astronauts and cosmonauts from 16 countries have worked on it, and it has been visited by five space tourists.

Although most of the experimentation that has been conducted aboard the ISS has occurred inside the pressurized compartments, some researchers have taken advantage of its unique position to study the space environment from outside. The Materials International Space Station Experiment (MISSE), is a series of experiments mounted externally on the ISS, that investigate the effects of long-term exposure of materials to the low Earth orbital environment. These are suitcase-sized experiment packages called Passive Experiment Carriers (PECS) that are mounted with half of the exposure surface facing the direction of motion of ISS through the exosphere (ram direction) and half the other side (wake direction). A photo of the MISSE-3 mounted on the ISS on orbit is shown in Figure 1.

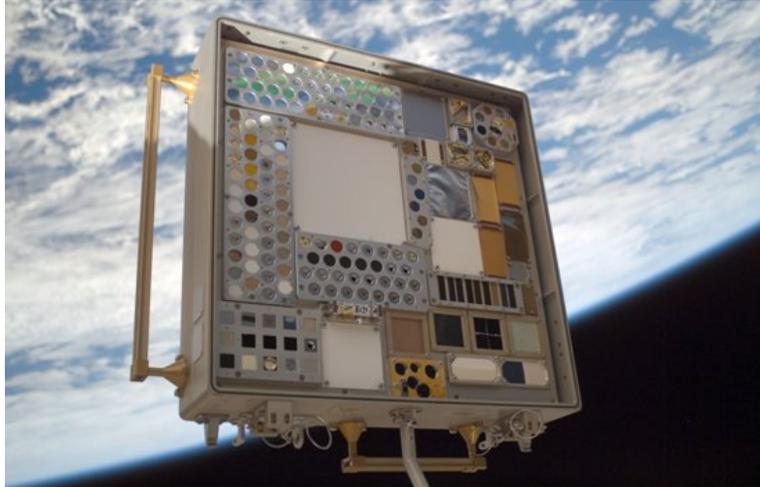


Figure 1.—MISSE-3 on orbit

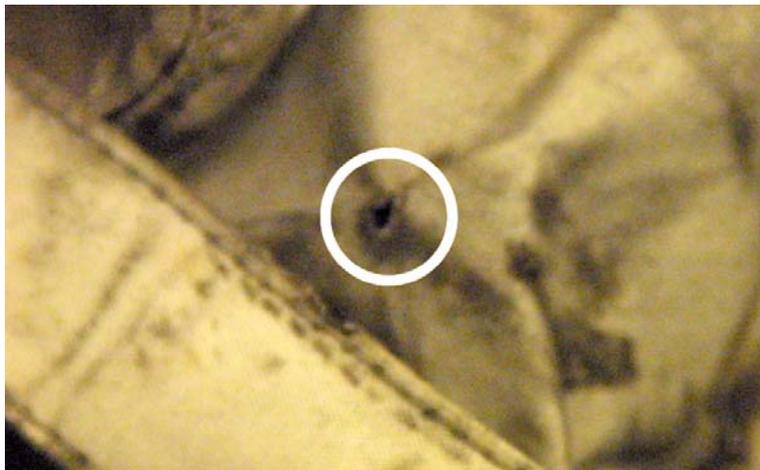


Figure 2.—A portion of the leg of Harrison Schmitt's Apollo 17 pressure garment assembly showing a hole worn through the outer layer above the boot.

MISSE-1 and MISSE-2 were attached to two separate airlock handrails located on the Quest Joint Airlock and high-pressure gas tanks in August 2001 and were retrieved in July 2005. MISSE-3 was installed on one of the high-pressure tanks around the crew lock and MISSE-4 on the outboard end of the Quest Joint Airlock in August 2006 and were retrieved a year later. MISSE-5 was installed on the P6 truss in July 2005 and was retrieved in September 2006. MISSE-6 was installed on the *Columbus* External Payload Facility in March 2008 and is due for retrieval after about one year of exposure. The MISSE-7 experiment package is being prepared at the time of writing, and will be installed on the S3 Truss segment on the Express Logistics Carrier, and is expected to launch on STS 129 in November 2009 and be retrieved by the last Shuttle flight.

When experiments were being considered for MISSE-7 there was particular interest in materials that would be important to the NASA's Space Exploration Program. One of the challenges facing the next generation of moon landings is to make extravehicular activity (EVA) suits that will stand up to months of use on the lunar surface. Although the Apollo Extravehicular Mobility Units (EMUs) performed nearly flawlessly, they were used no more than three times over a period that did not exceed 75 hr. The EMU Pressure Garment Assemblies (PGAs), commonly called "spacesuits", sustained much more abrasive damage during lunar surface operations than expected. For example, it was reported that, during Apollo

12, the suit material just beneath the tops of the lunar boots chafed sufficiently to wear through the outer layer in several spots and was beginning to wear through the Mylar (Ref. 1). Similar damage was observed during other missions as well (Fig. 2). Also reported was that the wear on the suits after just eight hours on the lunar surface was greater than that of the training suits after more than 100 hr of use (Ref. 2).

Since abrasion increases the surface area of the fabric's constituent fibers, and ultraviolet degradation is a surface phenomenon, there is concern that there may be a synergistic effect between dust abrasion and ultraviolet degradation of the outer PGA fabric. Therefore, it was proposed that an experiment be mounted on the wake side of MISSE-7 to investigate whether such an effect occurs, and if so, to what extent.

The MISSE-7 Spacesuit Fabrics Exposure Experiment consists of six samples of spacesuit fabric to be placed on the wake side of MISSE 7B. In this environment they will be exposed to approximately the same electromagnetic radiation environment they will be exposed to on the moon. This includes radiation in the vacuum ultraviolet (10-200 nm), which is screened from the earth's surface by the atmosphere. Radiation in this region of the spectrum is easily absorbed into the surface of materials and energetic enough to break chemical bonds. Atomic oxygen is the most prevalent species at this altitude in the exosphere, but since this experiment will be mounted on the wake side, the concentrations will be low, on the order of  $10^{-14}$  Torr (Ref. 3). Solar particle radiation is primarily trapped by the earth's magnetic field in the Van Allen belts, which are high above the space station orbit, between about 700 and 40,000 km from the surface.

During the Apollo program, the outer surface of the PGA was made of woven fluorinated ethylene-propylene (FEP) fabric. Although most of the PGAs were made with a plain-weave FEP, in some cases a twill-weave FEP was used. A small piece from the left knee region of the PGA worn on the lunar surface by Alan Bean during Apollo 12 was obtained (Fig. 3). This was one of the most heavily soiled portions of the PGA.

The sample shown in Figure 3 will be flown on MISSE-7 to look for synergistic effects between dust abrasion and the space environment. For comparison, a sample of the same twill weave FEP that was manufactured in the same era will be flown as a control. In addition, a sample of control fabric that has been ground-test abraded with the lunar soil simulant JSC-1A will be flown as well.

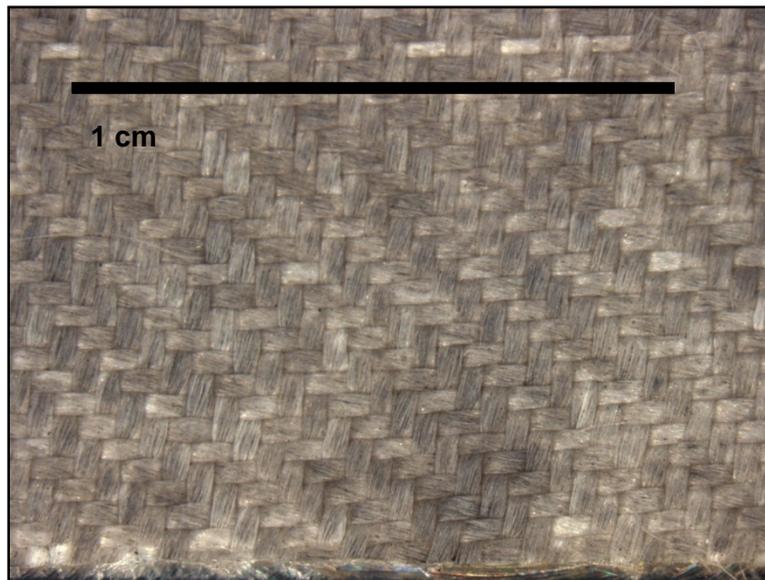


Figure 3.—A section of FEP fabric from Alan Bean's Apollo 12 PGA, near the left knee, covered with lunar dust.

PGA design has progressed since the Apollo era, and the suits worn by astronauts in their return to the moon will probably not have an outer layer of woven FEP. The current PGAs used in Space Shuttle and International Space Station EVAs use orthofabric as the outermost layer. Orthofabric is a complex weave of Nomex (DuPont) and Kevlar (DuPont) with an outer layer of Gortex (W.L. Gore & Associates) is made from expanded PTFE, so although the two fabric types are very different, they both have fluorinated hydrocarbons as the outermost material. Three samples of orthofabric will be flown as part of the MISSE-7 Spacesuit Fabrics Exposure Experiment as well, with one being pristine, a second abraded with JSC-1A to the same level as the FEP, and the third being abraded with JSC-1A for twice as long.

It is expected that most of the damage to the fabric during the space exposure will be caused by ultraviolet radiation. Since abrasion increases the surface area of the fabric fibers, and since ultraviolet radiation can only penetrate a short way into the surface of a material, it is thought that the total volume of the fiber damaged by the ultraviolet will increase with abrasion. If FEP Teflon (DuPont) film is an indicator, then the ultimate tensile strength and the elongation to failure of fibers can be expected to decrease on exposure (Ref. 4).

## 2.0 Methods and Materials

### 2.1 Abrasion Protocol

A Dust Abrasion of EVA Fabric Protocol was developed as a standardized set of procedures by which to abrade PGA fabrics for the MISSE-7 experiment. The goal was to reproduce damage seen on Alan Bean's Apollo 12 suit. An ASTM standard test was modified so that damage was inflicted on small patches of fabric using loose lunar dust simulant, rather than an abrasion wheel. A photograph of the abrasion apparatus is shown in Figure 4. Below is listed the steps in the protocol used to produce the abrasion shown in photomicrographs in the latter part of the report.

- 1) The fabric abrasion test was based on ASTM D 3884-01, "Standard Guide for Abrasion Resistance of Textile Fabrics (Rotary Platform, Double Head Method)." It differed, however, in that the abradant was a loose grit rather than an abrasive wheel.
- 2) Fabric samples were cut either to a size of 15 by 15 cm (6 by 6 in.) if a single sample was to be run, or to a size of 9 cm (3.5 in.) by 15 cm (6 in.) if four samples were to be run using a rotary cutter with a tungsten carbide blade.
- 3) The fabric samples were securely mounted onto a 15 cm (6.0 in.) diameter metallic disk covered with a PTFE sheet. The fabric must not stretch and wrinkle during the test. Mounting the 9 cm by 15 cm fabrics stretched and held by three no. 2 screws proved satisfactory.
- 4) A single fabric can be mounted on a plate, or if the smaller size is used four samples of fabric can be arranged in overlapping quarters.
- 5) The fabric was attached to the wheel using at least three screw holes
- 6) The circular edge was covered by overlapping cover

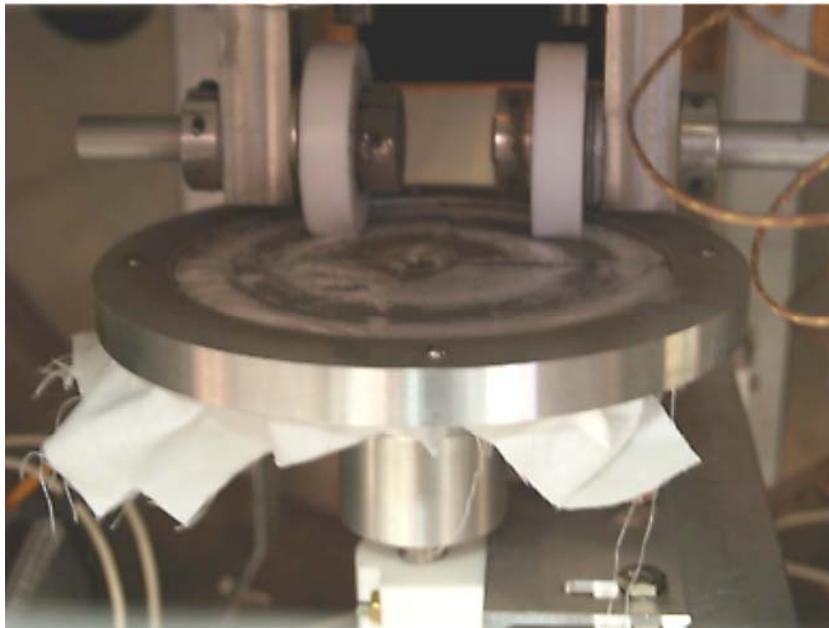


Figure 4.—A photograph showing the abrasion test set-up for the fabric samples.

- 7) Abrasion wheels were used which have a leather strip mounted to a brass hub (Taber Industries type S-39 or similar wheels).
- 8) A layer of lunar simulant with particles size  $< 100 \mu\text{m}$  was applied with a soft brush to the entire exposed surface of the fabric.
- 9) The simulant-covered fabric was mounted in a suitable vacuum chamber and evacuated to at least  $10^{-6}$  Torr.
- 10) The dust covered fabric was exposed to an air plasma for 60 min to oxidize off organic contaminants
- 11) The dust covered fabric was exposed to a 4 percent H in He (non-explosive mixture) plasma for 60 min to chemically reduce the surface of the simulant and to implant H into the simulant
- 12) The fabric was rotated against the leather wheels at 70 rpm for a standard number of revolutions (i.e., 8000 cycles)
- 13) After the test the chamber was brought up to ambient pressure, and the fabric wheel was removed from the chamber
- 14) The loose simulant was removed from the fabric using a vacuum cleaner with a soft brush
- 15) The fabric was removed from the wheel
- 16) The fabric was ultrasonically cleaned in a 20 mg/L solution of sodium dodecasulfate in distilled water for 30 min
- 17) The fabric was rinsed 4 times with distilled water
- 18) The fabric was gently blotted on a folded Kim-dry (or similar material) and set aside to air dry for at least 1 hr in a dust free environment

## 2.2 Characterization Protocols

Two types of fabric sample holders were developed for this experiment. To minimize confusion, the flight hardware was referred to as the sample holder, and the hardware to hold the sample during the analysis was referred to as the sample handler.

Samples of the fabric 15 by 17 mm were cut out of the abraded region and mounted in a sample handler that was designed to fit within the Field Emission Scanning Electron Microscope (FESEM) and the Atomic Force Microscope (AFM) used to characterize the samples. This enabled the samples to be stored and handled in a safe way that prevented additional damage which could confound the results.

The samples were first imaged under a Leica MZ16 optical microscope fitted with digital image capture. A full image of the fabric sample was first obtained centered in the middle of the fabric sample. Five regions including the center and positions 3 mm north, south, east, and west of the center were imaged at 10 $\times$ , 25 $\times$ , 50 $\times$ , and 100 $\times$  magnification.

The samples were then scanned with a Hitachi Model S-4700 FESEM using acceleration voltages ranging from 1 to 6 kV. This enabled the samples to be imaged without the addition of conducting coatings. The same five regions that were imaged with the optical microscope were scanned at 50 $\times$ , 100 $\times$ , 250 $\times$ , 1000 $\times$ , and 4500 $\times$  magnification.

Finally the samples were scanned with a Veeco Innova SPM used in the tapping mode. VEECO MPP-11120 unmounted cantilever probes were used. Square areas were imaged that were 80, 60, 10, 1 and 0.1  $\mu\text{m}$  on a side.

The sample handler was designed to hold the fabric while it was moved among the optical microscope, the field emission scanning electron microscope (FESEM) and the atomic force microscope (AFM). A photo of the sample handler is shown in Figure 5. Samples were cut to 15 $\times$ 17 mm, and about

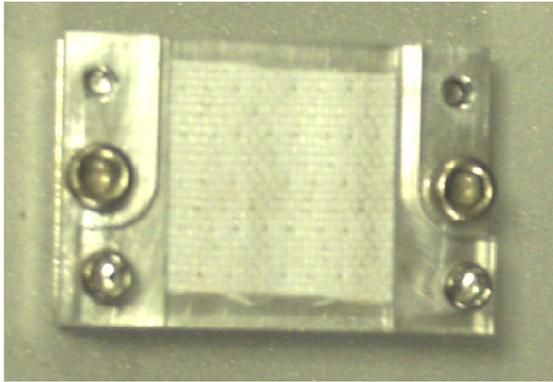


Figure 5.—Sample handler with a swatch of orthofabric installed.

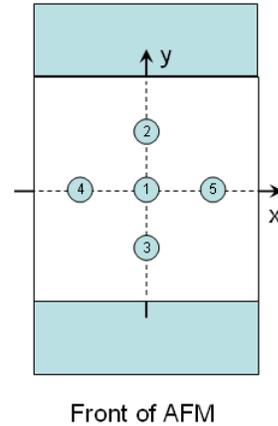


Figure 6.—Sampling areas for mounted PGA fabrics.

1 mm was clamped at the ends in the handler, exposing a 15 mm square sample area. A Lucite guard protected the samples and was only removed for the actual analysis. The protocols for the three characterization techniques are given below.

### 2.3 Optical Microscopy Protocol

- Samples were imaged while held in aluminum mounting brackets.
- Images were obtained using an optical microscope with digital image capture.
- Samples were to be oriented such that the numbers and letters written on the sample handler designating the sample were facing toward the right.
- A full image of the fabric sample was obtained centered in the middle of the fabric sample.
- Five areas were imaged at 10×, 25×, 50×, and 100× magnification.
- At each area the edge of the mounting bracket should be visible at 10× magnification. Scan locations: (0,0) and a centered square grid of four points around the center at (0, $y_o$ ), (0,- $y_o$ ), (- $x_o$ ,0), and ( $x_o$ ,0), where  $y_o = 3$  mm and  $x_o = 3$  mm are shown in Figure 6.
- The sample label was written on the side of the sample bracket that lies in the positive x direction.
- The images are identified using the convention S-P-N where S is the fabric sample (i.e., B1, OAA3, etc.), P is the position shown in Figure 6, and N in the photograph number.

### 2.4 Field Emission Scanning Electron Microscopy

- Samples were scanned with a field emission scanning electron microscope.
- Acceleration voltage was set to 2.0 kV.
- Scans were taken at 50×, 100×, 250×, and 1000× magnification.
- Other magnifications were be used as feature size requires.
- Scans were taken at each of the five regions shown in Figure 6.
- Other regions were imaged if they contain features deemed to be pertinent to this experiment.

## 2.5 Atomic Force Microscopy

- Analysis was carried out using Veeco Innova SPM
- Tapping Mode
- Cantilevers: Veeco MPP-11120 unmounted probes
- Each sample was assigned its own specific new cantilever
- Samples were mechanically mounted using sample handler using no adhesives
- Each sample was analyzed at five locations shown in Figure 6.
  - Locations: (0,0) and a centered square grid of four points around the center at  $(0,y_o)$ ,  $(0,-y_o)$ ,  $(-x_o,0)$ , and  $(x_o,0)$ , where  $y_o = 3$  mm and  $x_o = 3$  mm.
  - Letters designating sample name were kept to the right when facing the AFM
  - This was accomplished by turning position knob 5 turns from center position.
  - Locations were examined in the numerical order in the diagram.
  - At each location, two data points were examined, on one parallel tow and on one perpendicular tow
  - Each location was optically photographed through the Innova optical microscope
  - Each data point was examined at 4 scan sizes: 80 or 60  $\mu\text{m}$ , 10, 1, and 0.1  $\mu\text{m}$  (0.1  $\mu\text{m}$  may be too small to be of much use with the average cantilever). For each frame size, four to six points were examined at the next lower frame size, depending on the observed features. Choices of zoom in locations were a “typical” distribution of normal and defect/interesting sites.
  - Defects were categorized according to the following scheme (see Fig. 7)
    - ♦ Class I defects: (e.g., rips/tears in tows/fibers)
    - ♦ Class II defects: (e.g., scab-like or crater-like contusions)
    - ♦ Class III defects: (e.g., stretched upward)
  - A rough sense of the distribution/occurrence of the different types of defects was recorded.
  - Each data point was examined with the following AFM parameters:
    - ♦ Setpoint = determined by tuning curve
    - ♦ Proportional gain = 1
    - ♦ Integral gain = 0.5
    - ♦ Differential gain = 0
    - ♦ Scan rate = 1 to 0.5 Hz
    - ♦ Lettering indicating sample number is to be kept to the right

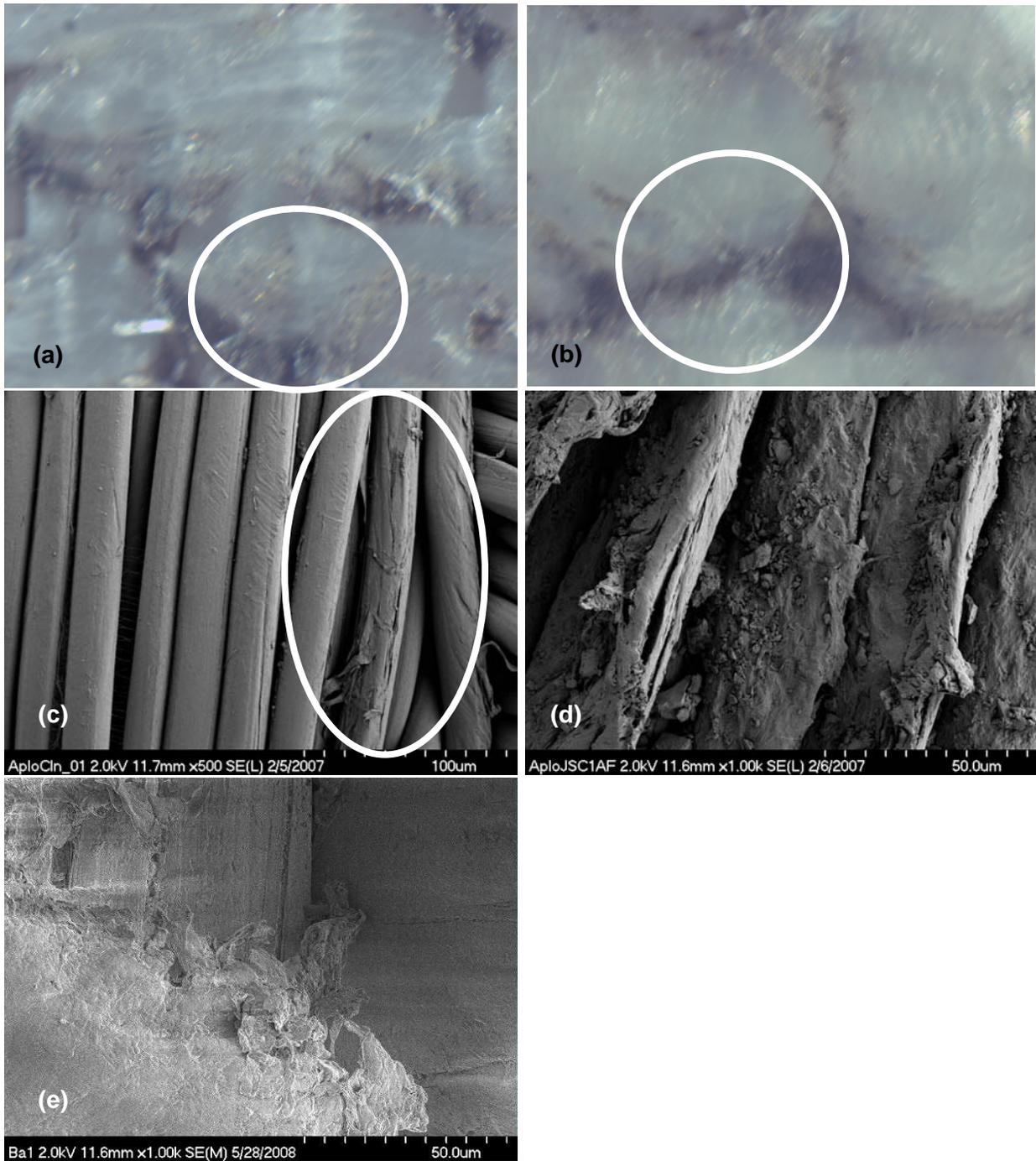


Figure 7.—Defects in fibers were classified as rips and tears (a) and (b), crater or scab contusions (c) and (d), or plastic deformation (e) are shown for Apollo-era FEP fabric.

### **3.0 Preflight Characterization Results**

Images recorded for each of the flight samples using all three microscopy techniques are shown in Appendices A to F. Together they have a dynamic range of five orders of magnitude. The frame size for the optical microscope ranges from 15,000 to 1  $\mu\text{m}$ , for the FESEM from 2000 to 20  $\mu\text{m}$ , and for the AFM from 60 to 0.10  $\mu\text{m}$ . Although the FESEM photos are generally of the highest quality and will probably be the most useful, the optical microscopy provides a more global view of the samples, and the AFM shows structures that are not visible on the FESEM photos.

#### **3.1 Pristine Apollo Fabric**

It is important to catalog the types of structures and defects found in the fabric samples preflight for two principal reasons. The first is to be clear what the features of the fabric are so that structures and defects that are the results of fabrication or ground handling are not attributed to the space environment. The second is that flaws and defects are expected to show the effects of environmental stresses most clearly, as these are areas where the microstructure has already been disrupted. The following comments refer to the photomicrographs cataloged in Appendix A.

At low magnification the pristine Apollo fabric appears to have a very smooth texture. But as the magnification is increased to about 50 $\times$ , cracks in the individual fibers are observed. When the magnification is increased to 4000 $\times$ , filaments are observed within the cracks. The filaments run in the axial direction, but traverse the cracks. As the fabric is exposed to ultraviolet light in the LEO environment, it will be interesting to see if the cracks expand and if there is damage noted to the filaments. Unfortunately, the AFM was not able to probe the crack areas because the cantilever tip would catch on these small structures and break.

There were also areas where scuff marks, on the order of a few tens of  $\mu\text{m}$ , were observed. A good example is shown in image B1-2 (1000 $\times$ ). Holes, on the order of a few  $\mu\text{m}$  were observed as well, as shown in B1-4 (4000 $\times$ ) and B1-4-4 (10  $\mu\text{m}$ ).

#### **3.2 Abraded Apollo Fabric**

The effects of the abrasion protocol can be seen in the photomicrographs in Appendix B. The most obvious difference between the pristine and abraded Apollo fabrics is the smashing and smearing of the top layer of fibers. It can be seen clearly in BA1-1 (100 $\times$ , Section B.1) that the top layer is smeared and flattened, but the second layer is not. This indicates that the abrasion wheel applied too much pressure to the fabrics.

Scuffing and scribing of the fabric can be seen in BA1-1 (1000 $\times$ ) and even more clearly in BA1-1-2 (60  $\mu\text{m}$ ). The parallel grooves in the latter were not observed in any of the pristine samples and were probably formed by the scraping of the abrasive dust particles along the fibers.

There are yet other areas where the fiber damage mechanism is not as clear, such as BA1-4 (1000 $\times$ ) and BA1-5 (1000 $\times$ ). The edge of the fiber is disrupted in a way that suggests plastic deformation followed by rupture and the reforming of structures.

#### **3.3 Bean Suit Fabric**

Appendix C contains the photomicrographs taken of the Apollo 12 spacesuit of Alan Bean. The damage caused by lunar dust during Apollo 12 shows characteristics that were not reproduced by the abrasion protocol. Most obvious was the darker color, shown clearly in Figure 10, which was caused by the embedding of fine particles into the surface of the fibers. This can be clearly seen in AB1-1 (250 $\times$ ). Magnification also reveals that the lunar dust particles were more effective at shredding the fibers. These

two observations taken together show the importance of the differences in the granular properties between the lunar dust and the simulant. The lunar dust has a finer and sharper component than does the simulant.

At high magnification it can be seen in BA-1-2 (4000×) that the fiber have been plastically deformed and reformed, much as they were in parts of the abraded Apollo fabric described above. But this sort of damage dominates Bean suit samples, whereas it is only found in a few places in the abraded sample.

## 4.0 Pristine Orthofabric

Photomicrographs of the pristine orthofabric in Appendix D show a number of triangular holes in the upper layer of the fibers, shown clearly in O1-1 (250×). They occur with such regularity and uniformity in shape and size as to suggest that they are an artifact of the weaving process. As can be seen in O1-2 (4000×), cracks are found that run down the fiber axis that are similar in size and form to those observed on the pristine Apollo-era fabric. Both of these types of sites will be foci to look for evidence of post-flight radiation damage.

### 4.1 Abraded Orthofabric

Appendix E contains photomicrographs of abraded orthofabric samples. The top fibers were smashed and smeared much like the Apollo era fabric that was abraded using the same protocol. The triangular pits so characteristic of the pristine orthofabric are all but gone in these photos, probably covered over by the smearing.

There are a large number of dust grains trapped in the some portion of the weave of the fabric. This can be seen, for example in the upper left quadrant of the OA1-2 (10×) image. Details can be observed in OA1-1 (250×). Most of the dust grains are smaller than 10 μm, with many in the 1 μm range. Dust was also found ground into cracks in the fiber, as shown in OA1-3 (1000×).

There are regions, such as that shown in OA1-2 (1000×), where the fibers are plastically deformed, much like was observed in the Bean suit samples. For the most part, these appeared to form on the tops of the weave, and so in different areas than where the dust grains were found.

### 4.2 Doubly Abraded Orthofabric

The photomicrographs of the double abraded orthofabric are found in Appendix F. These showed the same general features that were found in the singly abraded orthofabric. There were regions where the fibers were smeared together, like OAA1-3 (100×). Although there were regions where dust grains can be seen, such as OAA1-4-4 (10 μm), there appear to be far fewer than in the single abraded orthofabric samples. But there were regions where Apollo-like plastic deformation was seen on this fabrics as well, such as OAA1-3 (1000×).

To summarize, the structures on the FEP cloth abraded using the protocol were similar to those caused by the abrasion seen during Apollo in that both samples seem to have had their outer layer plastically deformed (Fig. 8). However, the Apollo sample had significant amounts of lunar dust embedded in the surface whereas the abraded sample did not. Also in many areas the FEP fabric abraded using the protocol results in smearing of the fibers together, a mechanism not observed in the Apollo samples (Fig. 9).

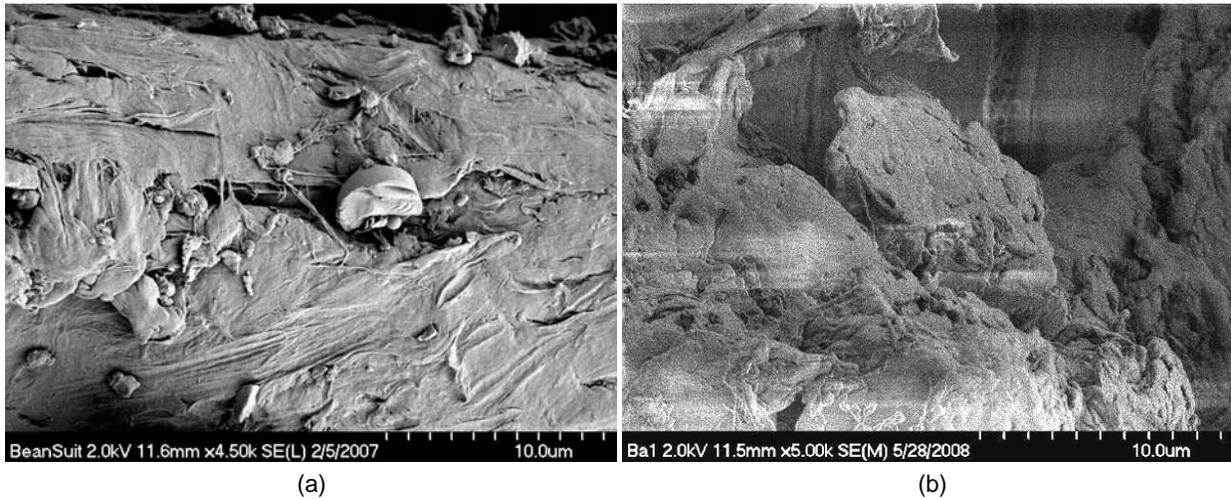


Figure 8.—Abrasion observed in the Bean suit left knee sample (a) is similar to that observed in FEP fabric abraded with the protocol described herein (b).

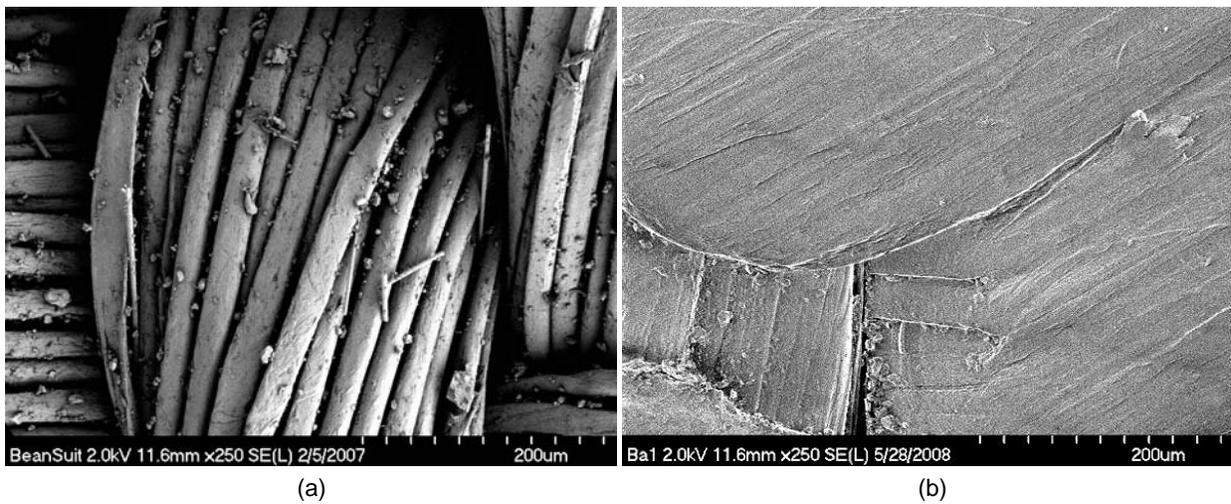


Figure 9.—Fibers were observed to remain intact in the Bean suit left knee sample (a), but when excess pressure was applied during the simulation the fibers in the FEP fabric smeared together (b).

## 5.0 Mounting Samples in Flight Hardware

For the flight, six samples are held in a 25.4 by 50.4 mm (1 by 2 in.) picture frame containing six 10 mm by 10 mm samples. The sample holder was constructed from 6061 Al, and the fasteners were all of flight qualified stainless steel. The sample holder holds six samples between a cover plate and backing plate. All sample holder components were washed in a dilute solution of Alconox, rinsed four times in distilled water, rinsed four times in absolute alcohol, and allowed to air dry under a glass dish that prevented dust from depositing on it.

Fabric samples were mounted sequentially using the following protocol. Although the work did not occur in a clean room, it was carried out in a clean lab while wearing nitrile gloves rinsed in absolute ethanol.

- 1) The **cover plate** was placed face side down on a clean sheet of paper in a clean workspace.
- 2) The **fabrics top** was placed face-side down on top of the cover plate and the two covered with a Petrie dish to keep dust off.
- 3) The first sample (Bean suit) was removed from the sample handler and trimmed to a 12 mm by 12 mm square using a rotary cutter with a new tungsten carbide blade against a PTFE cutting surface.
- 4) Using stainless steel forceps, the sample was pressed face down into the groove of the **fabrics top**.
- 5) Using stainless steel forceps, a 0.75 mm thick 12 by 12 mm 6061-T6 aluminum **backing plate** was pressed over the back of the sample, and immediately covered with the Petrie dish.
- 6) Steps 3, 4, and 5 were repeated for the other two FEP fabric samples.
- 7) Steps 3, 4, and 5 were repeated for the three orthofabric samples except that in step 5, 0.50 mm thick **backing plates** were used.
- 8) The **fabrics base** was placed face down over the **fabrics top**.
- 9) The entire assembly was inverted and two 8 mm (5/16 in.) long 4-40 screws were placed through the **cover plate** and the **fabrics top** into the threaded holes in the **backing plate** and tightened snugly.
- 10) Two 8 mm (5/16 in.) long 4-40 **assembly screws** were placed through the **fabrics top** into the threaded holes in the **backing plate** and tightened snugly.
- 11) The two screws applied in step 9 were removed, the **cover plate** was removed, and the assembly inspected for a snug fit of the fabric against the **fabrics top**.
- 12) The **cover plate** was replaced and the two screws from step 9 were tightened snugly.
- 13) The two **assembly screws** from step 10 were tightened to 64 oz-in of torque.
- 14) While the position of each of the **assembly screws** in step 13 was maintained with a hex key, silver plated stainless steel **locking hex nuts** were screwed onto the other side and tightened with a torque wrench to 128 oz-in (64 oz-in more than the torque required to turn the nuts onto the assembly screws).
- 15) The **cover plate** was removed as in step 11, the assembly was photographed, and the **cover plate** replaced as in step 12.
- 16) A sign reading, "Remove Cover Before Flight" was affixed to the **cover plate** using Kapton tape (DuPont).

- 17) The assembly was double-bagged in Kapron.
- 18) Eight 16 mm (5/8 in.) long 4-40 attachment screws were cleaned and double bagged in Kapron.
- 19) The double bagged assembly and double bagged attachment screws were placed in a zipper storage bag labeled “MISSE-7 Flight” and delivered to those who would pack and carry it to the Boeing facility in Huntsville, Alabama, for integration.

The samples mounted in the flight hardware, along with their protective cover are shown in Figure 10.

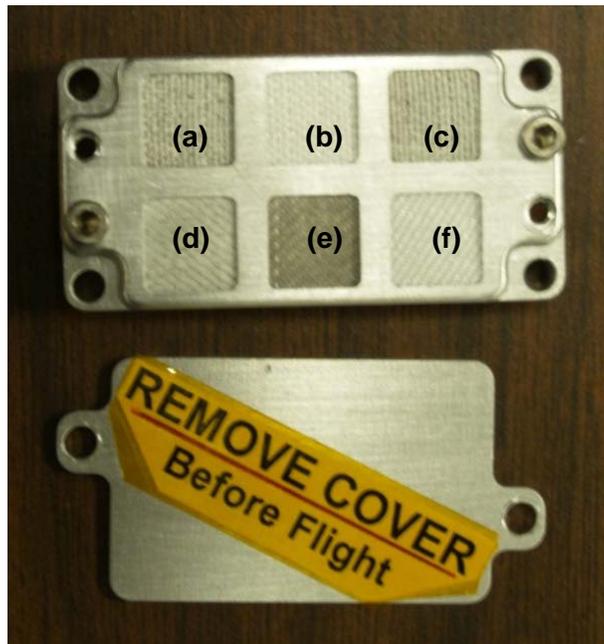


Figure 10.—Flight samples for the MISSE-7 Spacesuit Fabrics Exposure Experiment mounted in their flight hardware. The 1 cm samples include the abraded orthofabric (a), pristine orthofabric (b), double abraded orthofabric (c), abraded Apollo era fabric (d), Alan Bean Apollo 12 fabric (e), pristine Apollo era fabric (f).

## 6.0 Integration and Flight Plans

An experimental integration “traveler” document (Appendix G) was sent to the integration facility along with the hardware to describe its integration. The samples were integrated onto the wake side of the PEC in a class 1000 clean-room at the NASA Marshall Space Flight Center. A photo of the PEC after integration indicating the position of the Spacesuit Fabrics Experiment is shown in Figure 11. After vibration, thermal vacuum, and electromagnetic compatibility tests are conducted at the Naval Research Lab, the MISSE7 package will be delivered to the NASA Kennedy Space Center. It will be integrated into the Space Shuttle Discovery and launched in late 2009.

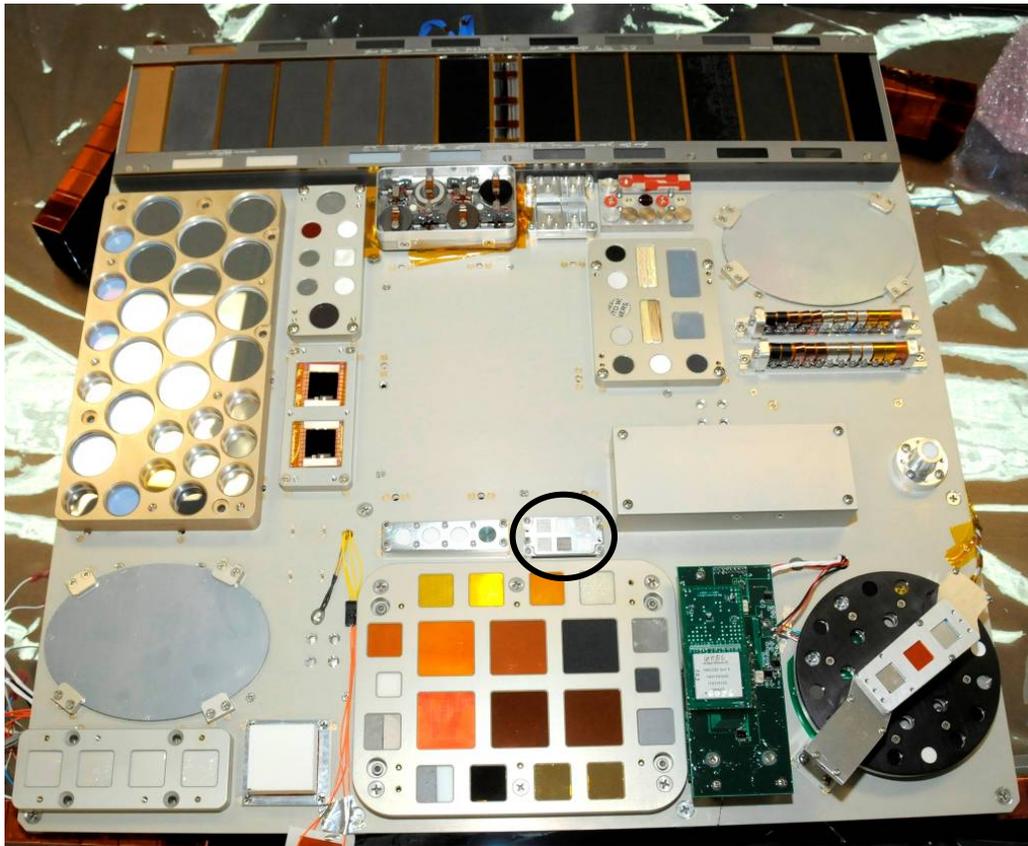


Figure 11.—Partially assembled wake side of MISSE-7 PEC showing the position of the Spacesuit Fabrics Experiment.

## 7.0 Conclusions

A series of six sample PGA fabric types were prepared for the MISSE-7 flight experiment to test the effects of damage by lunar dust on the susceptibility to radiation damage. These included pristine Apollo-era FEP fabric, Apollo-era FEP fabric that had been abraded with JSC-1A lunar simulant, and a piece of Alan Bean's Apollo 12 PGA sampled from near the left knee. Also included was a sample of pristine orthofabric, and orthofabric that had been abraded to two different levels with JSC-1A. The samples were characterized using optical microscopy, FESEM, and AFM. Two sets of six samples were then loaded in space environment exposure hardware, one of which was stored as control samples. The other set was affixed to the MISSE-7 experiment package, and will be mounted on the exterior of the ISS, and exposed to the wake-side low Earth orbit environment. It will be retrieved after an exposure of approximately 12 months, and returned for post flight analysis.

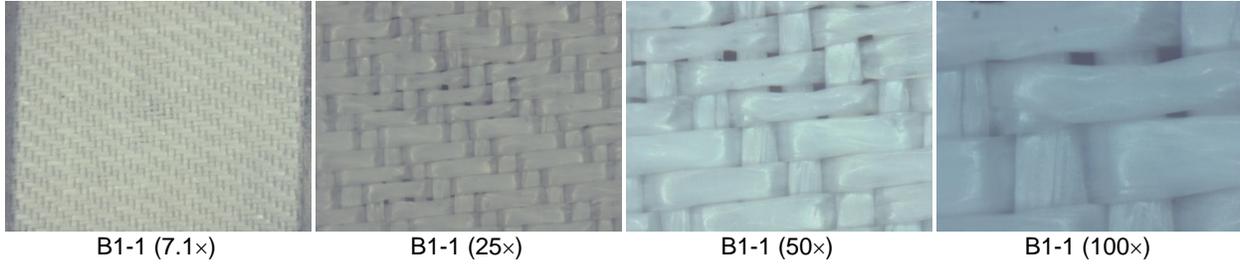
## 8.0 References

1. MSC01855 Apollo 12 Mission Report (March 1970) pp. 9–21.
2. Pete Conrad, Apollo 12 Technical Crew Debriefing (December 1, 1969) pp. 10–54.
3. J.A. Strozier, et al., “Wake Vacuum Measurement and Analysis for the WakeShield Facility Free Flying Platform,” *Vacuum* **64(2)** (2001) pp. 119–144.
4. J.A. Dever and C.A. McCracken, “Effects of Vacuum Ultraviolet Radiation of Various Wavelength Ranges on Teflon<sup>®</sup> FEP Film,” *High Performance Polymers* **16(2)** (2004) pp. 289–301.

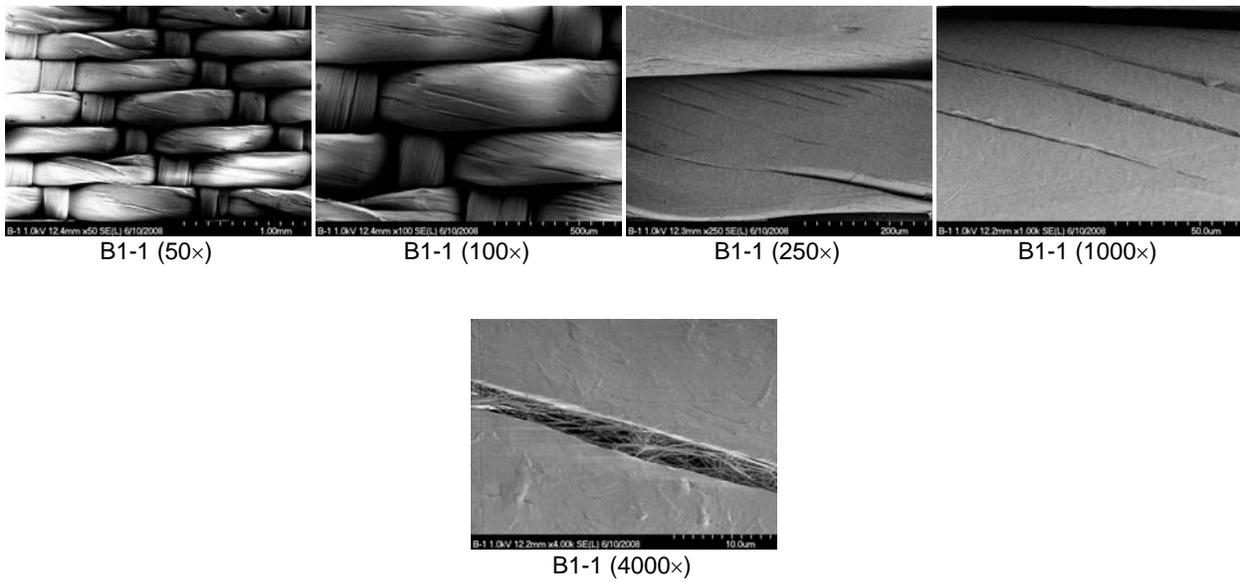
## Appendix A.—Pristine Apollo Fabric

### A.1 B1-1

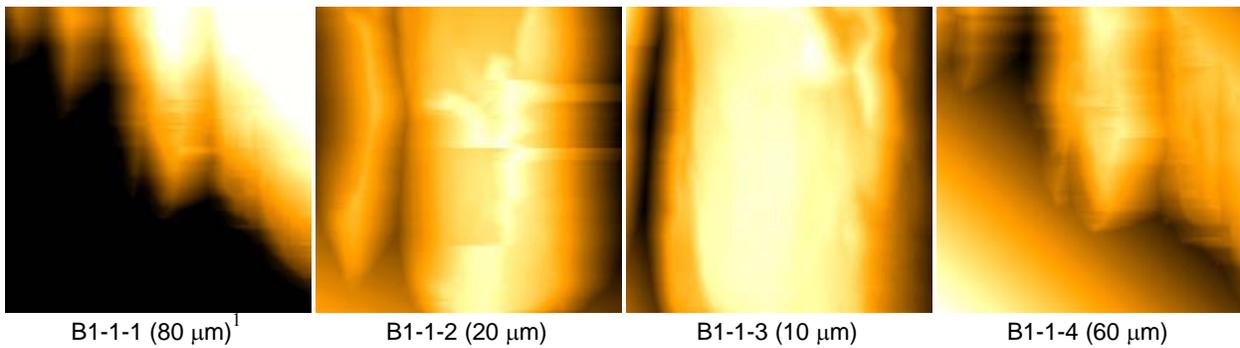
#### A.1.1 Optical Microscopy



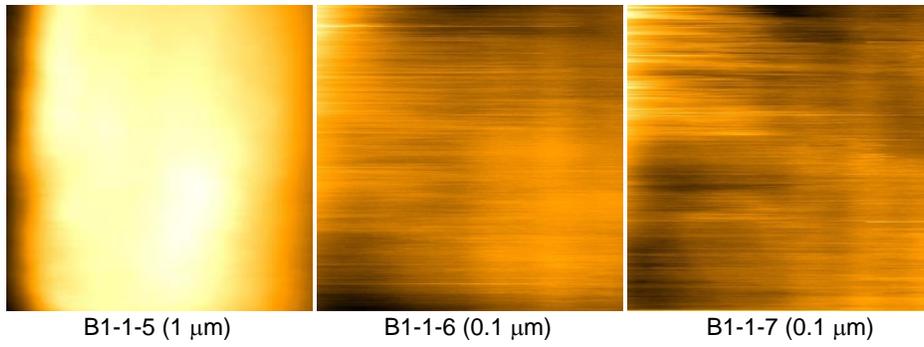
#### A.1.2 Electron Microscopy



#### A.1.3 Atomic Force Microscopy

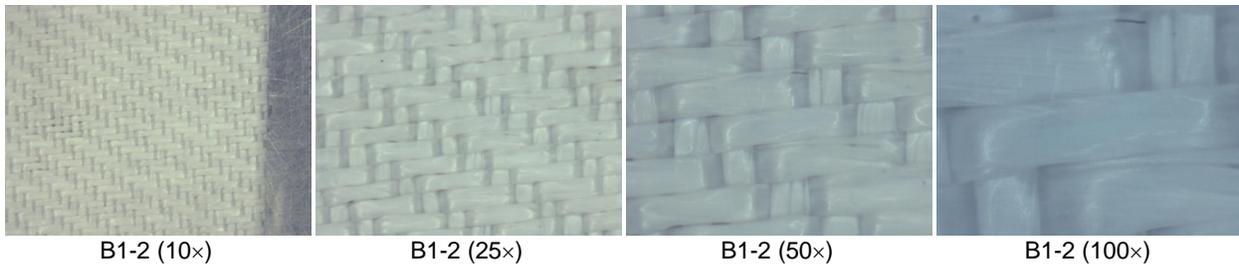


<sup>1</sup>Value in parenthesis is the length of a side of the scanned area.

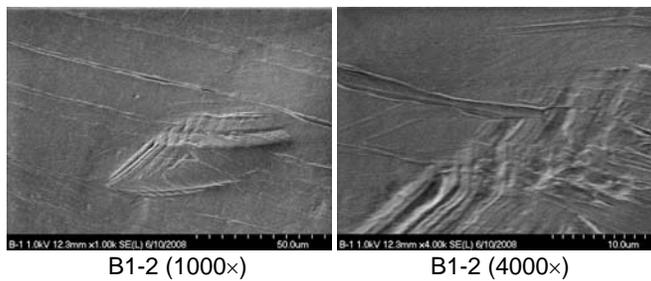
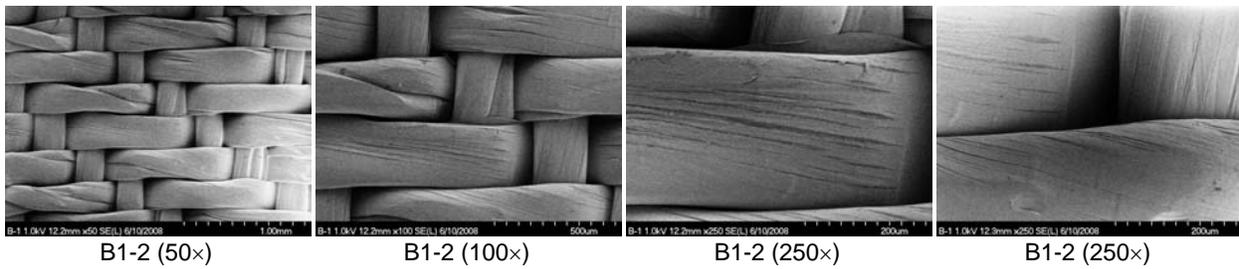


**A.2 B1-2**

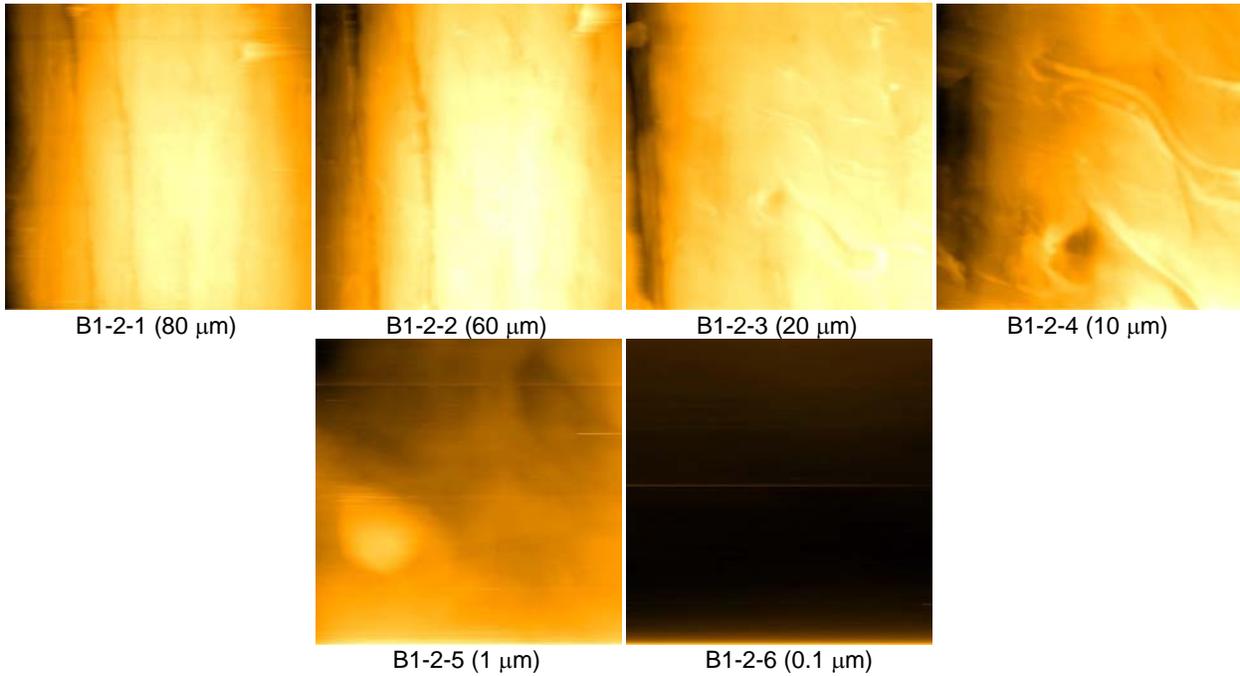
**A.2.1 Optical Microscopy**



**A.2.2 Electron Microscopy**

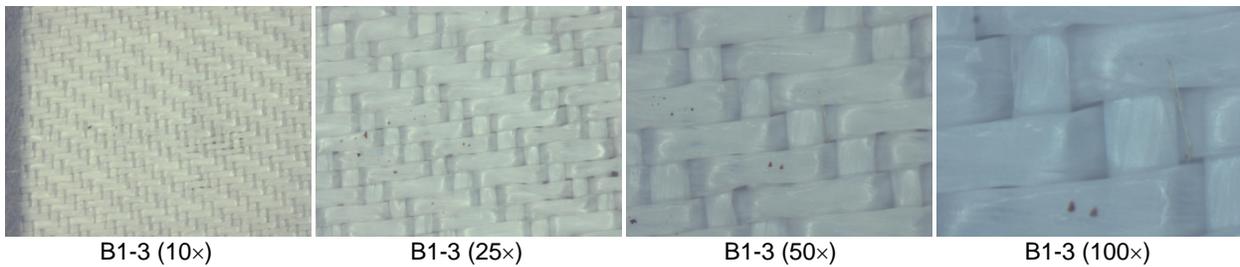


### A.2.3 Atomic Force Microscopy

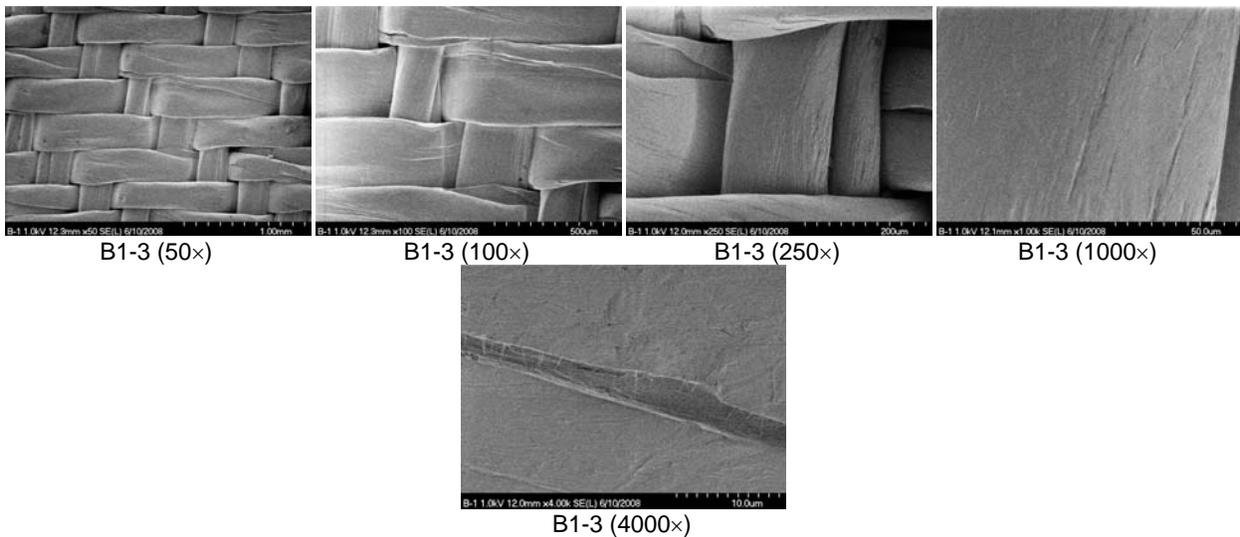


### A.3 B1-3

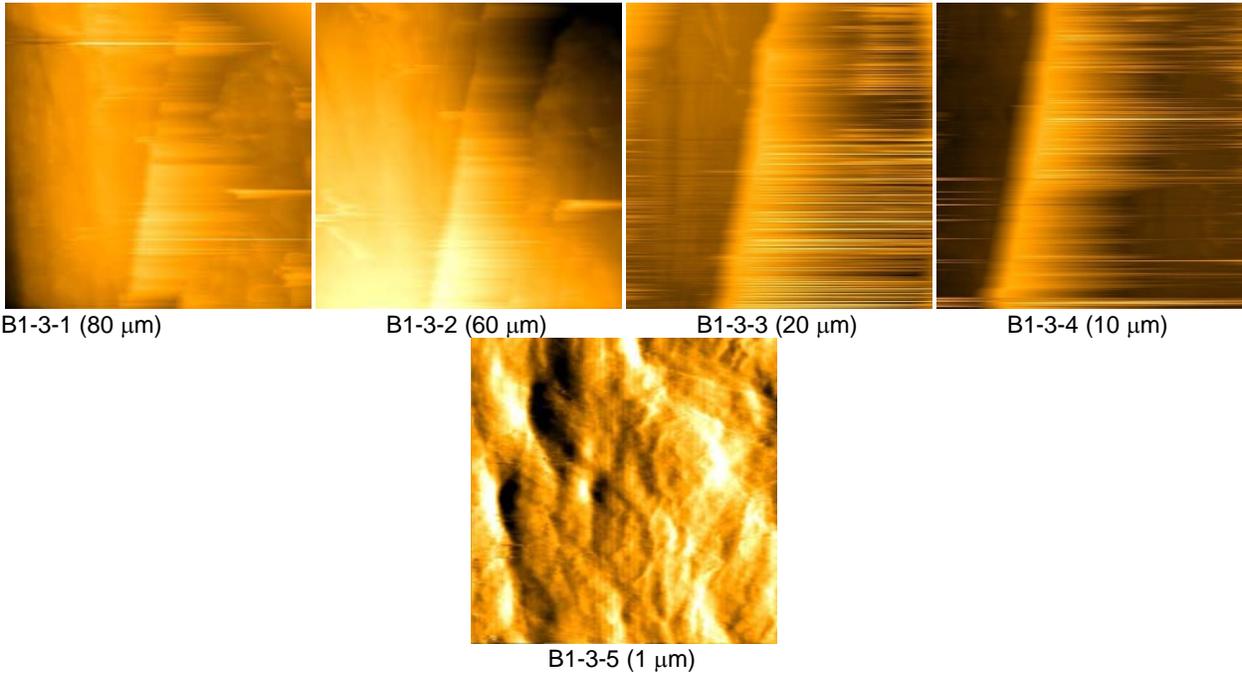
#### A.3.1 Optical Microscopy



#### A.3.2 Electron Microscopy

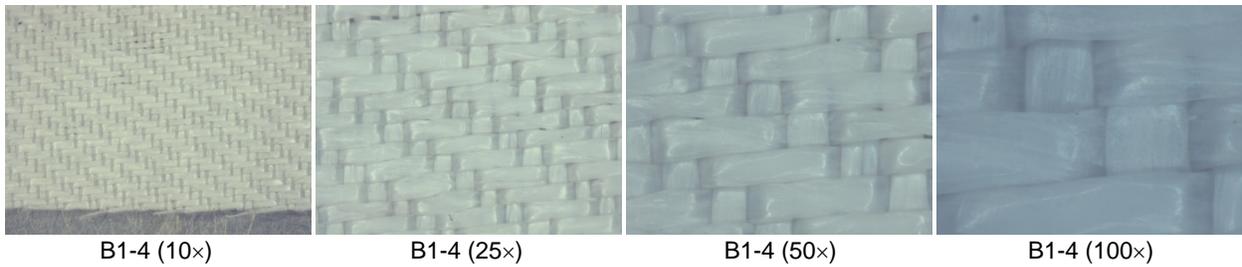


### A.3.3 Atomic Force Microscopy

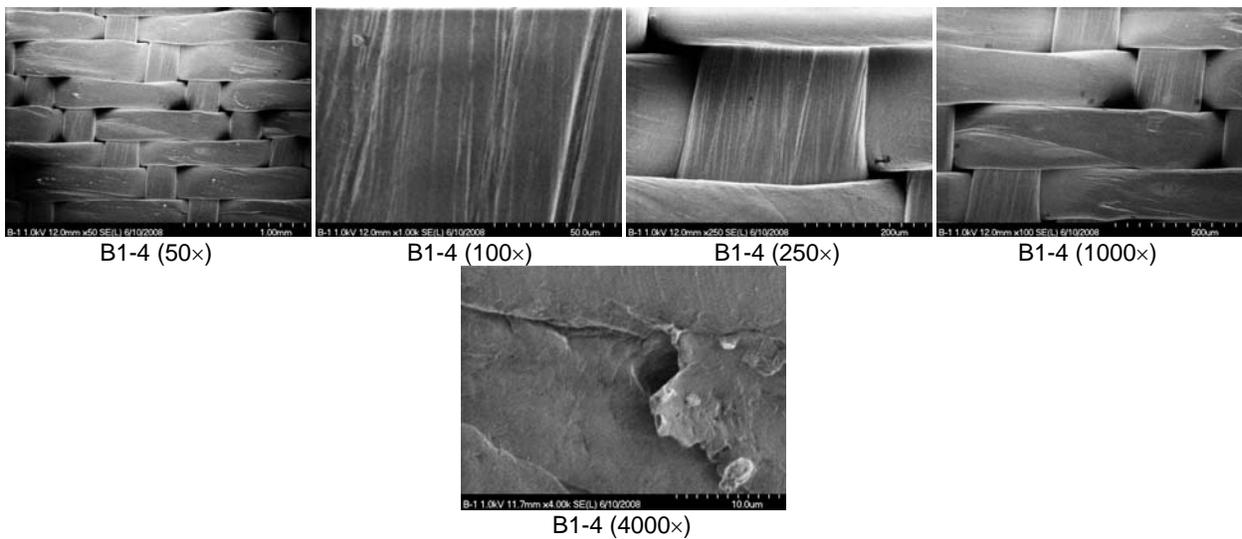


### A.4 B1-4

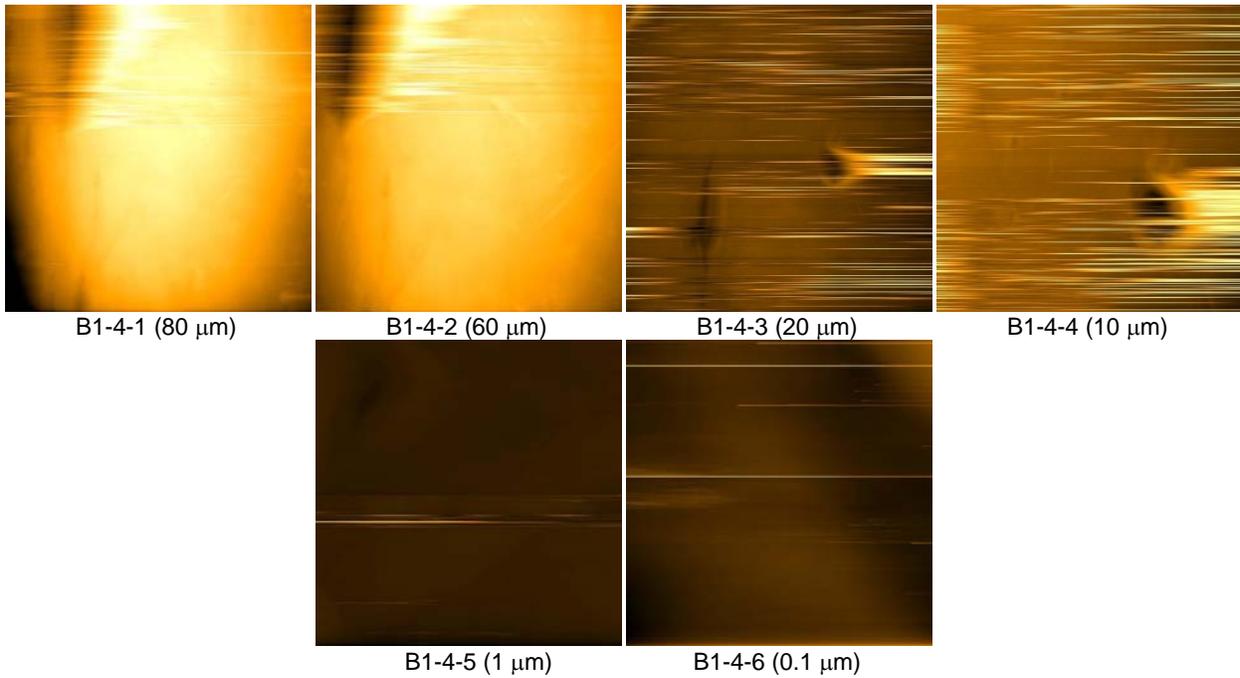
#### A.4.1 Optical Microscopy



#### A.4.2 Electron Microscopy

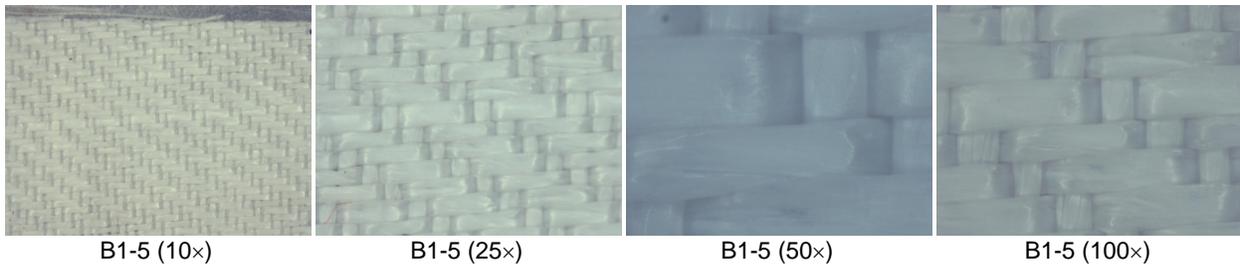


### A.4.3 Atomic Force Microscopy

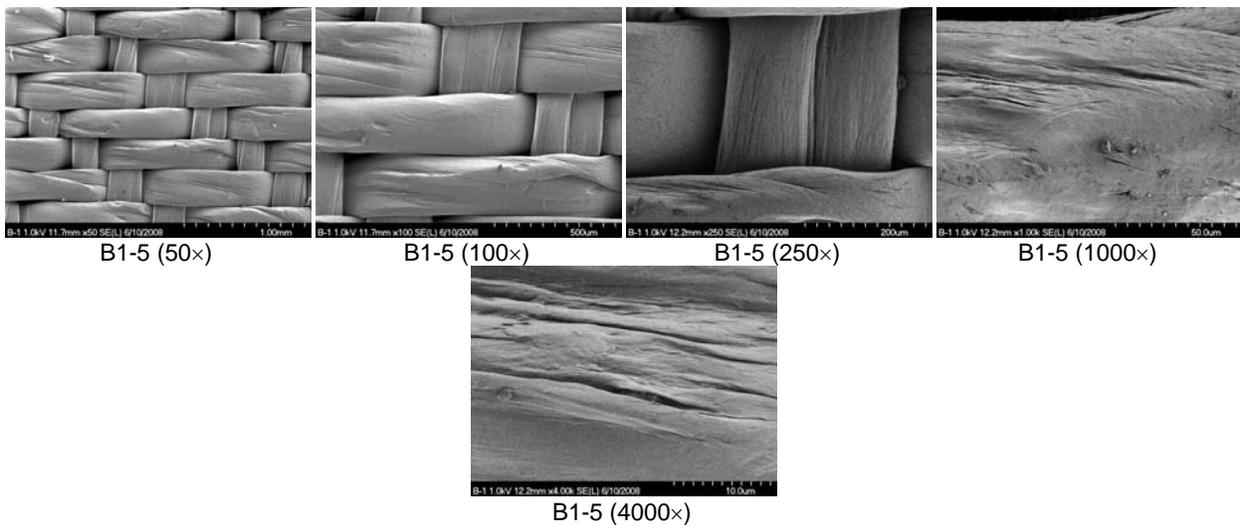


### A.5 B1-5

#### A.5.1 Optical Microscopy



#### A.5.2 Electron Microscopy



### A.5.3 Atomic Force Microscopy



B1-5-1 (80  $\mu\text{m}$ )



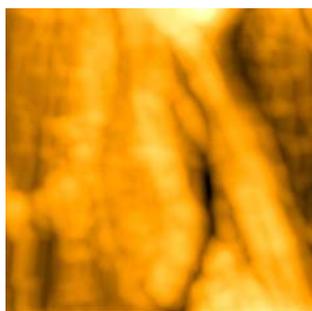
B1-5-2 (60  $\mu\text{m}$ )



B1-5-3 (20  $\mu\text{m}$ )



B1-5-4 (10  $\mu\text{m}$ )



B1-5-5 (1  $\mu\text{m}$ )



B1-5-6 (0.1  $\mu\text{m}$ )

## Appendix B.—Abraded Apollo Fabric

### B.1 BA1-1

#### B.1.1 Optical Microscopy



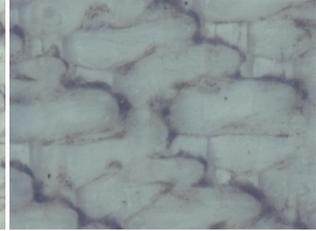
BA1-1 (7.1x)



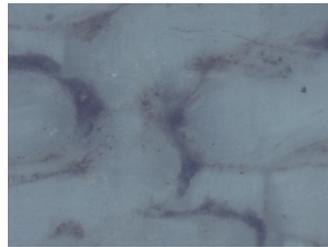
BA1-1 (10x)



BA1-1 (25x)

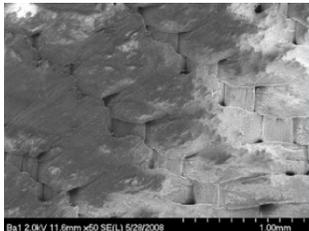


BA1-1 (50x)

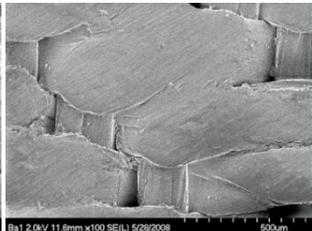


BA1-1 (100x)

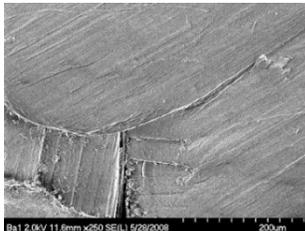
#### B.1.2 Electron Microscopy



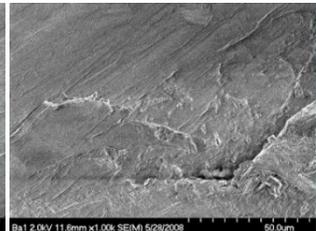
BA1-1 (50x)



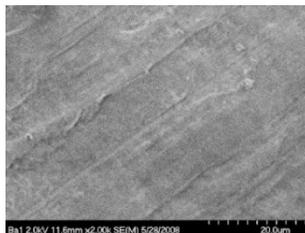
BA1-1 (100x)



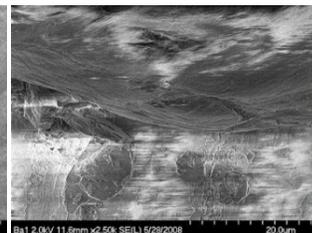
BA1-1 (250x)



BA1-1 (1000x)

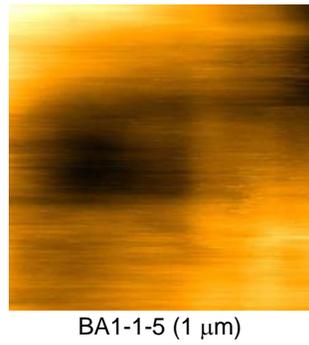
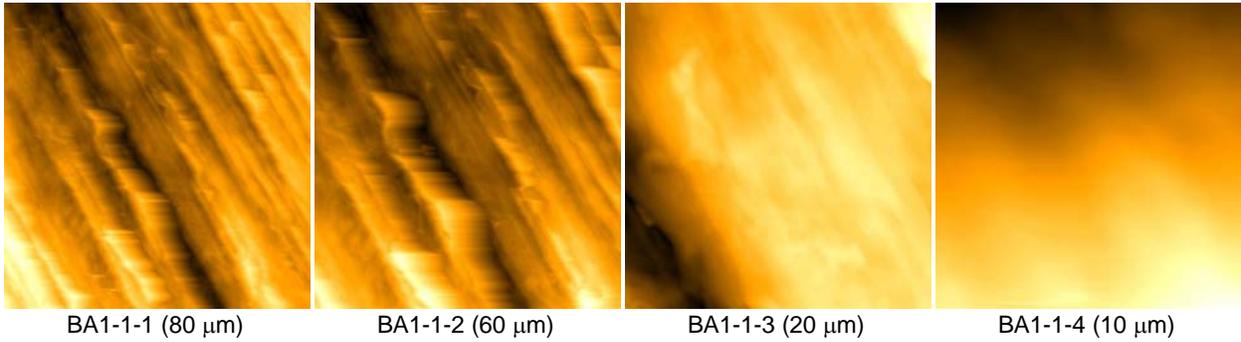


BA1-1 (2000x)



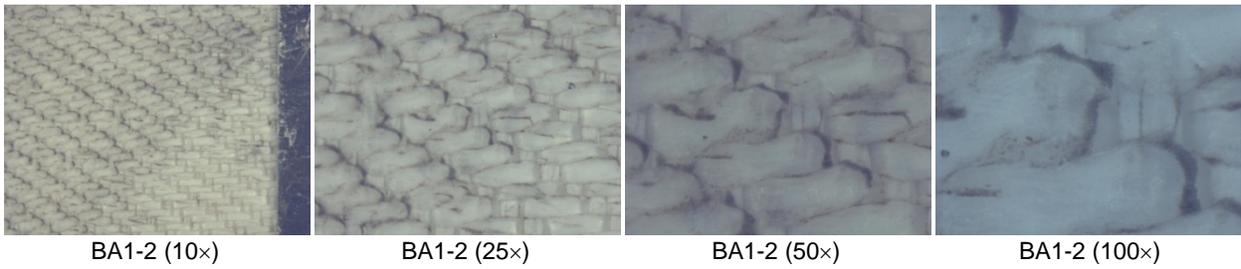
BA1-1 (2500x)

### B.1.3 Atomic Force Microscopy

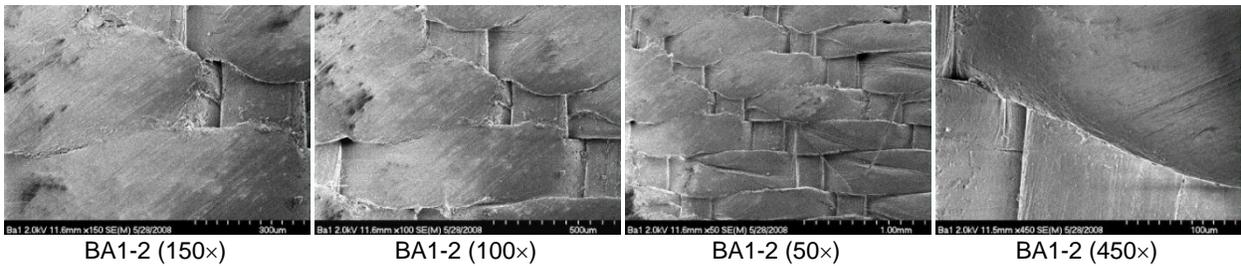


## B.2 BA1-2

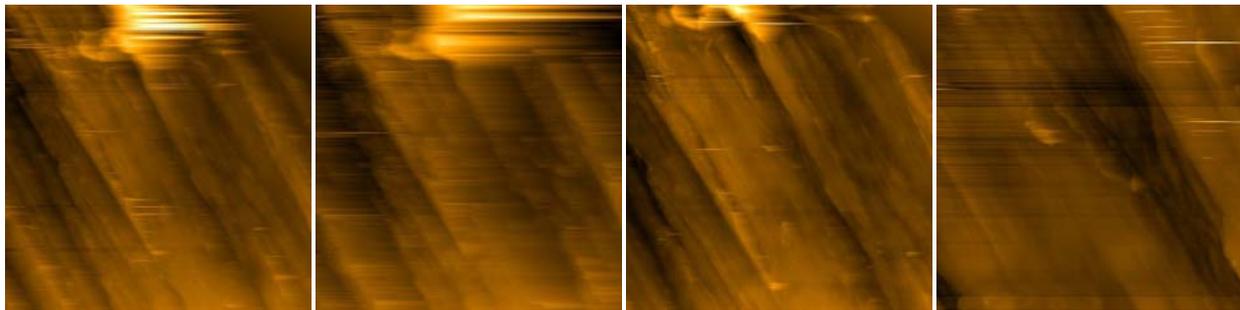
### B.2.1 Optical Microscopy



### B.2.2 Electron Microscopy



### B.2.3 Atomic Force Microscopy

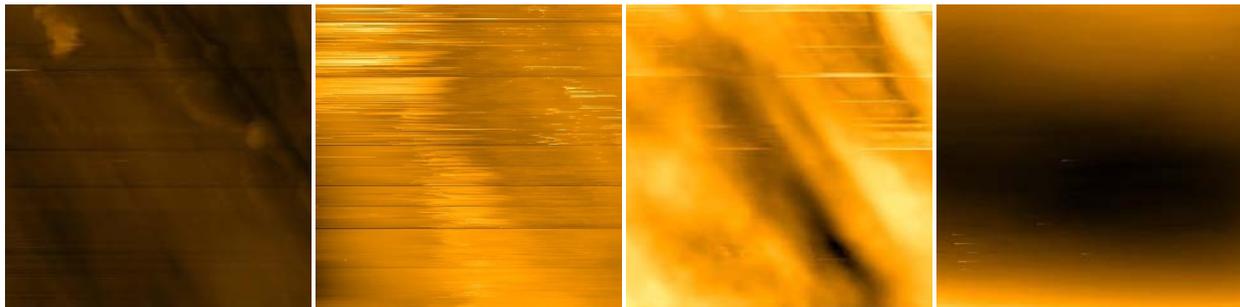


BA1-2-1 (80  $\mu\text{m}$ )

BA1-2-2 (80  $\mu\text{m}$ )

BA1-2-3 (60  $\mu\text{m}$ )

BA1-2-4 (20  $\mu\text{m}$ )

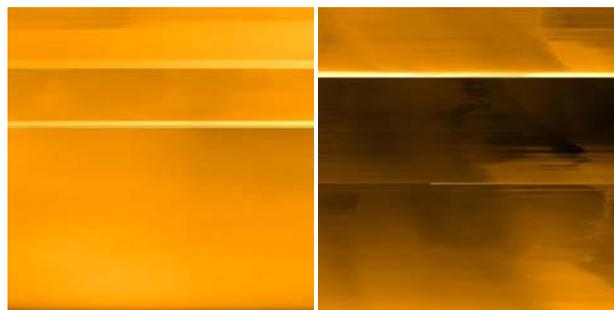


BA1-2-5 (10  $\mu\text{m}$ )

BA1-2-6 (1  $\mu\text{m}$ )

BA1-2-7 (1  $\mu\text{m}$ )

BA1-2-8 (0.1  $\mu\text{m}$ )

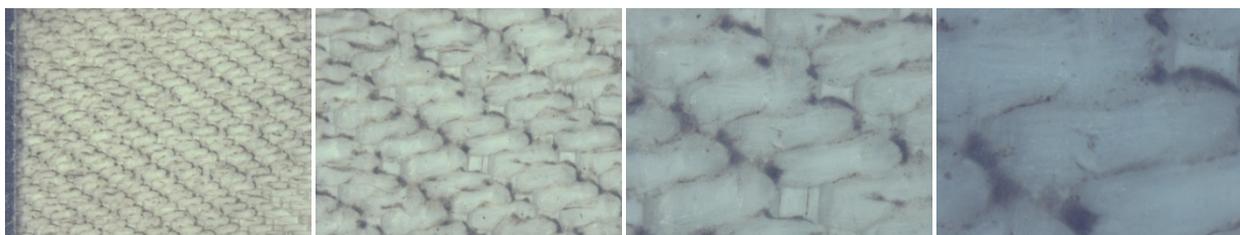


BA1-2-9 (0.1  $\mu\text{m}$ )

BA1-2-10 (0.1  $\mu\text{m}$ )

### B.3 BA1-3

#### B.3.1 Optical Microscopy



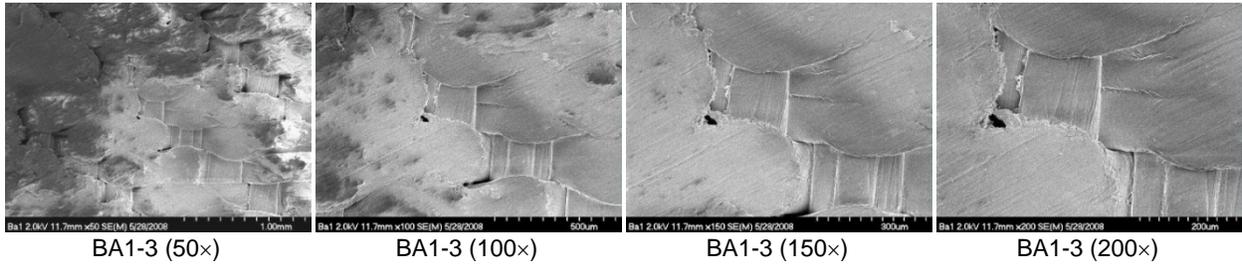
BA1-3 (10 $\times$ )

BA1-3 (25 $\times$ )

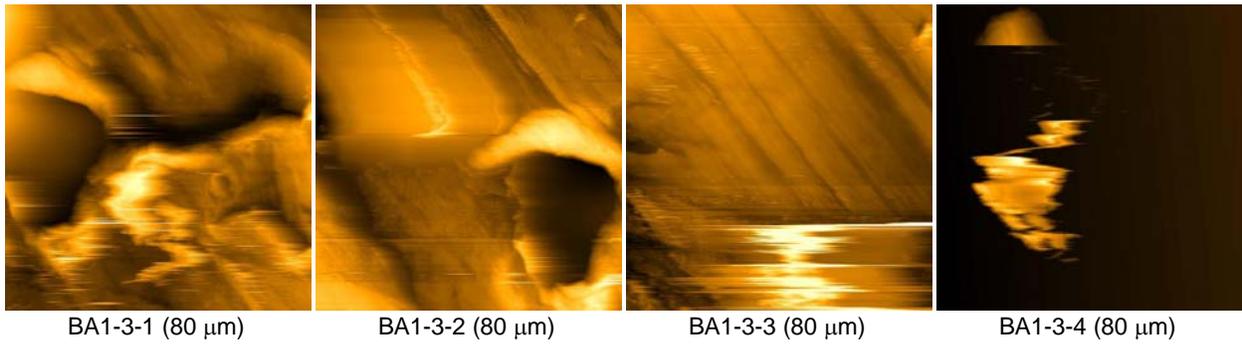
BA1-3 (50 $\times$ )

BA1-3 (100 $\times$ )

### B.3.2 Electron Microscopy

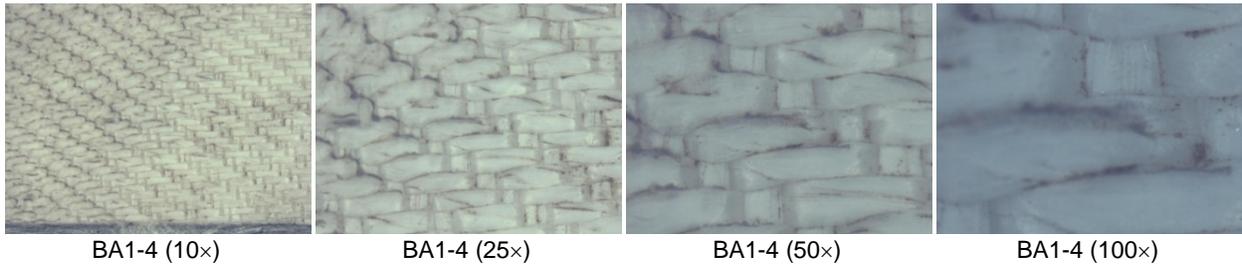


### B.3.3 Atomic Force Microscopy

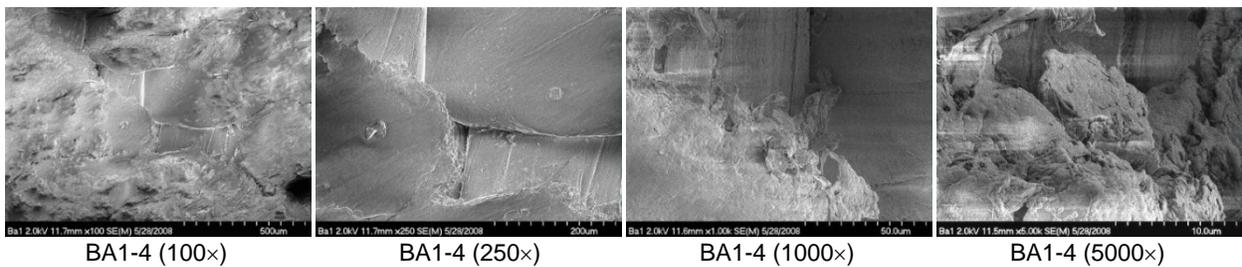


## B.4 BA1-4

### B.4.1 Optical Microscopy



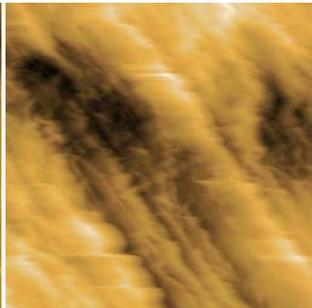
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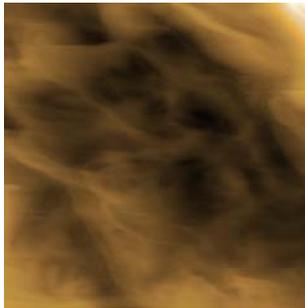
### B.4.3 Atomic Force Microscopy



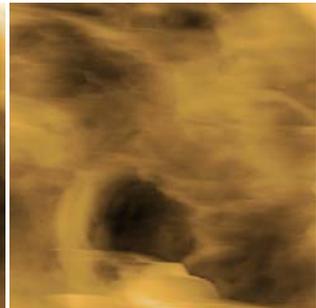
Ba1-4-1 (60  $\mu\text{m}$ )



Ba1-4-2 (10  $\mu\text{m}$ )



Ba1-4-3 (10  $\mu\text{m}$ )



Ba1-4-4 (10  $\mu\text{m}$ )



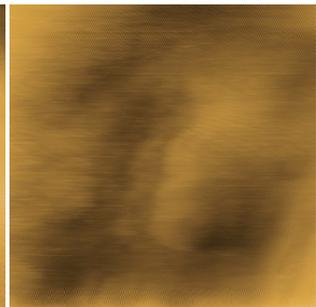
Ba1-4-5 (1  $\mu\text{m}$ )



Ba1-4-6 (1  $\mu\text{m}$ )



Ba1-4-7 (1  $\mu\text{m}$ )



Ba1-4-8 (60  $\mu\text{m}$ )



Ba1-4-9 (10  $\mu\text{m}$ )



Ba1-4-10 (10  $\mu\text{m}$ )



Ba1-4-11 (10  $\mu\text{m}$ )



Ba1-4-12 (1  $\mu\text{m}$ )



Ba1-4-13 (1  $\mu\text{m}$ )



Ba1-4-14 (1  $\mu\text{m}$ )



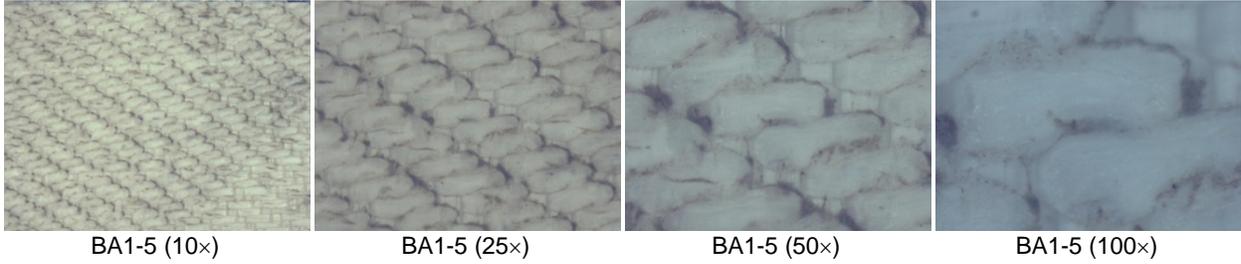
Ba1-4-15 (1  $\mu\text{m}$ )



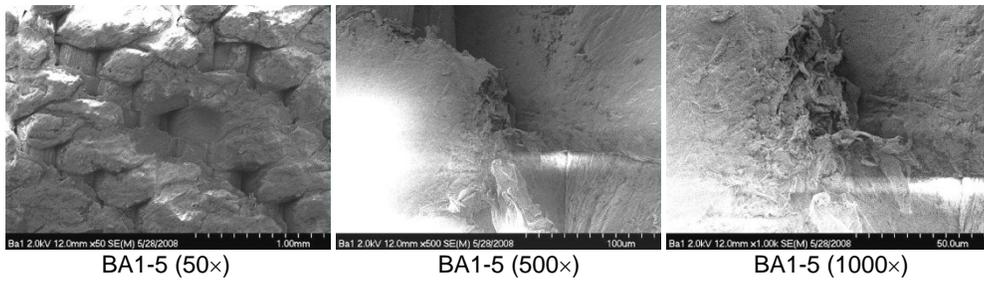
Ba1-4-16 (1  $\mu\text{m}$ )

## B.5 BA1-5

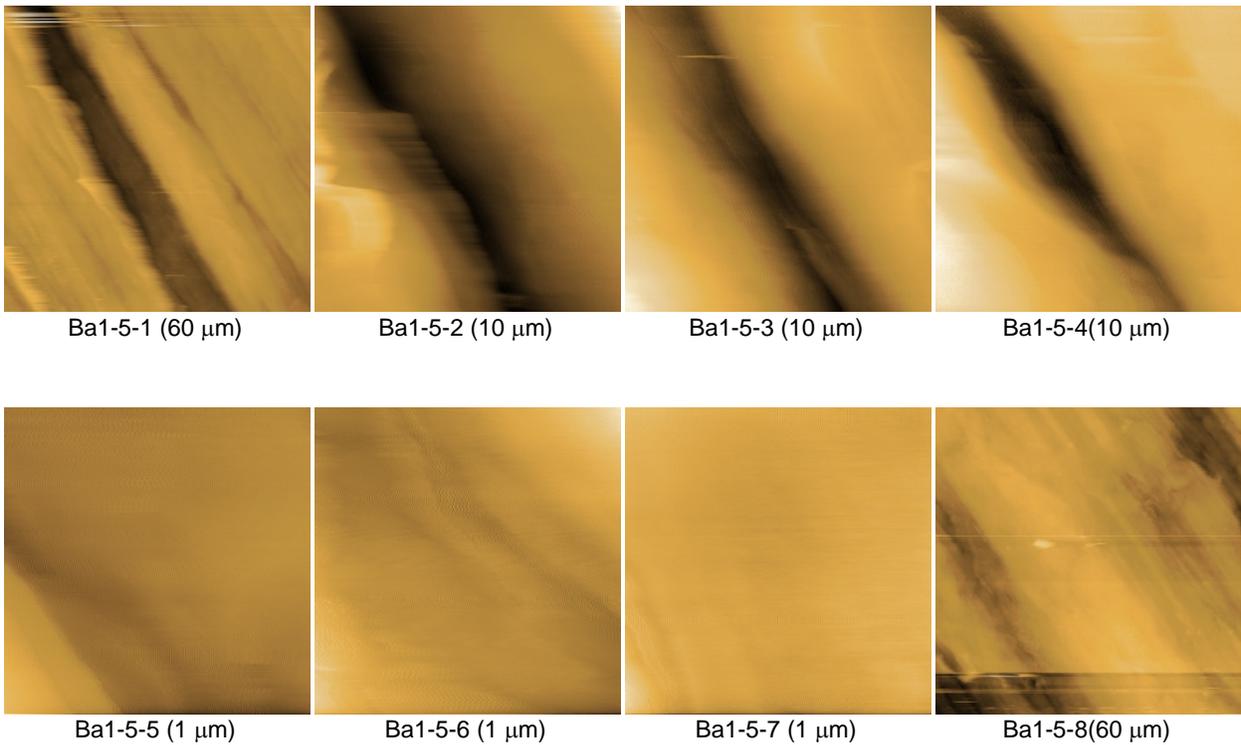
### B.5.1 Optical Microscopy

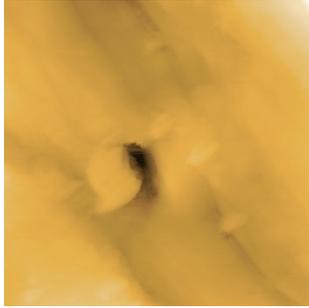


### B.5.2 Electron Microscopy

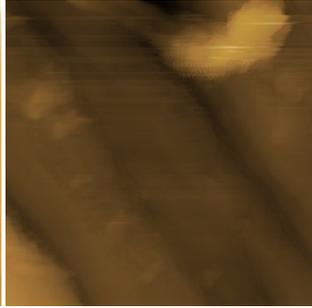


### B.5.3 Atomic Force Microscopy





Ba1-5-9 (10  $\mu\text{m}$ )



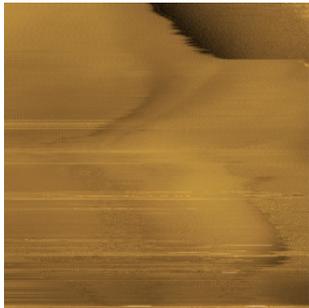
Ba1-5-10 (1  $\mu\text{m}$ )



Ba1-5-11 (10  $\mu\text{m}$ )



Ba1-5-12 (1  $\mu\text{m}$ )



Ba1-5-13 (1  $\mu\text{m}$ )



Ba1-5-14 (1  $\mu\text{m}$ )



Ba1-5-15 (1  $\mu\text{m}$ )



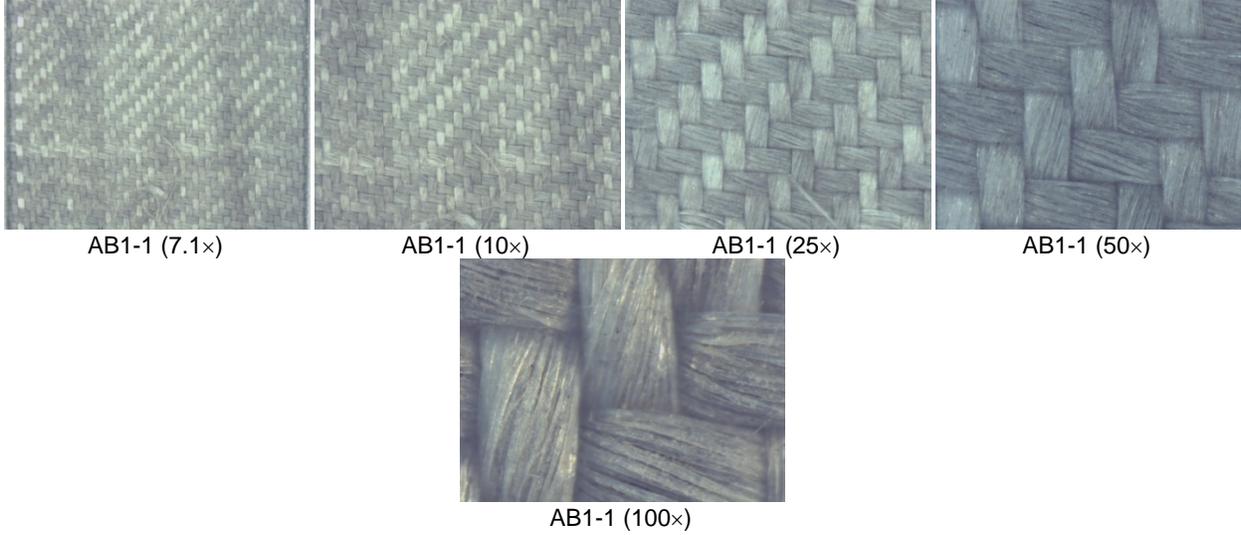
Ba1-5-16 (1  $\mu\text{m}$ )



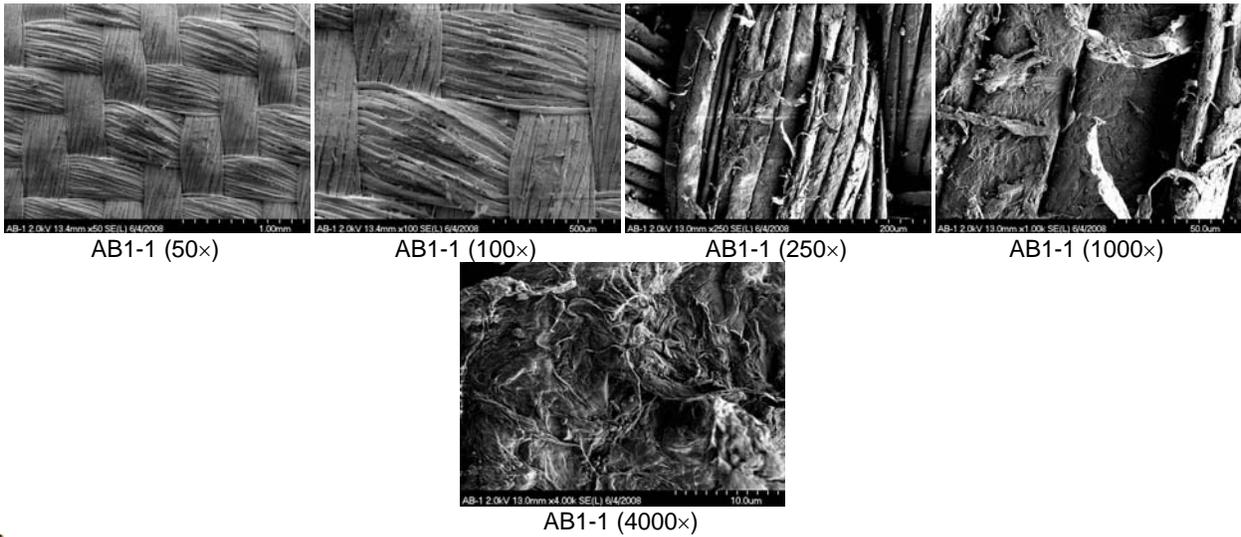
## Appendix C.—Alan Bean Apollo 12 Fabric

### C.1 AB1-1

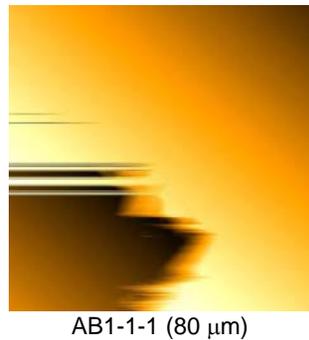
#### C.1.1 Optical Microscopy



#### C.1.2 Electron Microscopy



#### C.1.3 Atomic Force Microscopy



## C.2 AB1-2

### C.2.1 Optical Microscopy



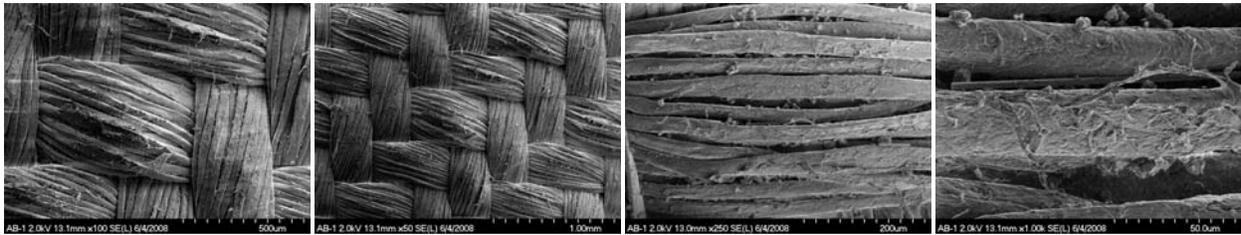
AB1-2 (10×)

AB1-2 (25×)

AB1-2 (50×)

AB1-2 (100×)

### C.2.2 Electron Microscopy

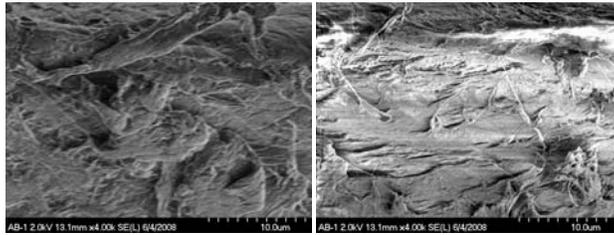


BA1-2 (50×)

BA1-2 (100×)

BA1-2 (250×)

BA1-2 (1000×)



BA1-2 (4000×)

BA1-2 (4000×)

## C.3 AB1-3

### C.3.1 Optical Microscopy



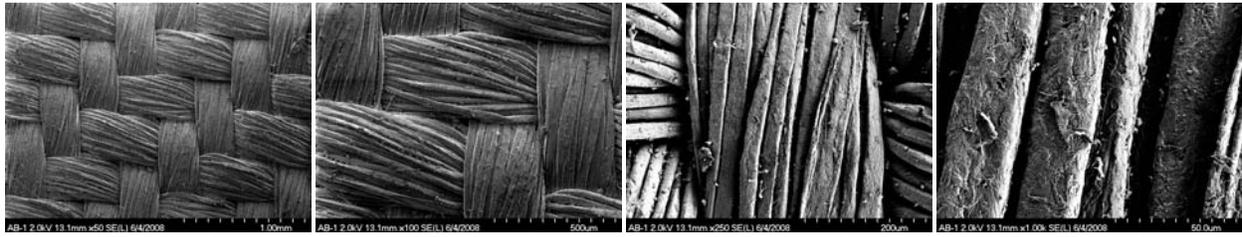
AB1-3 (10×)

AB1-3 (25×)

AB1-3 (50×)

AB1-3 (100×)

### C.3.2 Electron Microscopy

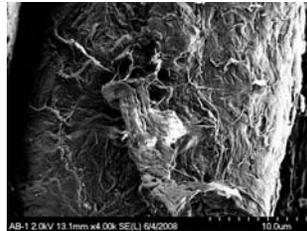


AB1-3 (50x)

AB1-3 (100x)

AB1-3 (250x)

AB1-3 (1000x)



AB1-3 (4000x)

### C.3.3 Optical Microscopy

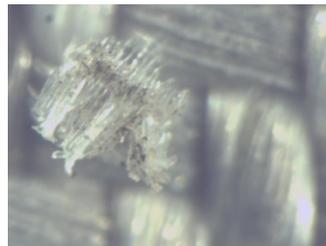


AB1-4 (10x)

AB1-4 (25x)

AB1-4 (50x)

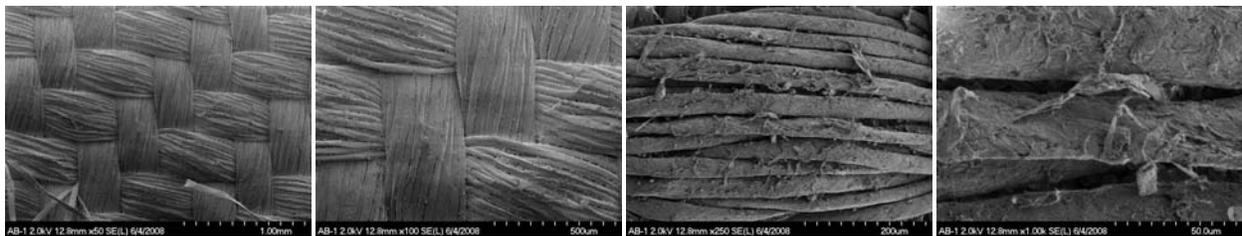
AB1-4 (100x)



AB1-4 (100x)

## C.4 AB1-4

### C.4.1 Electron Microscopy

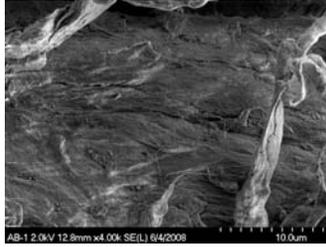


AB1-4 (50x)

AB1-4 (100x)

AB1-4 (250x)

AB1-4 (1000x)



AB1-4 (4000x)

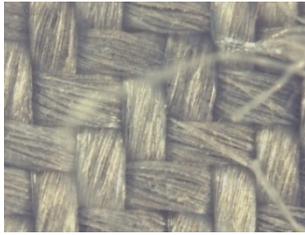
### C.4.2 Optical Microscopy



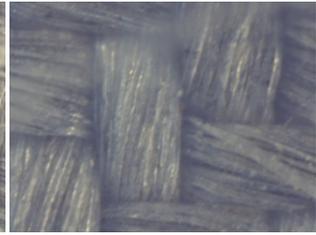
AB1-5 (10x)



AB1-5 (25x)

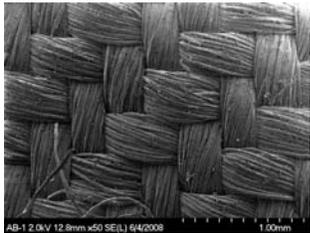


AB1-5 (50x)



AB1-5 (100x)

### C.4.3 Electron Microscopy



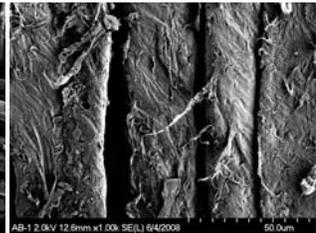
AB1-5 (50x)



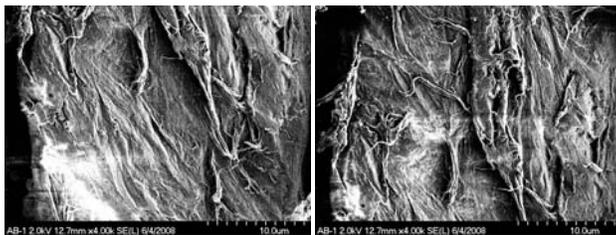
AB1-5 (100x)



AB1-5 (250x)



AB1-5 (1000x)



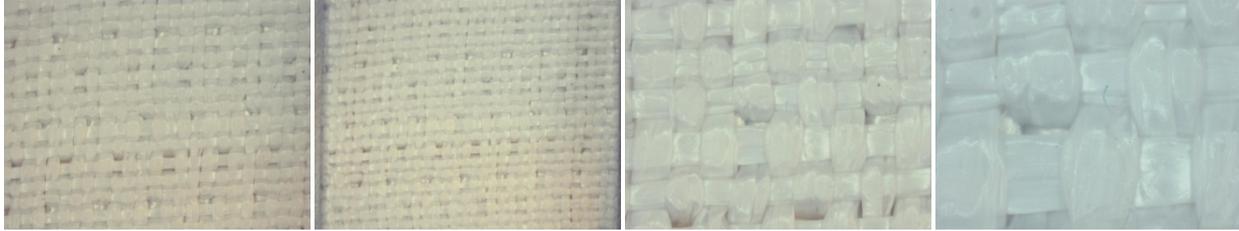
AB1-5 (4000x)

AB1-5 (4000x)

## Appendix D.—Pristine Orthofabric

### D.1 O1-1

#### D.1.1 Optical Microscopy



O1-1 (7.1x)

O1-1 (10x)

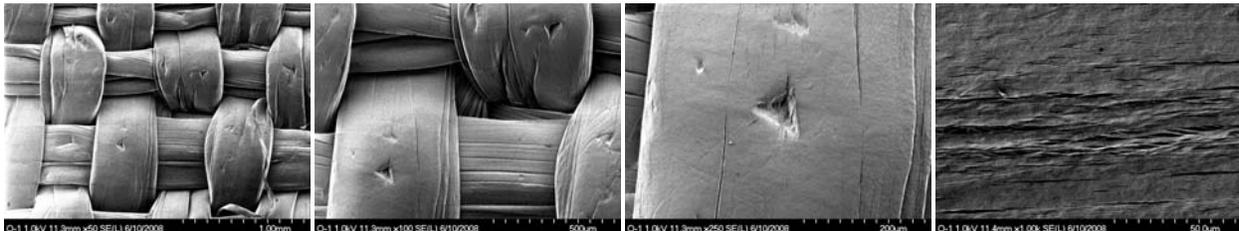
O1-1 (25x)

O1-1 (50x)



O1-1 (100x)

#### D.1.2 Electron Microscopy

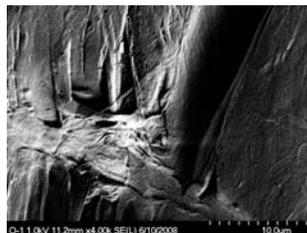


O1-1 (50x)

O1-1 (100x)

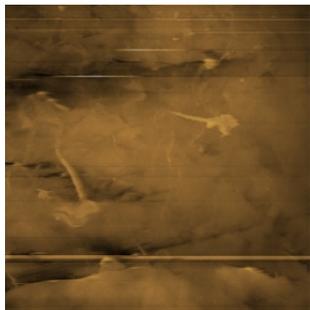
O1-1 (250x)

O1-1 (1000x)

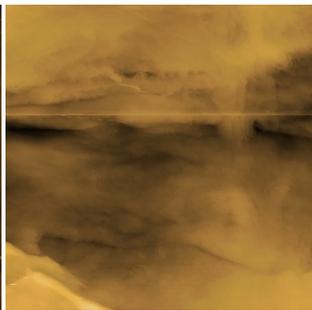


O1-1 (4000x)

### D.1.3 Atomic Force Microscopy



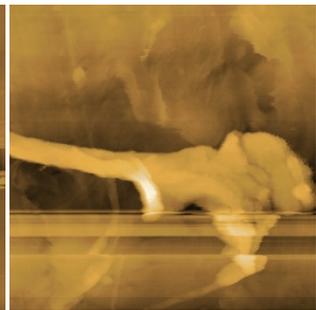
O1-1-1 (60 μm)



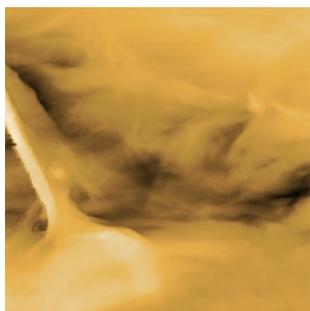
O1-1-2 (10 μm)



O1-1-3 (10 μm)



O1-1-4 (10 μm)



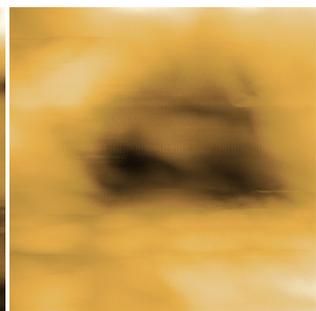
O1-1-5 (10 μm)



O1-1-6 (1 μm)



O1-1-7 (1 μm)



O1-1-8 (1 μm)



O1-1-9 (1 μm)



O1-1-10 (1 μm)



O1-1-11 (1 μm)



O1-1-12 (1 μm)



O1-1-13 (1 μm)



O1-1-14 (1 μm)



O1-1-15 (1 μm)



O1-1-16 (1 μm)



O1-1-17 (1  $\mu\text{m}$ )

O1-1-18 (1  $\mu\text{m}$ )

O1-1-19 (0.1  $\mu\text{m}$ )

O1-1-20 (0.1  $\mu\text{m}$ )



O1-1-21 (0.1  $\mu\text{m}$ )

O1-1-22 (0.1  $\mu\text{m}$ )

O1-1-23 (60  $\mu\text{m}$ )

O1-1-24 (10  $\mu\text{m}$ )



O1-1-25 (60  $\mu\text{m}$ )

O1-1-26 (1  $\mu\text{m}$ )

O1-1-27 (60  $\mu\text{m}$ )

## D.2 O1-2

### D.2.1 Optical Microscopy



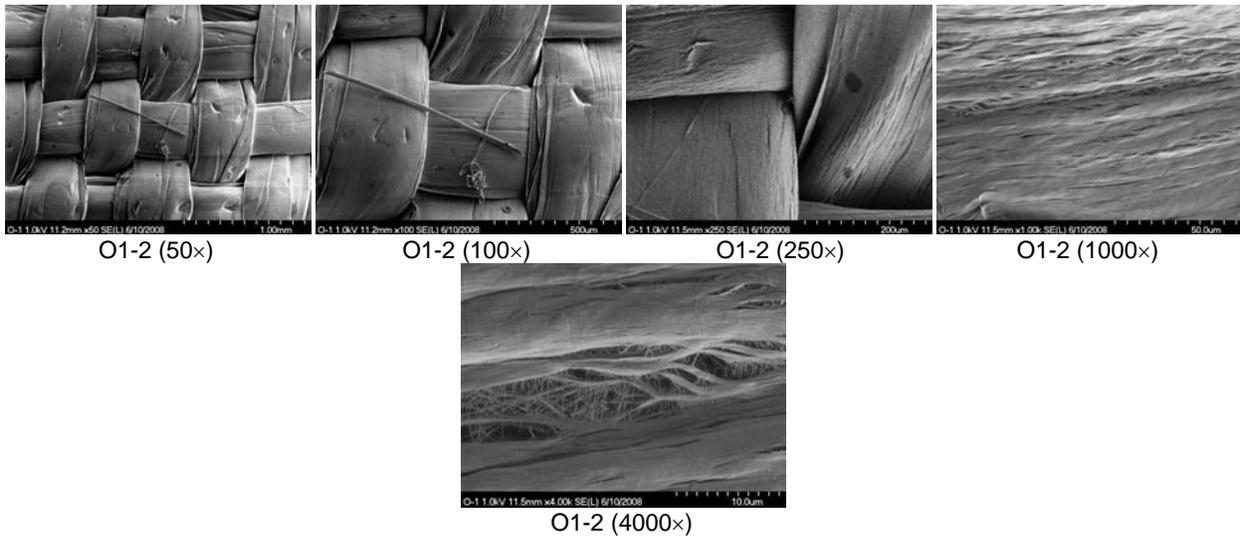
O1-2 (10 $\times$ )

O1-2 (25 $\times$ )

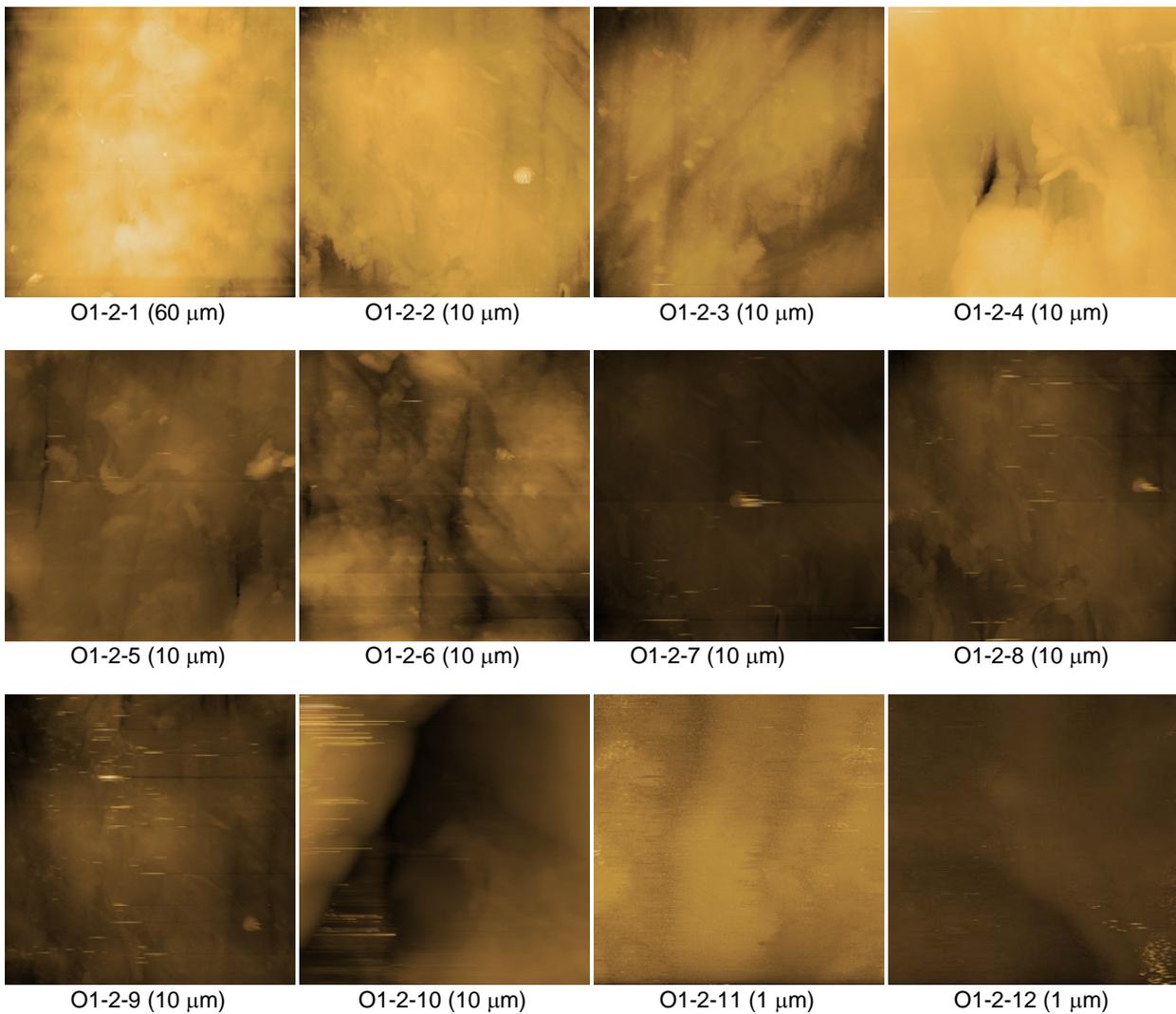
O1-2 (50 $\times$ )

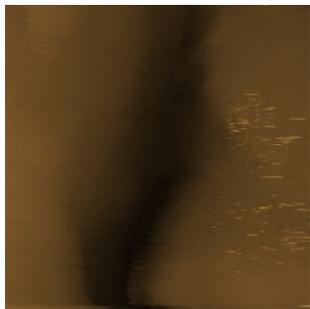
O1-2 (100 $\times$ )

## D.2.2 Electron Microscopy



## D.2.3 Atomic Force Microscopy





O1-2-13 (1 μm)



O1-2-14 (1 μm)



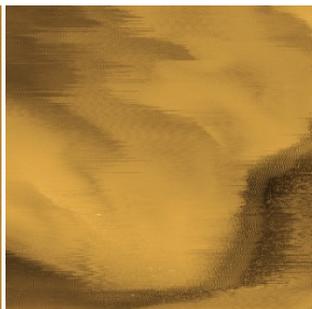
O1-2-15 (1 μm)



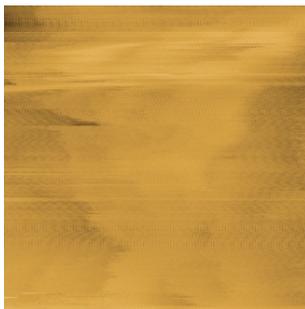
O1-2-16 (1 μm)



O1-2-17 (1 μm)



O1-2-18 (1 μm)



O1-2-19 (10 μm)



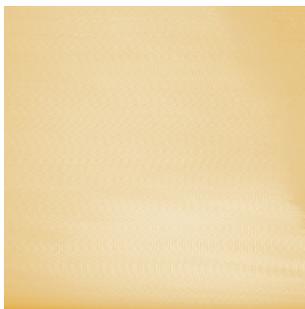
O1-2-20 (10 μm)



O1-2-21 (0.1 μm)



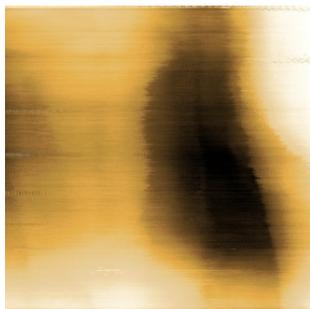
O1-2-22 (0.1 μm)



O1-2-23 (0.1 μm)



O1-2-24 (0.1 μm)



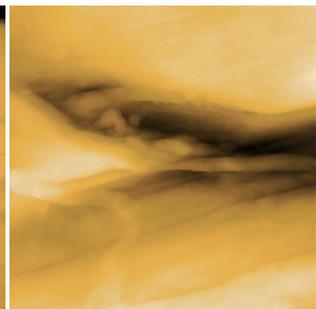
O1-2-25 (0.1 μm)



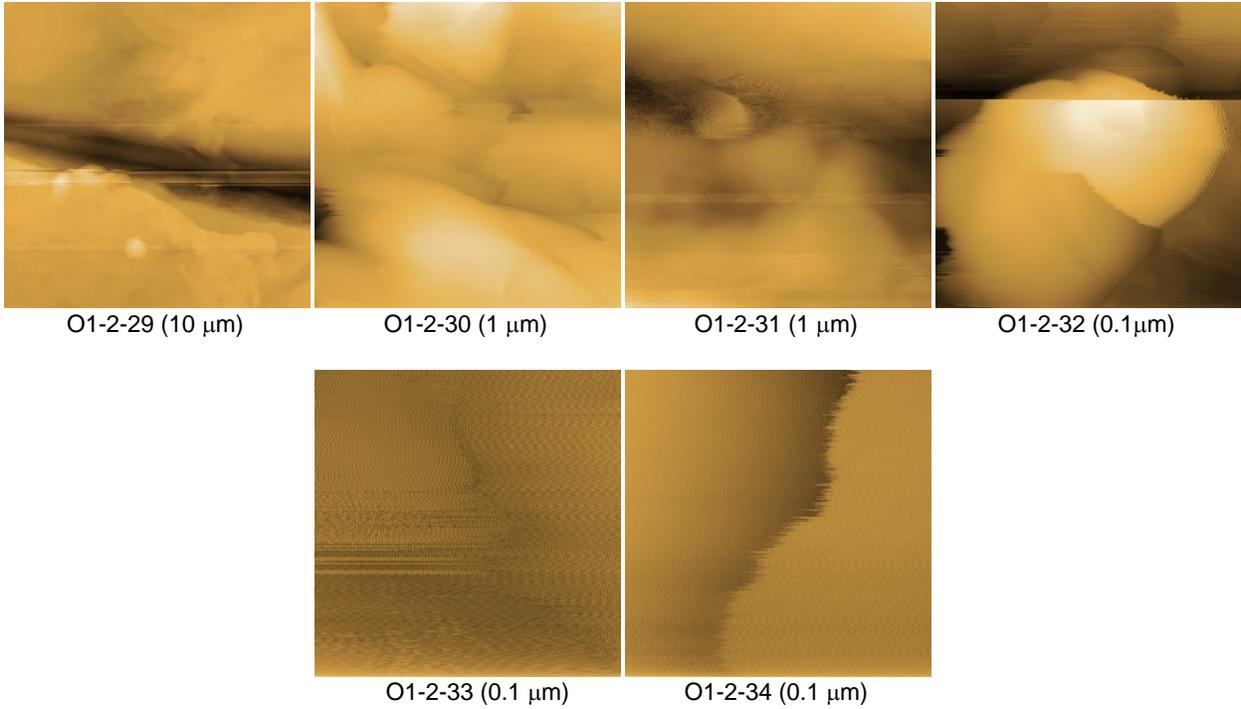
O1-2-26 (0.1 μm)



O1-2-27 (60 μm)

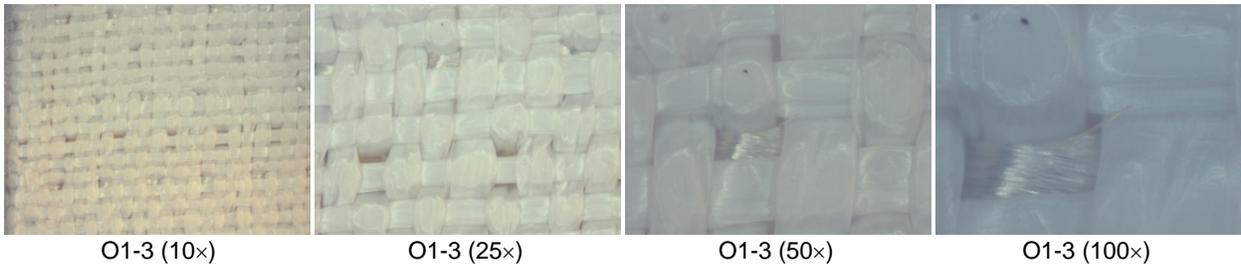


O1-2-28 (10 μm)

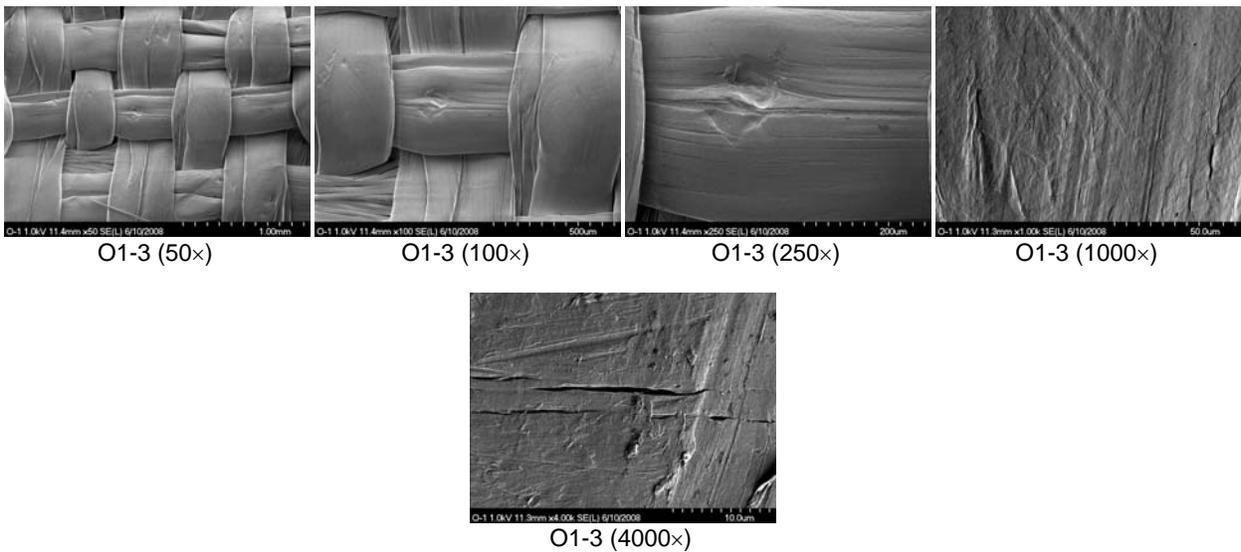


**D.3 O1-3**

**D.3.1 Optical Microscopy**



**D.3.2 Electron Microscopy**



### D.3.3 Atomic Force Microscopy

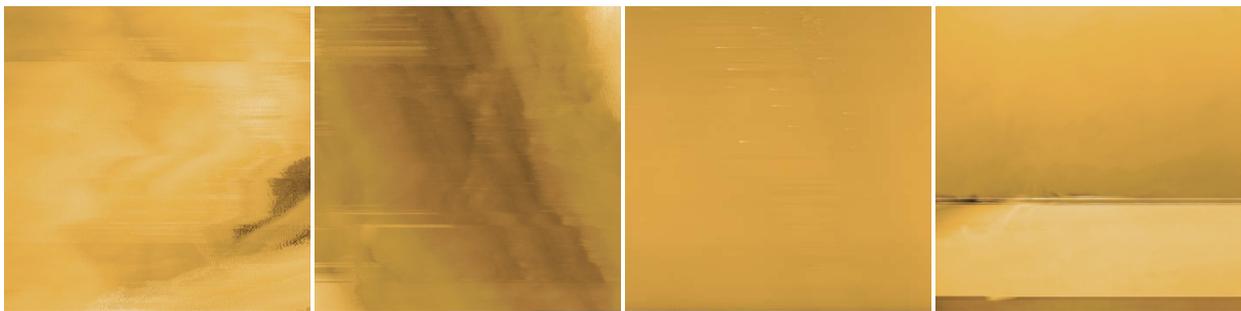


O1-3-1 (60 μm)

O1-3-2 (10 μm)

O1-3-3 (10 μm)

O1-3-4 (1 μm)



O1-3-5 (1 μm)

O1-3-6 (1 μm)

O1-3-7 (0.1 μm)

O1-3-8 (60 μm)



O1-3-9 (10 μm)

O1-3-10 (10 μm)

O1-3-11 (1 μm)

O1-3-12 (1 μm)



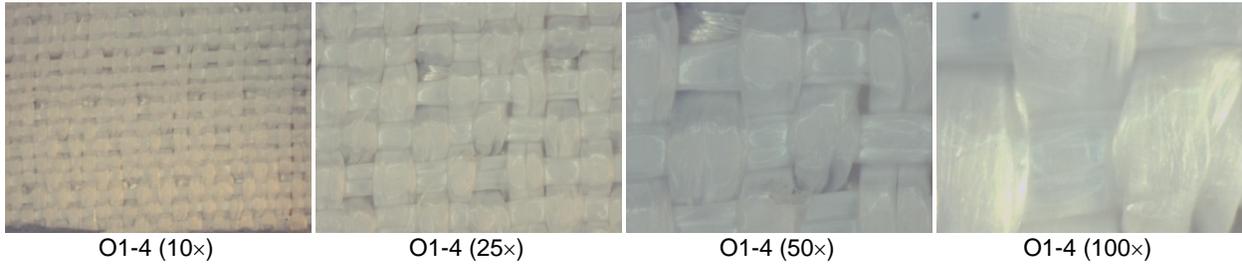
O1-3-13 (1 μm)

O1-3-14 (0.1 μm)

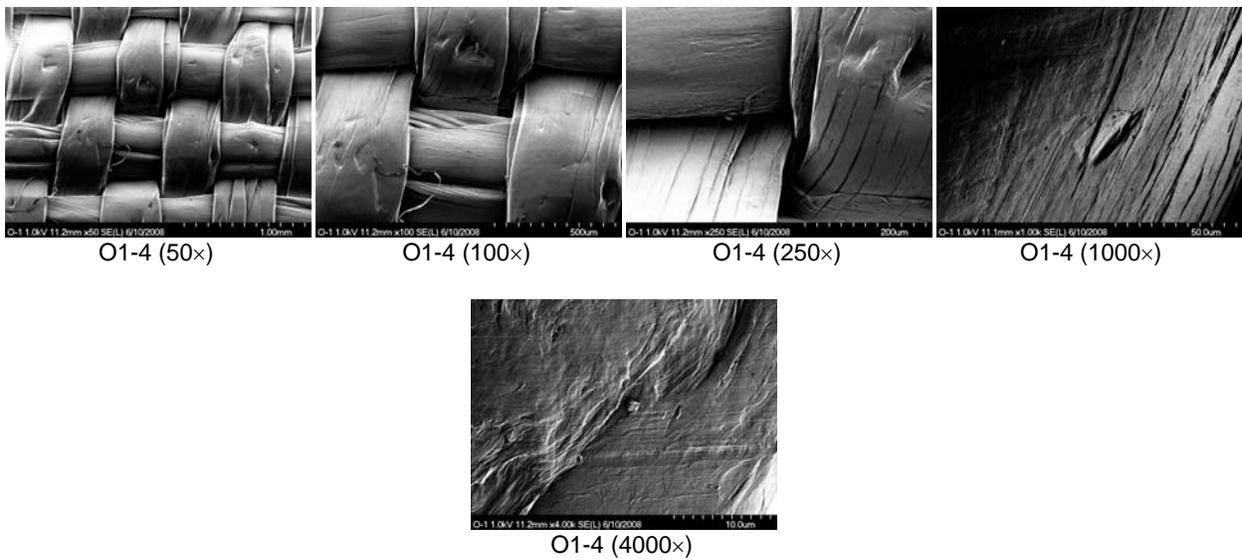
O1-3-15 (0.1 μm)

## D.4 O1-4

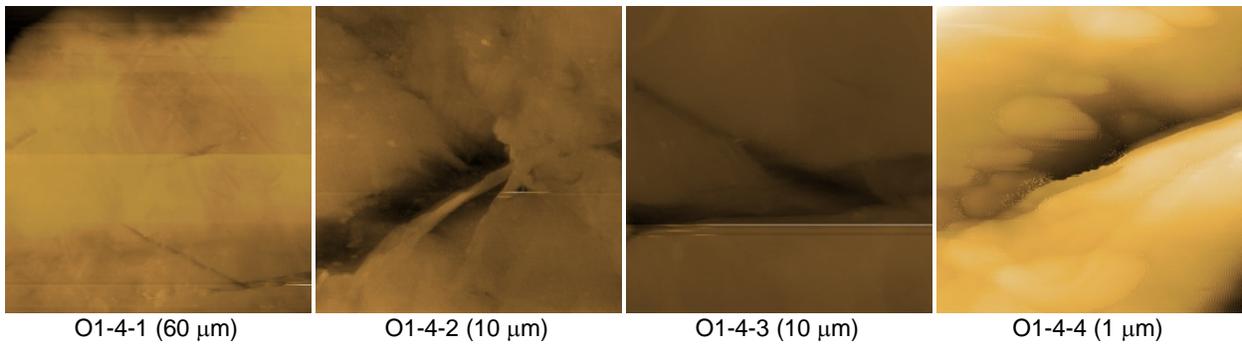
### D.4.1 Optical Microscopy

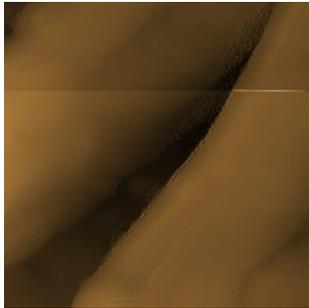


### D.4.2 Electron Microscopy



### D.4.3 Atomic Force Microscopy





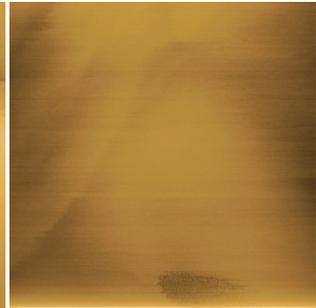
O1-4-5 (1 μm)



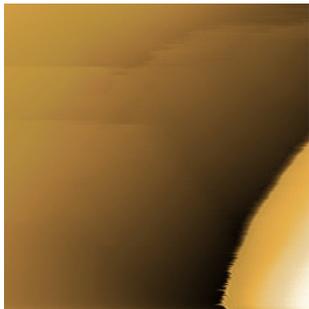
O1-4-6 (1 μm)



O1-4-7 (1 μm)



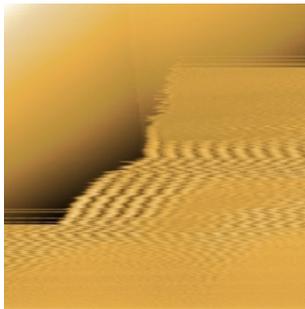
O1-4-8 (0.1 μm)



O1-4-9 (0.1 μm)



O1-4-10 (0.1 μm)



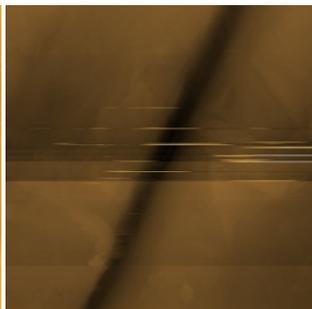
O1-4-11 (0.1 μm)



O1-4-12 (60 μm)



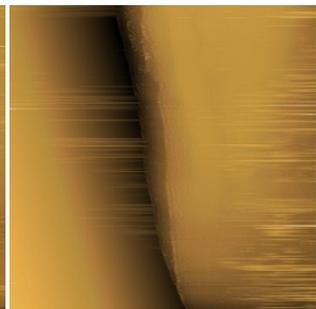
O1-4-13 (10 μm)



O1-4-14 (10 μm)



O1-4-15 (1 μm)



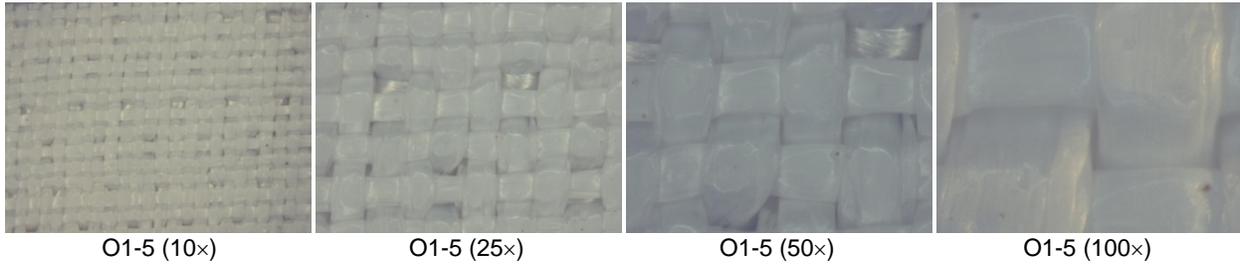
O1-4-16 (1 μm)



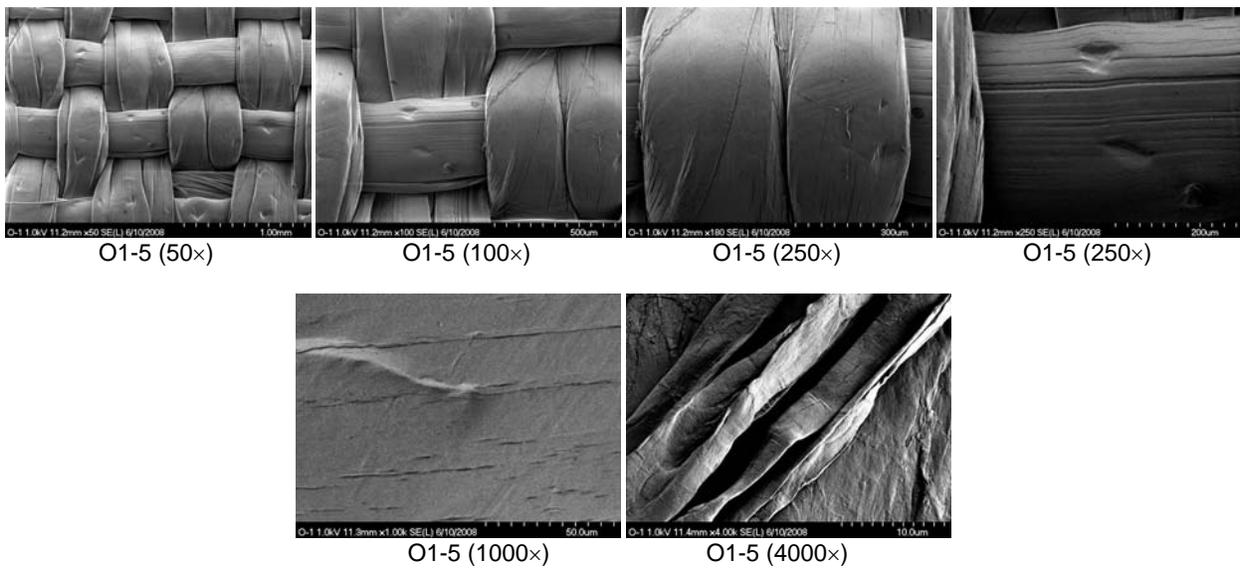
O1-4-17 (1 μm)

## D.5 O1-5

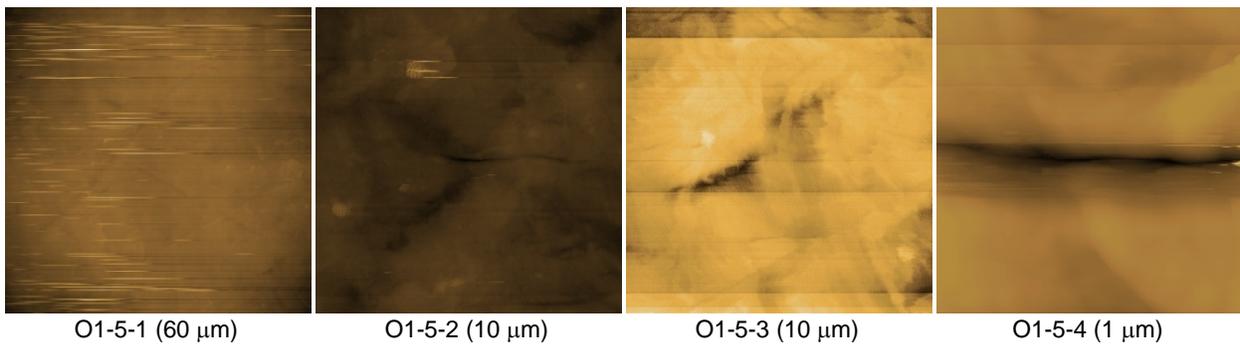
### D.5.1 Optical Microscopy



### D.5.2 Electron Microscopy



### D.5.3 Atomic Force Microscopy





O1-5-5 (1  $\mu\text{m}$ )



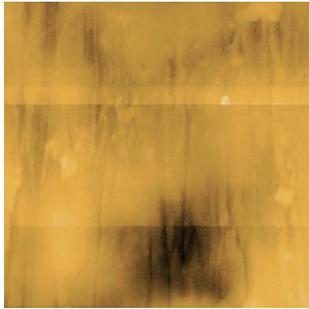
O1-5-6 (1  $\mu\text{m}$ )



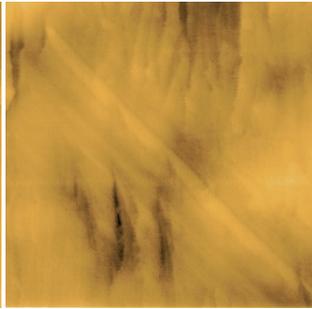
O1-5-7 (0.1  $\mu\text{m}$ )



O1-5-8 (60  $\mu\text{m}$ )



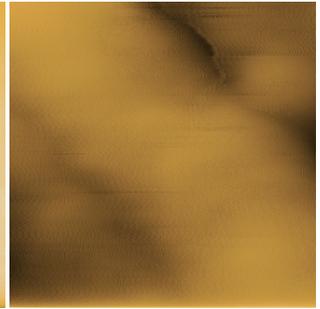
O1-5-9 (10  $\mu\text{m}$ )



O1-5-10 (10  $\mu\text{m}$ )



O1-5-11 (1  $\mu\text{m}$ )



O1-5-12 (1  $\mu\text{m}$ )



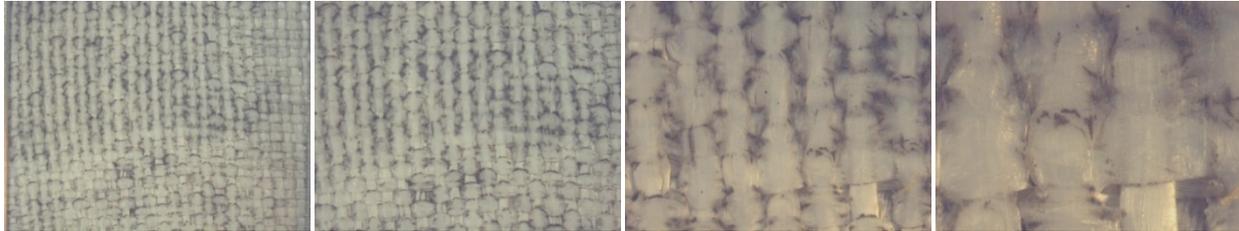
O1-5-13 (0.1  $\mu\text{m}$ )



## Appendix E.—Abraded Orthofabric

### E.1 OA1-1

#### E.1.1 Optical Microscopy



OA1-1 (7.1x)

OA1-1 (10x)

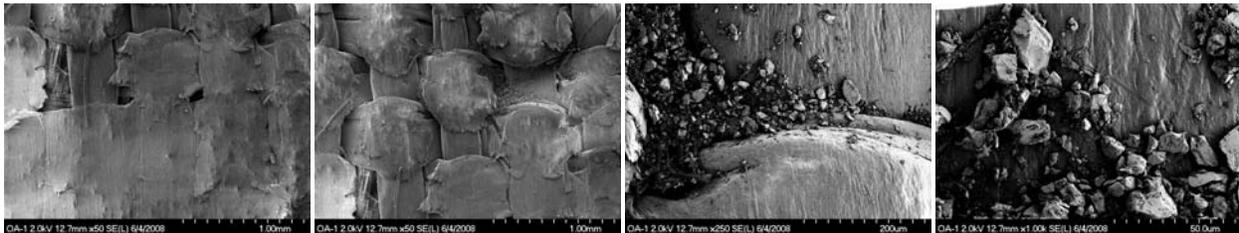
OA1-1 (25x)

OA1-1 (50x)



OA1-1 (100x)

#### E.1.2 Electron Microscopy

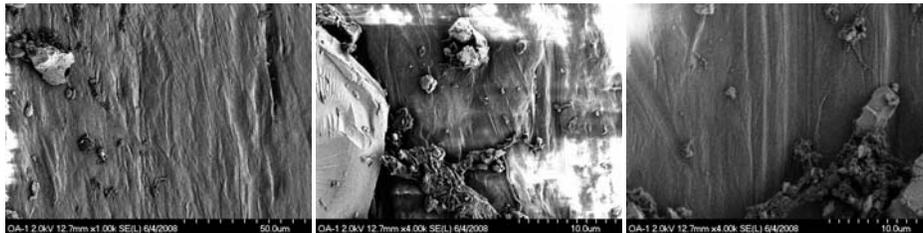


OA1-1 (50x)

OA1-1 (50x)

OA1-1 (250x)

OA1-1 (1000x)

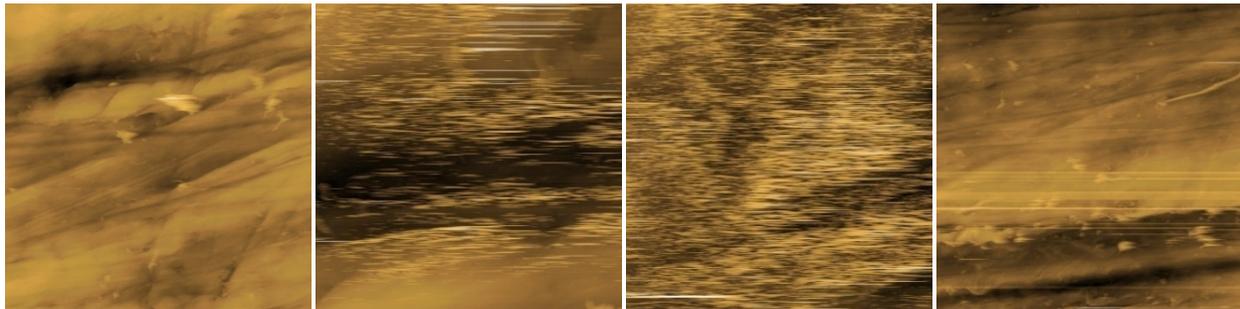


OA1-1 (1000x)

OA1-1 (4000x)

OA1-1 (4000x)

### E.1.3 Atomic Force Microscopy

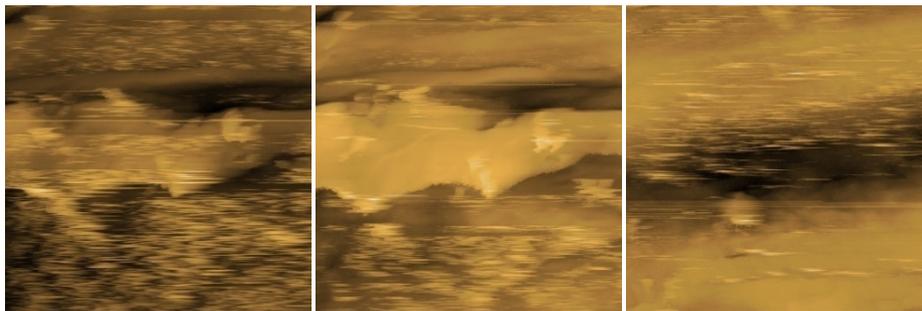


OA1-1-1 (60 μm)

OA1-1-2 (10 μm)

OA1-1-3 (10 μm)

OA1-1-4 (60 μm)



OA1-1-5 (10 μm)

OA1-1-6 (10 μm)

OA1-1-7 (10 μm)

OA1-1-8 (10 μm)



OA1-1-9 (1 μm)

OA1-1-10 (0.1 μm)

## E.2 OA1-2

### E.2.1 Optical Microscopy



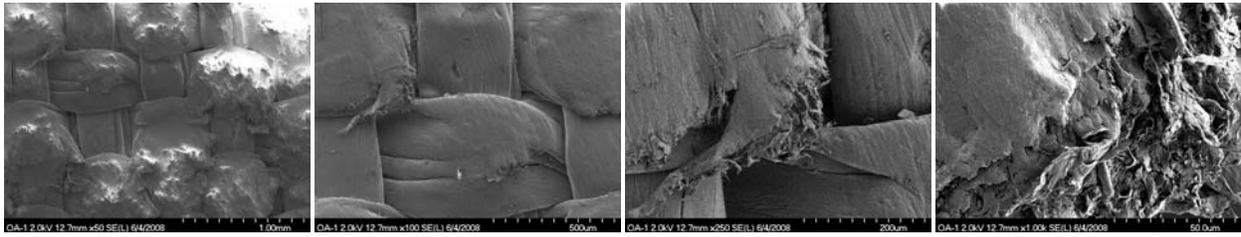
OA1-2 (10x)

OA1-2 (25x)

OA1-2 (50x)

OA1-2 (100x)

## E.2.2 Electron Microscopy

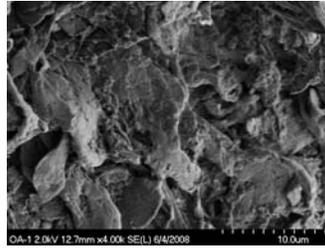


OA1-2 (50×)

OA1-2 (100×)

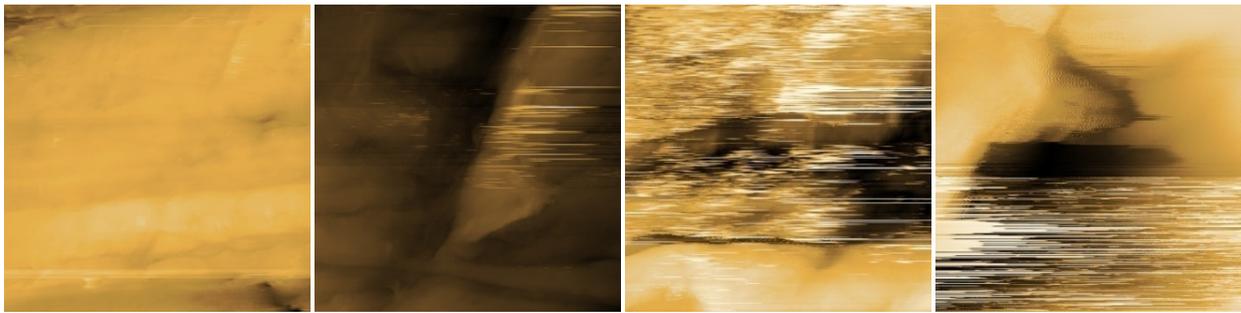
OA1-2 (250×)

OA1-2 (1000×)



OA1-2 (4000×)

## E.2.3 Atomic Force Microscopy



OA1-2-1 (60 µm)

OA1-2-2 (10 µm)

OA1-2-3 (10 µm)

OA1-2-4 (1 µm)

## E.3 OA1-3

### E.3.1 Optical Microscopy



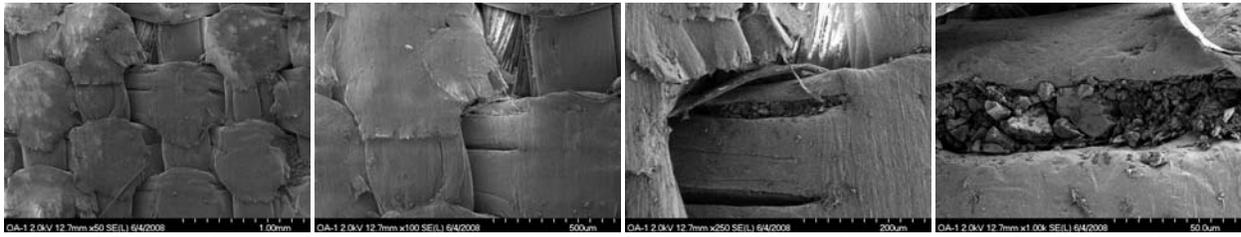
OA1-3 (10×)

OA1-3 (25×)

OA1-3 (50×)

OA1-3 (100×)

### E.3.2 Electron Microscopy

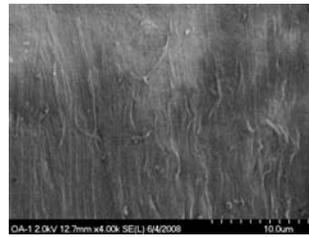


OA1-3 (50x)

OA1-3 (100x)

OA1-3 (250x)

OA1-3 (1000x)



OA1-3 (4000x)

### E.3.3 Atomic Force Microscopy



OA1-3-1 (60 µm)

OA1-3-2 (10 µm)

OA1-3-3 (1 µm)

## E.4 OA1-4

### E.4.1 Optical Microscopy



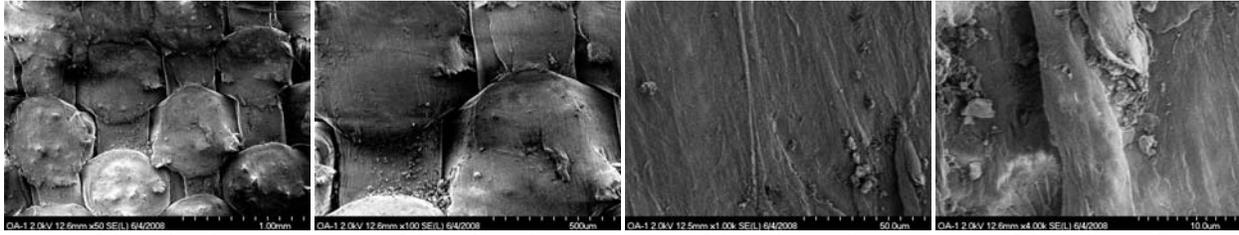
OA1-4 (10x)

OA1-4 (25x)

OA1-4 (50x)

OA1-4 (100x)

## E.4.2 Electron Microscopy



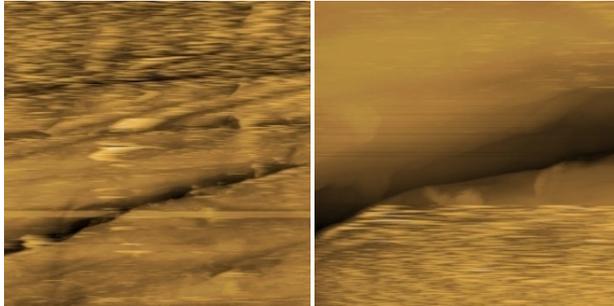
OA1-4 (50×)

OA1-4 (100×)

OA1-4 (1000×)

OA1-4 (4000×)

## E.4.3 Atomic Force Microscopy



OA1-4-1 (60 μm)

OA1-4-2 (10 μm)

OA1-4-3 (10 μm)

OA1-4-4 (1 μm)

## E.5 OA1-5

### E.5.1 Optical Microscopy



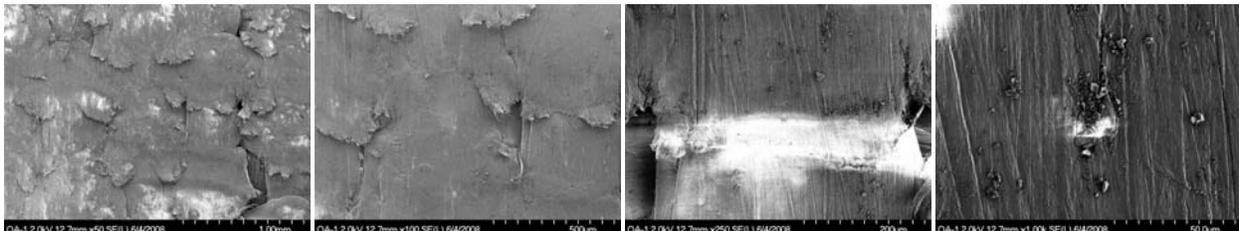
OA1-5 (10×)

OA1-5 (25×)

OA1-5 (50×)

OA1-5 (100×)

### E.5.2 Electron Microscopy

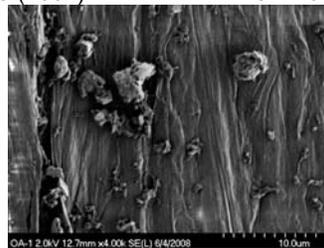


OA1-5 (50×)

OA1-5 (100×)

OA1-5 (250×)

OA1-5 (250×)



OA1-5 (4000×)

### E.5.3 Atomic Force Microscopy



OA1-5-1 (60  $\mu\text{m}$ )

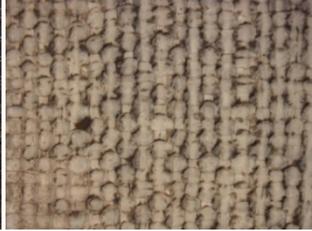
## Appendix F.—Doubly Abraded Orthofabric

### F.1 OAA1-1

#### F.1.1 Optical Microscopy



OAA1-1 (7.1x)



OAA1-1 (10x)



OAA1-1 (25x)

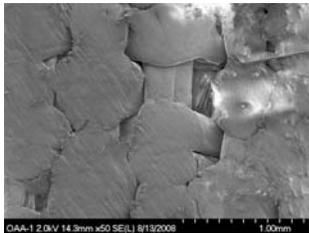


OAA1-1 (50x)

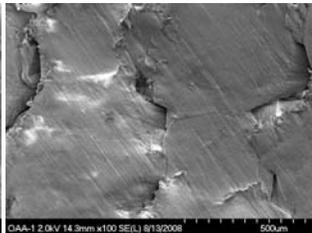


OAA1-1 (100x)

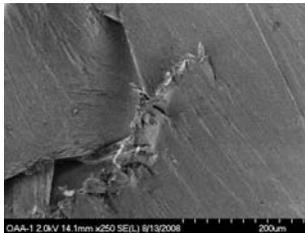
#### F.1.2 Electron Microscopy



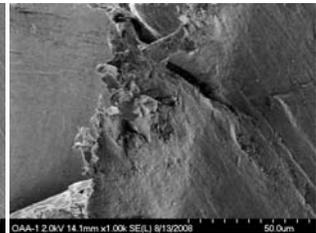
OAA1-1 (50x)



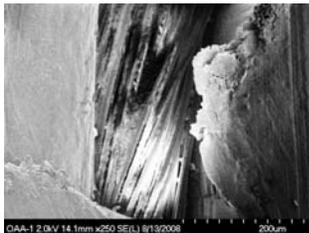
OAA1-1 (100x)



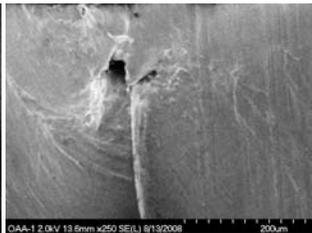
OAA1-1 (250x)



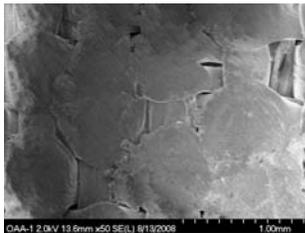
OAA1-1 (1000x)



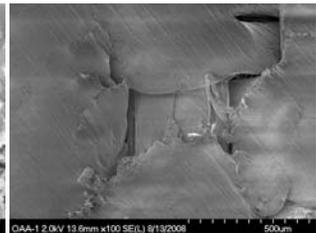
OAA1-1 (250x)



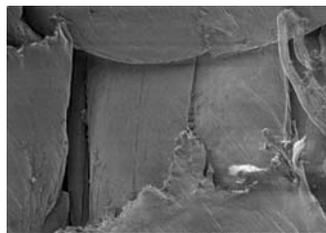
OAA1-1 (250x)



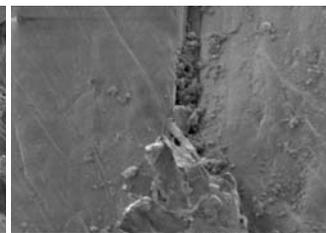
OAA1-1 (50x)



OAA1-1 (100x)

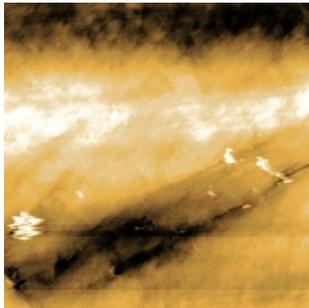


OAA1-1 (250x)



OAA1-1 (1000x)

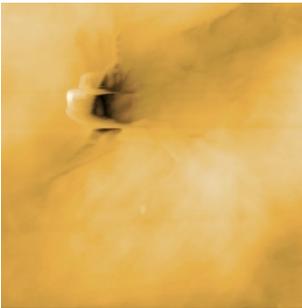
### F.1.3 Atomic Force Microscopy



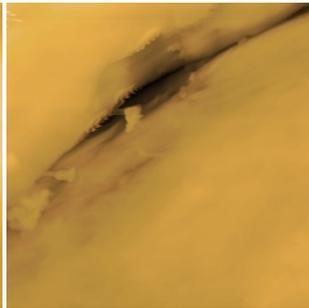
OAA1-1-1 (60  $\mu\text{m}$ )



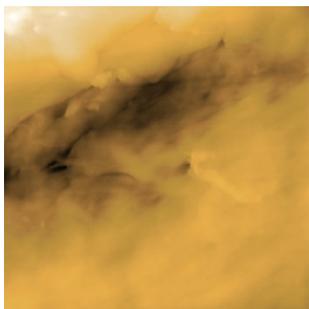
OAA1-1-2 (10  $\mu\text{m}$ )



OAA1-1-3 (10  $\mu\text{m}$ )



OAA1-1-4 (10  $\mu\text{m}$ )



OAA1-1-5 (10  $\mu\text{m}$ )



OAA1-1-6 (1  $\mu\text{m}$ )



OAA1-1-7 (1  $\mu\text{m}$ )



OAA1-1-8 (1  $\mu\text{m}$ )



OAA1-1-9 (1  $\mu\text{m}$ )



OAA1-1-10 (1  $\mu\text{m}$ )



OAA1-1-11 (1  $\mu\text{m}$ )



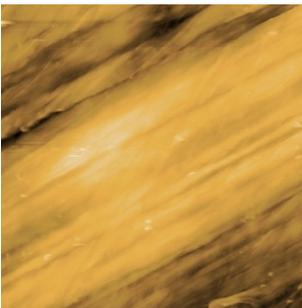
OAA1-1-12 (1  $\mu\text{m}$ )



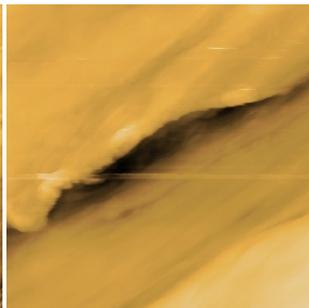
OAA1-1-13 (0.1  $\mu\text{m}$ )



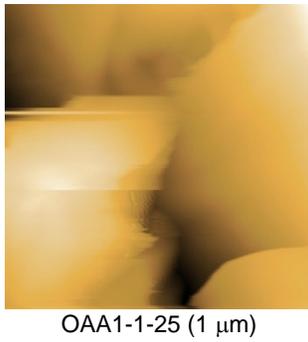
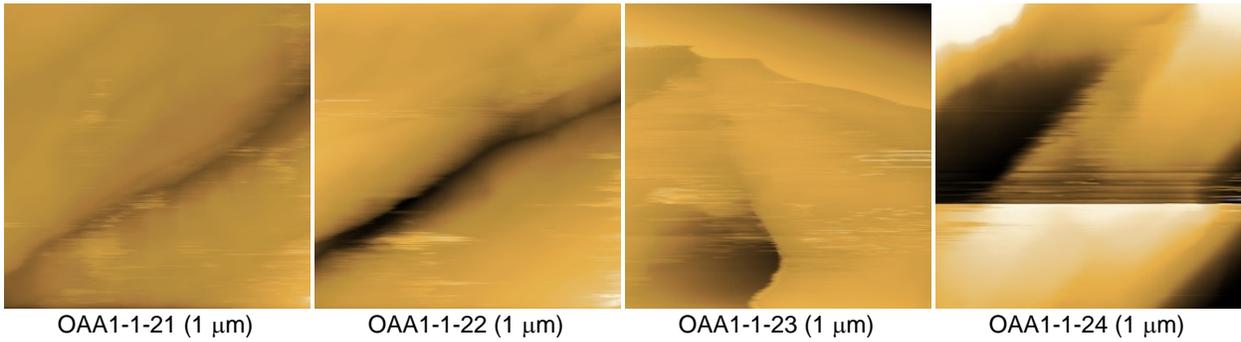
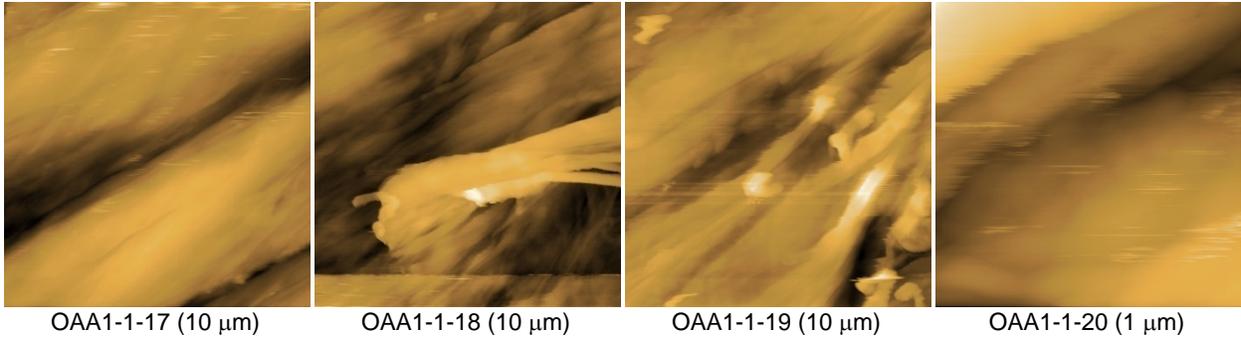
OAA1-1-14 (0.1  $\mu\text{m}$ )



OAA1-1-15 (60  $\mu\text{m}$ )

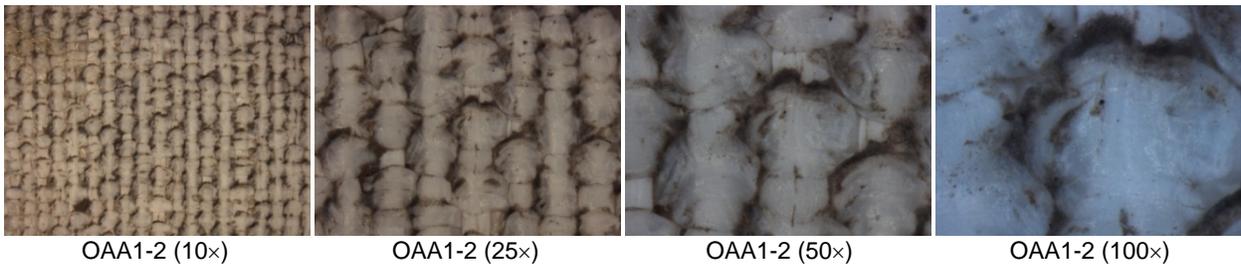


OAA1-1-16 (10  $\mu\text{m}$ )

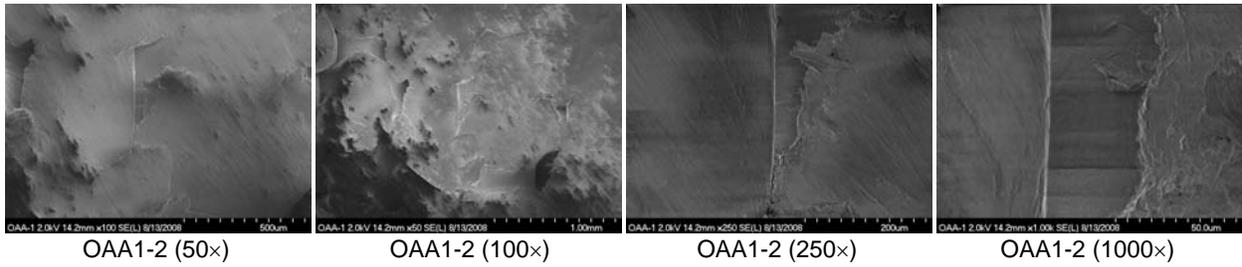
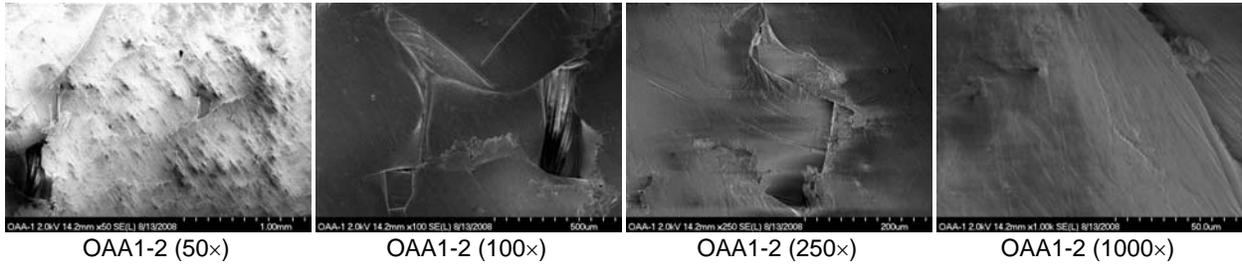


## F.2 OAA1-2

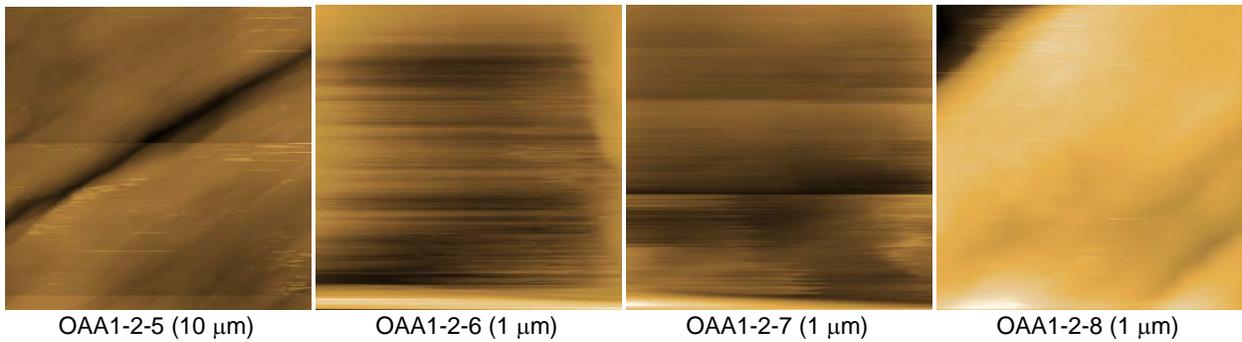
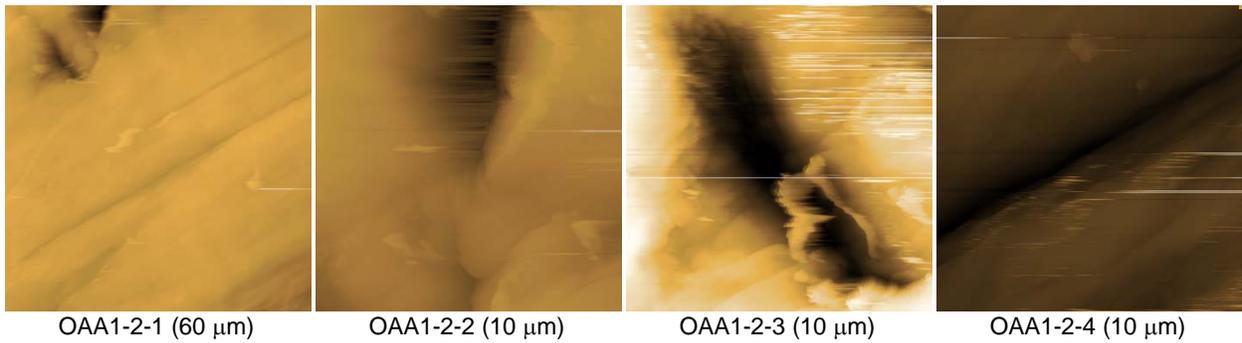
### F.2.1 Optical Microscopy

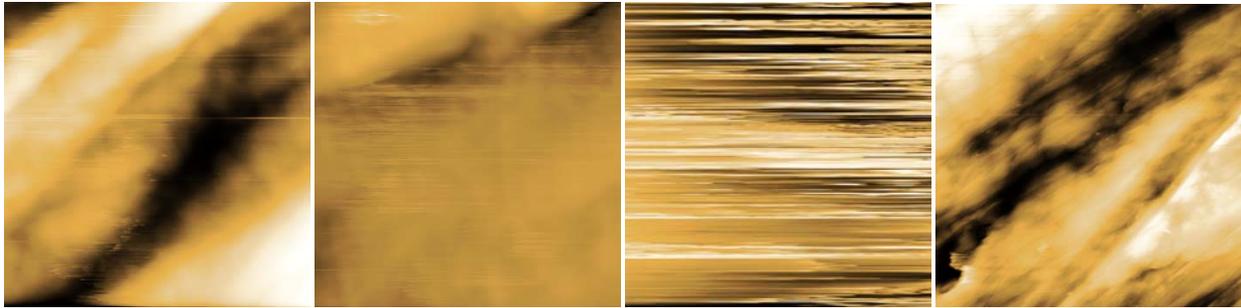


## F.2.2 Electron Microscopy



## F.2.3 Atomic Force Microscopy



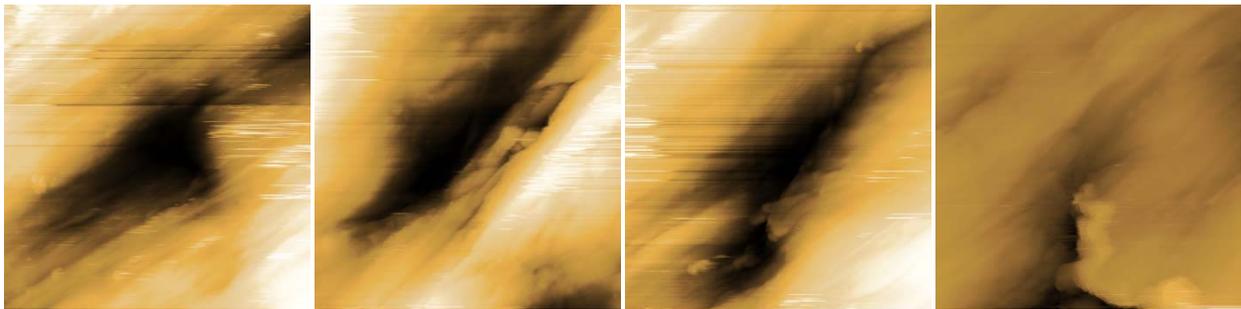


OAA1-2-9 (1  $\mu\text{m}$ )

OAA1-2-10 (1  $\mu\text{m}$ )

OAA1-2-11 (0.1  $\mu\text{m}$ )

OAA1-2-12 (60  $\mu\text{m}$ )

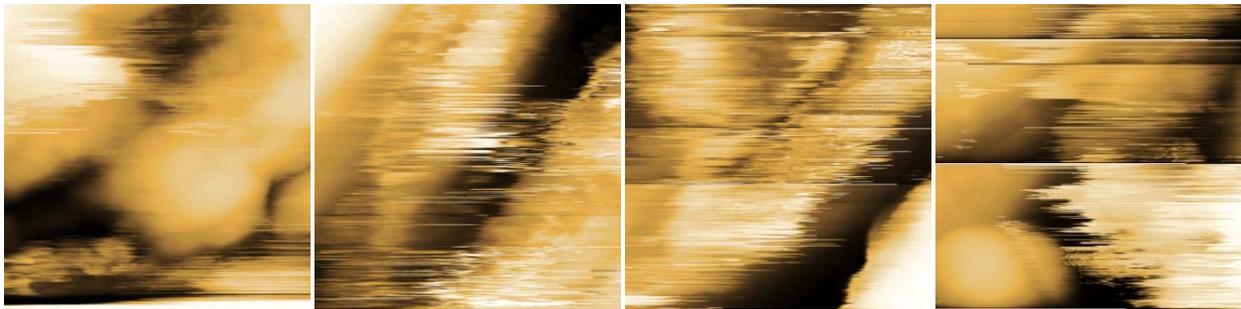


OAA1-2-13 (10  $\mu\text{m}$ )

OAA1-2-14 (10  $\mu\text{m}$ )

OAA1-2-15 (10  $\mu\text{m}$ )

OAA1-2-16 (10  $\mu\text{m}$ )

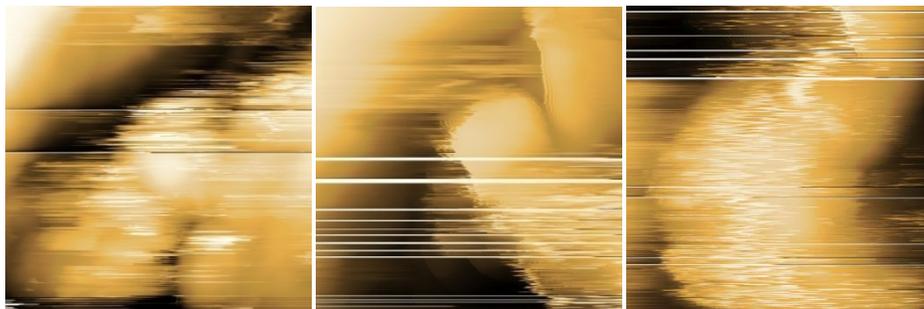


OAA1-2-17 (1  $\mu\text{m}$ )

OAA1-2-18 (1  $\mu\text{m}$ )

OAA1-2-19 (1  $\mu\text{m}$ )

OAA1-2-20 (1  $\mu\text{m}$ )



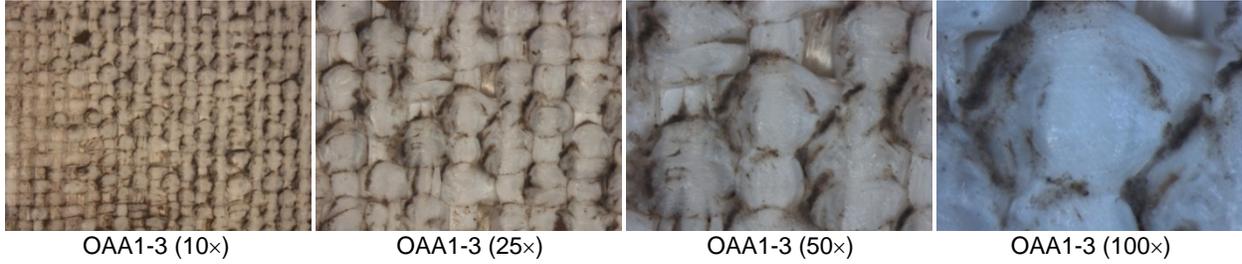
OAA1-2-21 (1  $\mu\text{m}$ )

OAA1-2-22 (1  $\mu\text{m}$ )

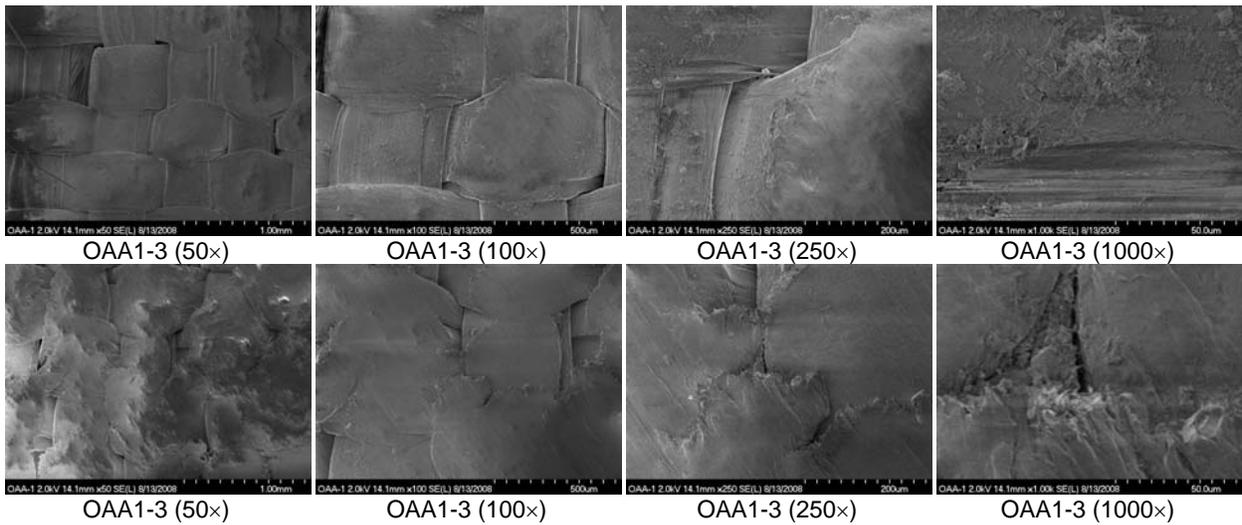
OAA1-2-23 (1  $\mu\text{m}$ )

### F.3 OAA1-3

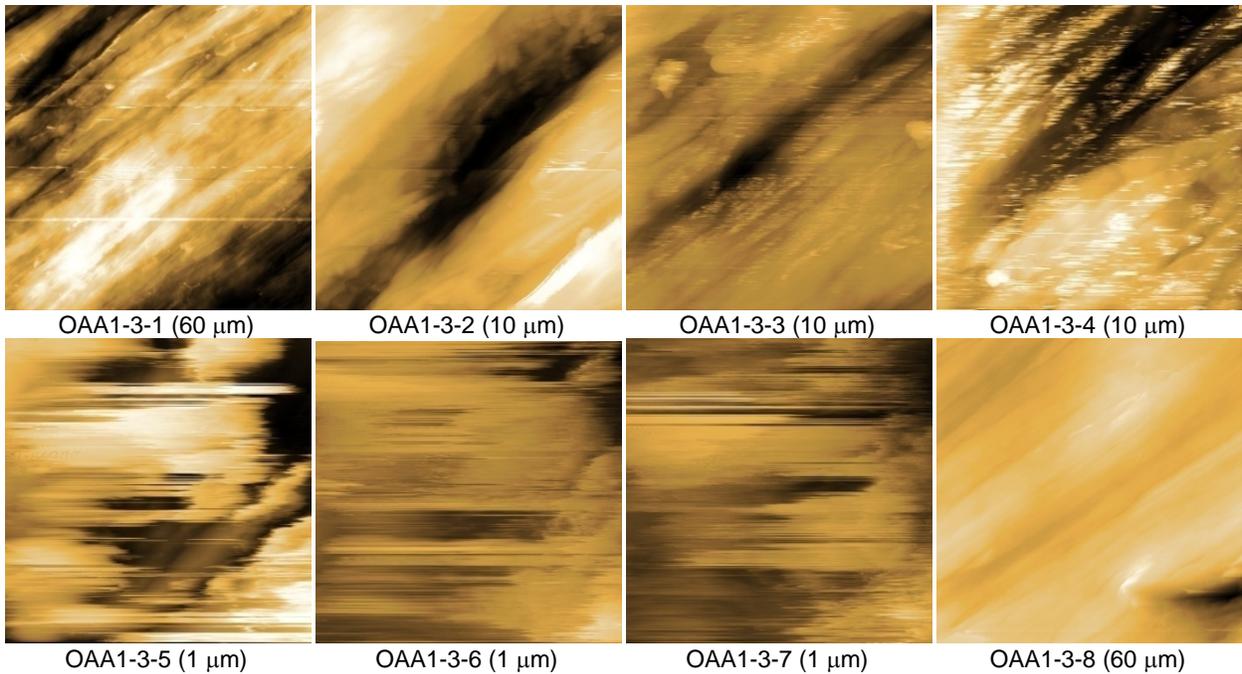
#### F.3.1 Optical Microscopy

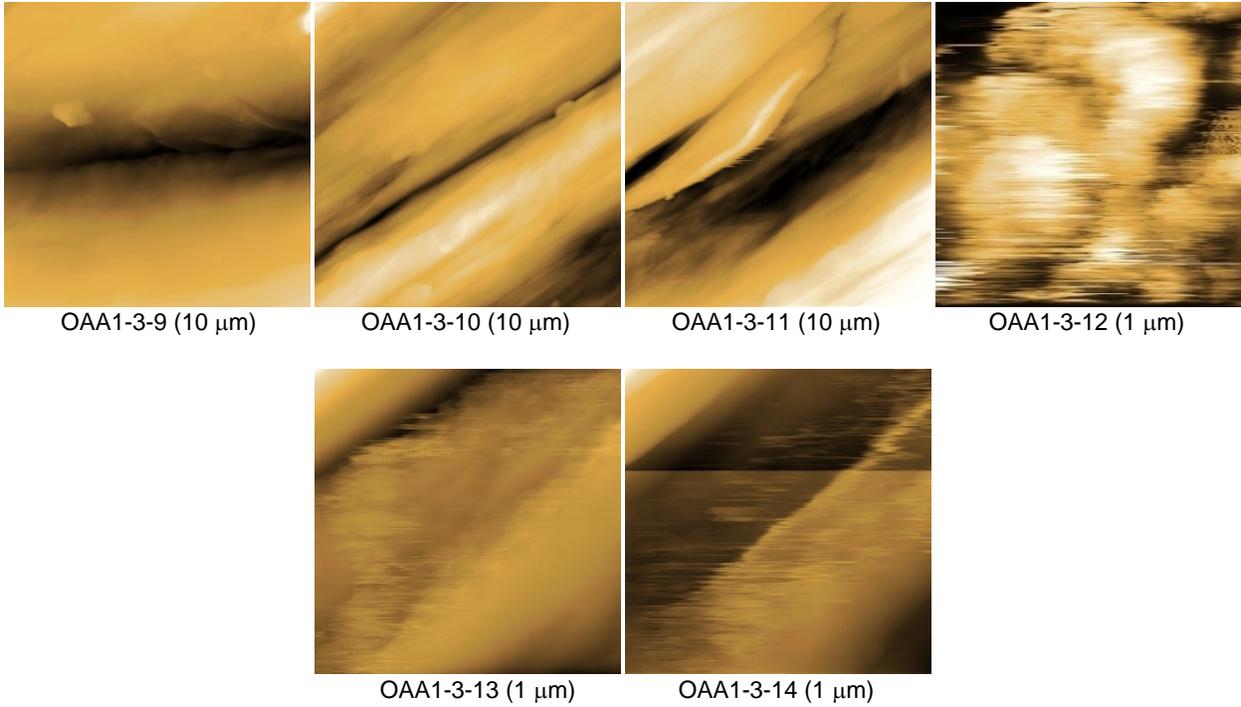


#### F.3.2 Electron Microscopy



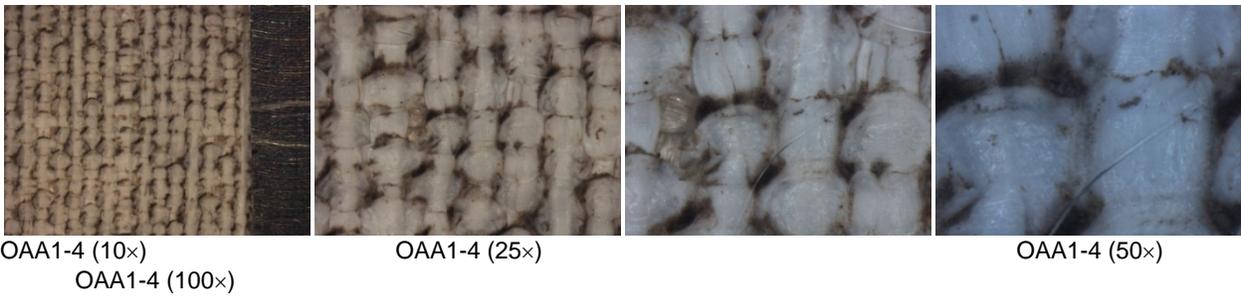
#### F.3.3 Atomic Force Microscopy



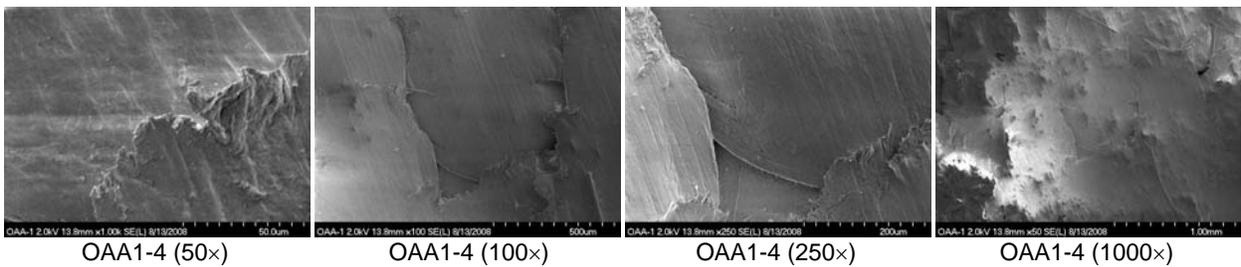


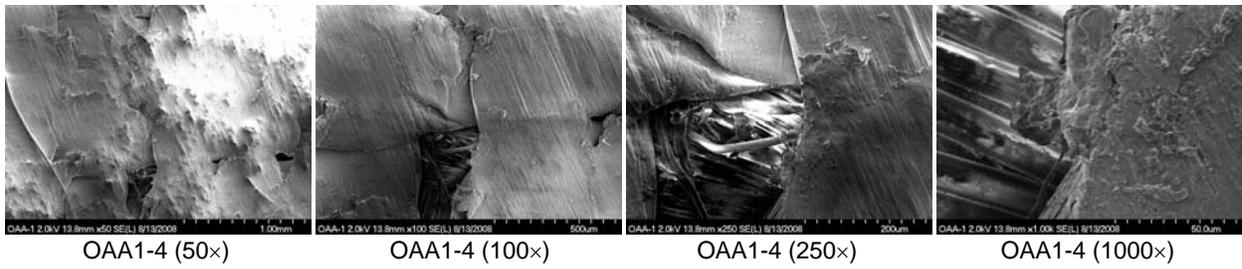
## F.4 OAA1-3

### F.4.1 Optical Microscopy

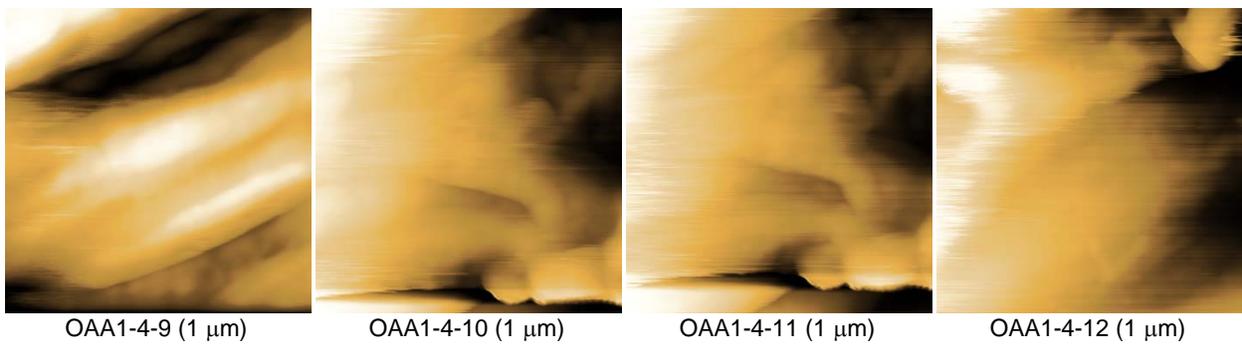
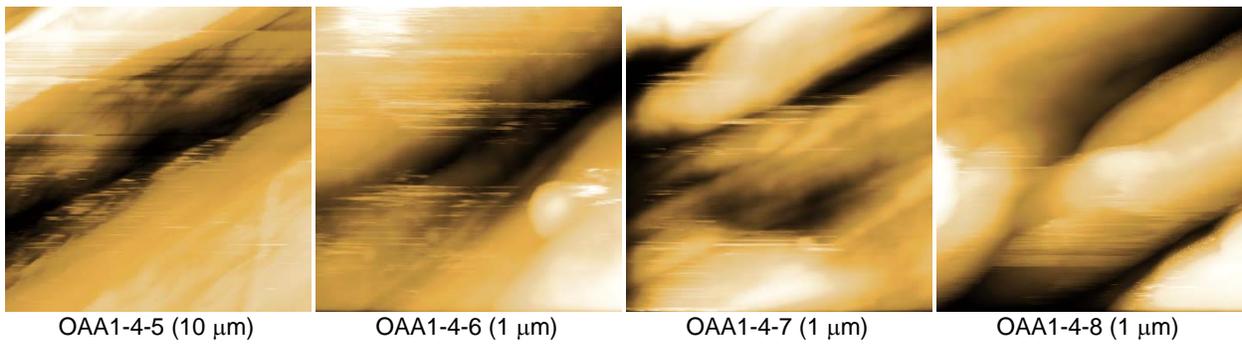
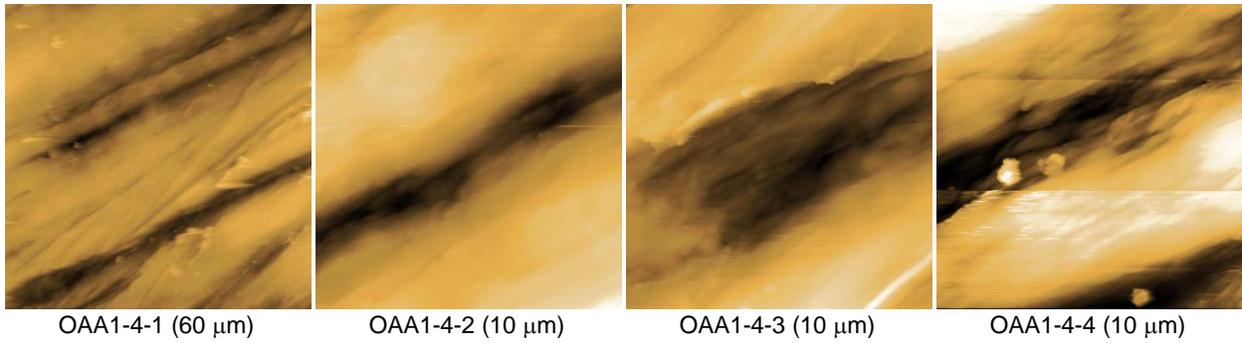


### F.4.2 Electron Microscopy



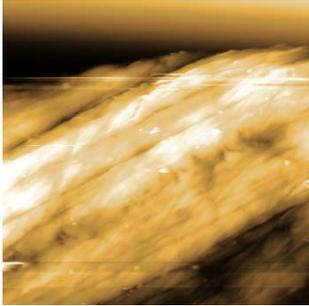


**F.4.3 Atomic Force Microscopy**

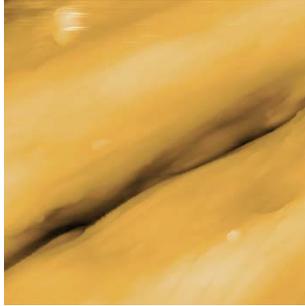




OAA1-4-13 (60 μm)



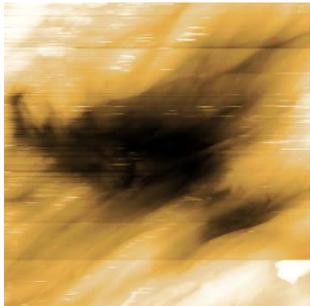
OAA1-4-14 (10 μm)



OAA1-4-15 (10 μm)



OAA1-4-16 (10 μm)



OAA1-4-17 (10 μm)



OAA1-4-18 (1 μm)



OAA1-4-19 (1 μm)



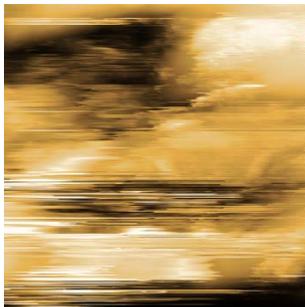
OAA1-4-20 (1 μm)



OAA1-4-21 (1 μm)



OAA1-4-22 (1 μm)



OAA1-4-23 (1 μm)



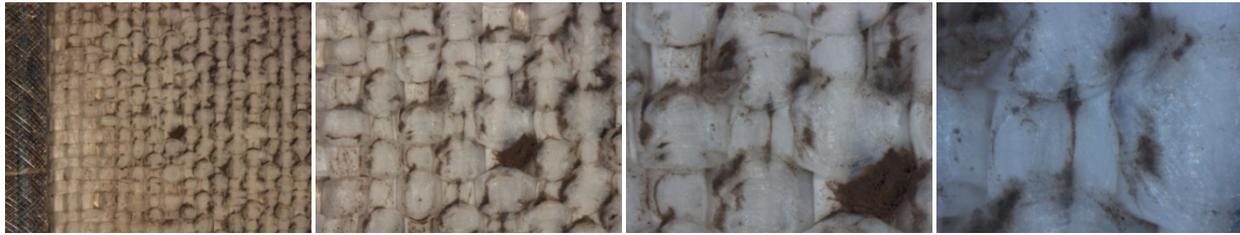
OAA1-4-24 (1 μm)



OAA1-4-25 (1 μm)

## F.5 OAA1-5

### F.5.1 Optical Microscopy



OAA1-5 (10×)

OAA1-5 (25×)

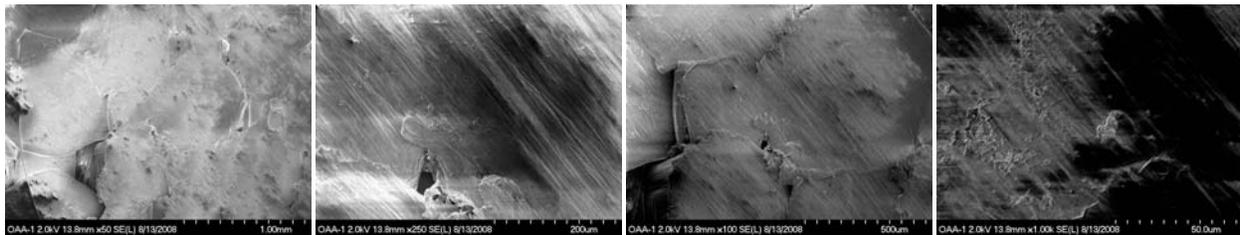
OAA1-5 (50×)

OAA1-5 (100×)



OAA1-5 (100×)

### F.5.2 Electron Microscopy

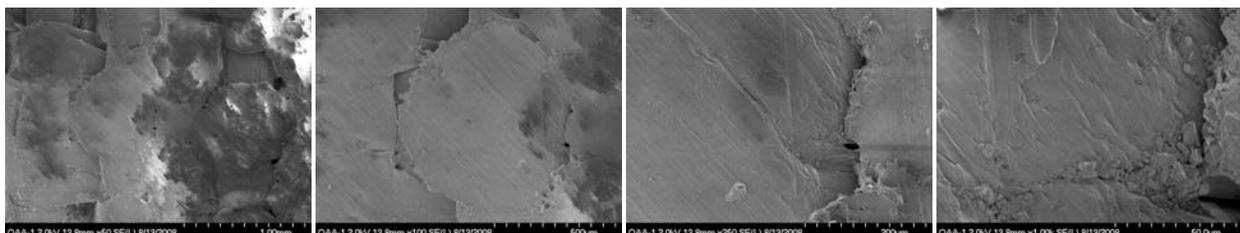


OAA1-5 (50×)

OAA1-5 (100×)

OAA1-5 (250×)

OAA1-5 (1000×)

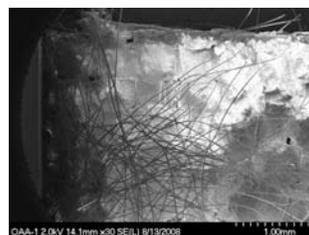


OAA1-5 (50×)

OAA1-5 (100×)

OAA1-5 (250×)

OAA1-5 (1000×)



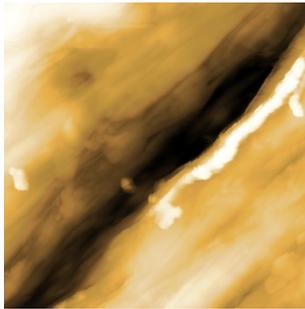
OAA1-5 (30×)

### F.5.3 Atomic Force Microscopy

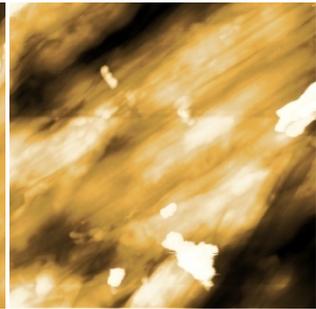


OAA1-5-1 (1  $\mu\text{m}$ )

OAA1-5-2 (60  $\mu\text{m}$ )



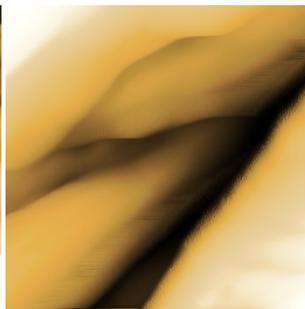
OAA1-5-3 (10  $\mu\text{m}$ )



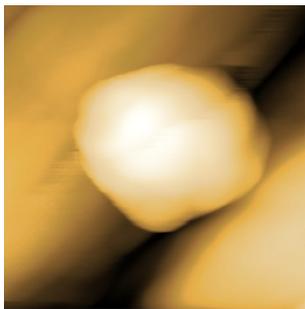
OAA1-5-4 (10  $\mu\text{m}$ )



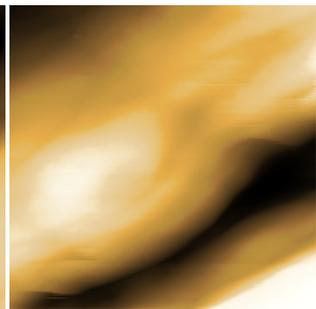
OAA1-5-5 (10  $\mu\text{m}$ )



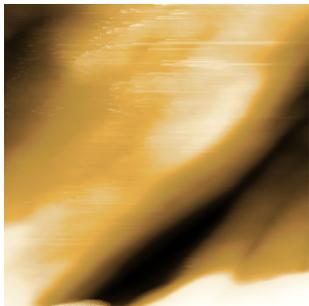
OAA1-5-6 (1  $\mu\text{m}$ )



OAA1-5-7 (1  $\mu\text{m}$ )



OAA1-5-8 (1  $\mu\text{m}$ )



OAA1-5-9 (1  $\mu\text{m}$ )



OAA1-5-10 (1  $\mu\text{m}$ )



OAA1-5-11 (1  $\mu\text{m}$ )



OAA1-5-12 (0.1  $\mu\text{m}$ )



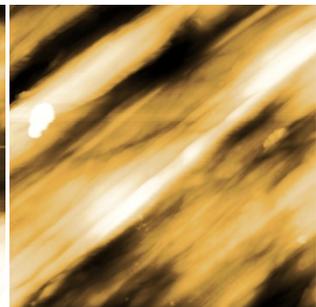
OAA1-5-13 (0.1  $\mu\text{m}$ )



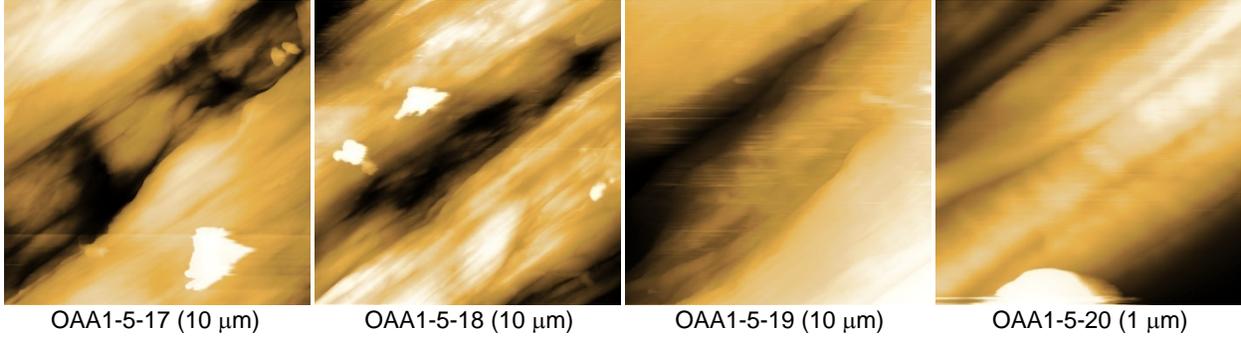
OAA1-5-14 (0.1  $\mu\text{m}$ )



OAA1-5-15 (60  $\mu\text{m}$ )



OAA1-5-16 (10  $\mu\text{m}$ )

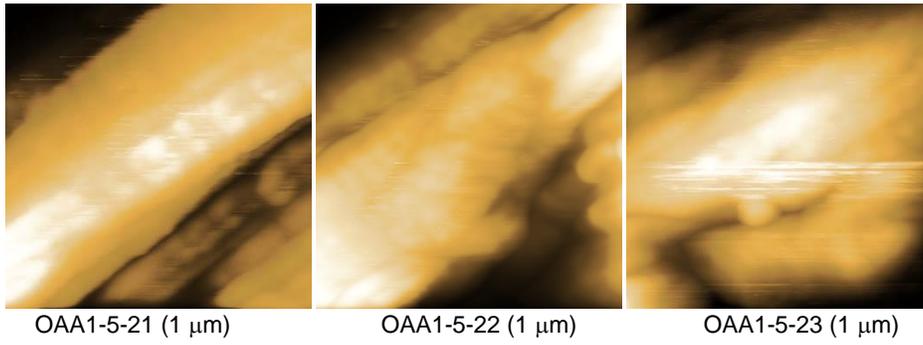


OAA1-5-17 (10 μm)

OAA1-5-18 (10 μm)

OAA1-5-19 (10 μm)

OAA1-5-20 (1 μm)



OAA1-5-21 (1 μm)

OAA1-5-22 (1 μm)

OAA1-5-23 (1 μm)

# Appendix G.—Experiment Traveler

## Spacesuit Fabrics Exposure Experiment

### Sample Integration Procedure & Traveler Document

October 2, 2008

#### Principal Investigator

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[Donald.A.Jaworske@nasa.gov](mailto:Donald.A.Jaworske@nasa.gov)

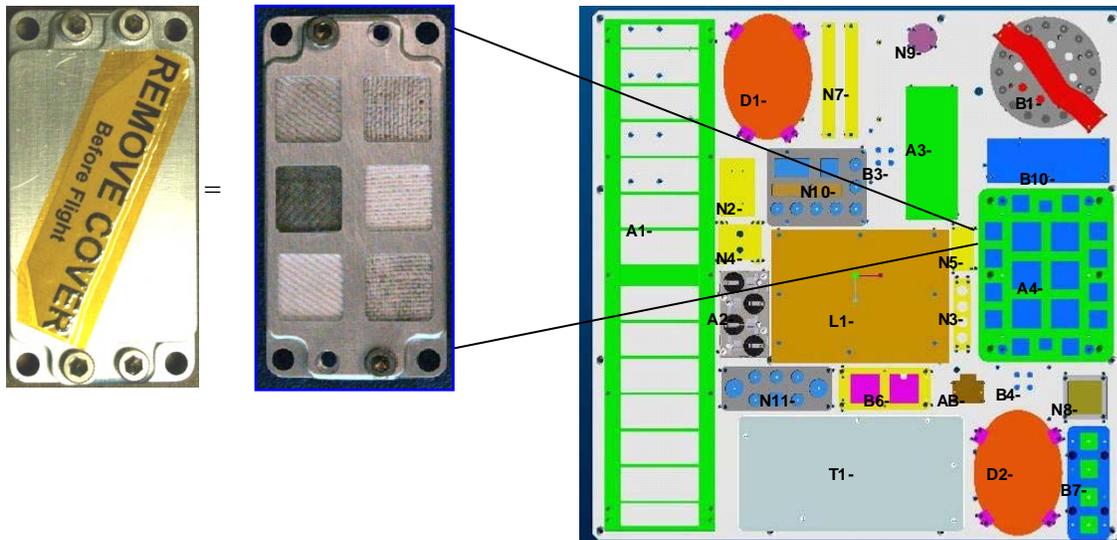
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#### Co-Principal Investigator

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The Spacesuit Fabrics Exposure Experiment is a passive experiment that consists of 6 – 1 cm square fabrics samples in an aluminum holder. The Spacesuit Fabrics Exposure Experiment should be attached to the wake facing tray of MISSE 7B in the area allotted for N5-W as below:



**Attach sample assembly N5-W to baseplate. Torque each 4-40 socket head cap screw fastener (NAS1352C04-10) holding sample assembly to baseplate to 4.0 in.-lb.**

**Critical:** The experiment has a protective cover (labeled as “**REMOVE COVER** Before Flight”). This protective cover **needs to be removed prior to the EMI , vibration, and thermal vacuum-bakeout tests** and should be kept off for **flight**.

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<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> A series of six sample spacesuit pressure garment assembly (PGA) fabric samples were prepared for the Materials International Space Station Experiment 7 (MISSE-7) flight experiment to test the effects of damage by lunar dust on the susceptibility of the fabrics to radiation damage. These included pristine Apollo-era fluorinated ethylene-propylene (FEP) fabric, Apollo-era FEP fabric that had been abraded with JSC-1A lunar simulant, and a piece of Alan Bean's Apollo 12 PGA sectioned from near the left knee. Also included was a sample of pristine orthofabric, and orthofabric that had been abraded to two different levels with JSC-1A. The samples were characterized using optical microscopy, field emission scanning electron microscopy, and atomic force microscopy. Two sets of six samples were then loaded in space environment exposure hardware, one of which was stored as control samples. The other set was affixed to the MISSE-7 experiment package, and will be mounted on the International Space Station, and exposed to the wake-side low Earth orbit environment. It will be retrieved after an exposure of approximately 12 months, and returned for post flight analysis.					
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