3 REMOTE SENSING AND SPECTROSCOPY

3.1 Introduction

Given the extensiveness of the fall deposits at Sunset Crater and the vegetation patterns within the depositional area, the use of satellite and airborne image data for reconnaissance mapping at Sunset Crater is time-efficient and cost-effective. Geomorphologic and structural relationships can be extended over large areas with minimal ground control, and the identification of lithologic and vegetation units can be extrapolated on the basis of spectral characteristics. Furthermore, this type of data can be used to evaluate uncertainties in published tephra deposit patterns and distribution characteristics. These tephra deposition analyses are in process and are not fully discussed in this report.

The complex relationship between tephra thickness, vegetation, elevation, lithology, and weathering in the Sunset Crater area can also be assessed using field and laboratory spectroscopy. Using a portable instrument, field spectroscopy includes studies of reflectance or radiance properties of vegetation, soils, rocks, and water bodies under solar illumination. Visible and near-infrared spectroscopy is a successful technique to characterize volcanic materials based on their physical properties.

The inherent characteristics of radar systems make them especially valuable for terrain analyses involving texture, shape, and topographic relief. Surface roughness has the most important influence on the radar return signal amplitude because it controls the extent of backscatter. Radar data are used to map surface morphology, while multispectral data are used to map compositional information. Mapping an area using multisensor data fusion encompasses the additional benefit of mixing a variety of remote sensing data types. Field spectral profiles, digital elevation models, band ratios of optical data, and texture measurements were used as a starting point for analyses of Sunset Crater data. Spectra for basaltic lava, primary tephra, eolian tephra, and vegetation are being interpreted for distinguishing features to be used for the identification of mixtures of each of these components or endmembers. Analyses of the spectra obtained from rock and vegetation samples are being compared to the hyperspectral remote sensing image to identify patterns, trends, and unique features in the Sunset Crater area. These analyses are not complete.

3.2 Geographic Information System Database

A project Geographic Information System[4] (GIS) database was constructed to aid field mapping and to avoid duplication of previous work. It also facilitated integration between field teams and the respective field activities. A brief description of critical products in the database follows.

- USGS digital raster graphic files are digital map products scanned from USGS topographic paper maps (USGS, 2001). The digital image is georeferenced to the true ground coordinates of the 2.5-minute grid ticks and projected to the Universal Transverse Mercator (UTM)[5] for projection consistency with USGS digital orthophoto

[4] Geographic Information System is used frequently in this document; therefore, the acronym GIS has been used.
[5] Universal Transverse Mercator is used frequently in this document; therefore, the acronym UTM has been used.

quadrangles and digital line graphs. Color values are also standard between digital raster graphic quadrangles. Each digital image is accompanied by a metadata file (Federal Geographic Data Committee, 1994).

- Digital Orthophoto Quarter Quadrangles are computer-generated images of aerial photographs in which the image displacement caused by terrain relief and camera tilt has been removed. USGS digital orthophoto quadrangles have 1-m [3.3-ft] ground resolution and combine the image characteristics of the original photograph with the georeferenced qualities of a map. These quadrangles are black and white, natural color, or color-infrared images.

- Digital Elevation Model data are raster products assembled by the USGS as part of the National Elevation Dataset. Fine resolution of 10 m [33 ft] is available for the 7.5-minute digital elevation models that encompass the study site. These grid data are spatially referenced.

- A previously published digital vegetation map of the Sunset Crater Volcano National Monument was included in the database. This vegetation mapping project around the volcano was initiated in the spring of 1999 as part of and in accordance with the U.S. Geological Survey-National Park Service (USGS-NPS) and was completed in the spring of 2004 (Hansen, et al., 2004). The final products include vegetation classification descriptions, a land-use classification system, a vegetation classification key, digital and hard copy vegetation maps, accuracy assessment results, and Federal Geographic Data Committee-compliant metadata.

- Optical satellite data from the Landsat Program and from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)[6] comprise a valuable component of the database. Landsat is a joint effort of the USGS and the National Aeronautics and Space Administration (NASA)[7] to gather Earth resource data using a series of satellites (USGS, 2003). The Thematic Mapper sensor has a spatial resolution of 120 m [394 ft] for the thermal-infrared band and 30 m [98 ft] for the six reflective bands. The newest satellite in the series, Landsat 7, carries the ETM+, with 30 m [98 ft] visible and infrared bands, a 60-m [197-ft] spatial resolution thermal band, and a 15-m [49-ft] panchromatic band. ASTER is a part of NASA's Earth Observing System and provides 14 spectral bands with 15- to 90-meter [49- to 295-ft] resolution depending on the band(s).

- Airborne imagery from the Airborne Synthetic Aperture Radar (AIRSAR)[8] instrument is another useful dataset. AIRSAR is a side-looking imaging radar that is able to collect polarimetric data irrespective of daylight or cloud cover. The instrument can be operated in many different modes due to the complexity and flexibility of the instrument. The

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[6] Advanced Spaceborne Thermal Emission and Reflection Radiometer is used frequently in this document; therefore, the acronym ASTER has been used.
[7] National Aeronautics and Space Administration is used frequently in this document; therefore, the acronym NASA has been used.
[8] Airborne Synthetic Aperture Radar is used frequently in this document; therefore, the acronym AIRSAR has been used.

length of the radar antenna determines the resolution in the azimuth (along-track) direction of the image: the longer the antenna, the finer the resolution in this dimension.

- Links to landuse/landcover data, soil maps, geologic data, and U.S. Forest Service map information are included. Upon availability from field and laboratory team members, links were also added for digital field photographs, geologic sample locations, and geologic and spectroscopic sample information or analyses.

3.3 Field Activities and Data Collection

Thematic maps of the field area were created and distributed to all team members. Shaded-relief images and georegistered Landsat and ASTER satellite images were used as a background (see Figures 2-1, 2-2, and 2-4). These maps had a variety of value-added information including points of known coordinates from previous field campaigns, preselected sampling sites and geologic targets, roads, and relevant cultural features. All maps were in the same coordinate system: UTM zone 12, North American Datum of 1983 (NAD83). Field positions were located using georeferenced imagery and a portable computer that was attached to a Global Positioning System instrument. This allowed field personnel to display in real time the current location in the field, find preselected sites of interest, and select new areas of investigation. The search and selection of candidate sites for spectroscopic measurements was a critical field activity. These training sites or type localities were valuable for (i) volcanologic and geomorphologic interpretation, (ii) understanding the modification of the tephra deposit, (iii) developing classification schemes, (iv) examining the relationship between vegetation and tephra cover, and (v) searching for candidate sites of tephra (ash) resuspension.

The Analytical Spectral Devices FieldSpec® 3 spectroradiometer was used to collect reflectance, radiance, and irradiance measurements. Light measurements require data collection in clear conditions or stable overcast conditions with a high solar angle (± 2 hours from noon). Cloudiness and variable weather conditions limited data collection. When optical data collection was not possible, the team performed extensive field reconnaissance and assembled geologic samples for later laboratory analysis.

During the 2005 and 2006 field campaigns data were collected at numerous observation points to document lithology, vegetation, and morphology for remote sensing and spectroscopic analyses. For spectroscopic analysis, a total of 91 geologic samples were collected containing representative volcanic (e.g., basaltic tephra and lava) and nonvolcanic (e.g., sandy carbonate and calcareous sandstone to shale) materials. These are summarized in Appendices E and F. The locations of these samples were used to create several layers in the project GIS database (Figure 3-1). This figure also includes several vegetation mapping locations by Hansen, et al. (2004).

The geologic samples were analyzed in the laboratory using the spectroradiometer and the Spectral Analysis and Management System Software. A library containing all Sunset Crater geologic samples collected in 2005 and 2006 was created.

Core Lab™ Petroleum Services conducted bulk and clay-fraction x-ray diffraction analyses on 16 samples collected in 2005, including

- Basaltic lava and sodium feldspar standards
- Primary, reworked, and eolian tephra from the Sunset Crater eruption
- Heavily oxidized and/or weathered Sunset Crater tephra
- Weathered basaltic lava from an eruption prior to Sunset Crater volcanism
- Sedimentary samples from the Kaibab and Moenkopi Formations
- Rhyodacite from the O'Leary Peak volcanic complex
- Fluvial sand from the Little Colorado River basin
- Alluvium from the Sunset Crater-Black Bottom Crater region
- Thinly bedded tuffaceous material (probably from a hydrovolcanic eruption east of Sunset Crater)

These analyses provided necessary information regarding mineralogical composition and spectroscopic response and/or patterns. They were valuable for geologic interpretation and identifying specific points of interest for subsequent field work in 2006.

3.4 Surface Lithology and Vegetation Classes

Optical satellite data, specifically ETM+ and ASTER, were effective in detecting areas of eolian tephra or eolian-reworked tephra from the Sunset Crater eruption. These are areas affected by eolian remobilization and were verified in numerous locations by field work. By utilizing the GIS database, an area of 17 km^2 [6.5 mi^2] was calculated to be covered by eolian-reworked Sunset tephra. Large eolian deposits could be relatively easily extracted during image processing; however, difficulties in misclassification occurred for areas affected by a mixed surface covering.

Polarimetric AIRSAR data were synthesized from the complex scattering matrix, filtered, slant-to-ground corrected, and coregistered to the optical datasets. Radar discrimination capabilities were used to provide preliminary characterization of tephra deposits. Each scatterer was accurately identified to a basic scattering mechanism using efficient polarimetric indicators. The results of this identification were used to map lava flows and supplement the overall classification of the study area. For example, sparsely vegetated patches of tephra have a smooth surface microtopography that reflects all the radar energy and no energy is returned to the antenna. A dark signature is produced in this scenario. This is in contrast to the rough, uneven surface of lava beds, which diffusely scatter all the radar energy, causing a relatively strong backscattered component. This produces a bright signature (Figure 3-2). Details in surface texture and morphology can be discerned in the lava flows from Sunset Crater. Therefore, AIRSAR proved to be a valuable tool for separating lava- versus tephra-covered areas. The separation of volcanic materials, however, is difficult in highly vegetated regions.

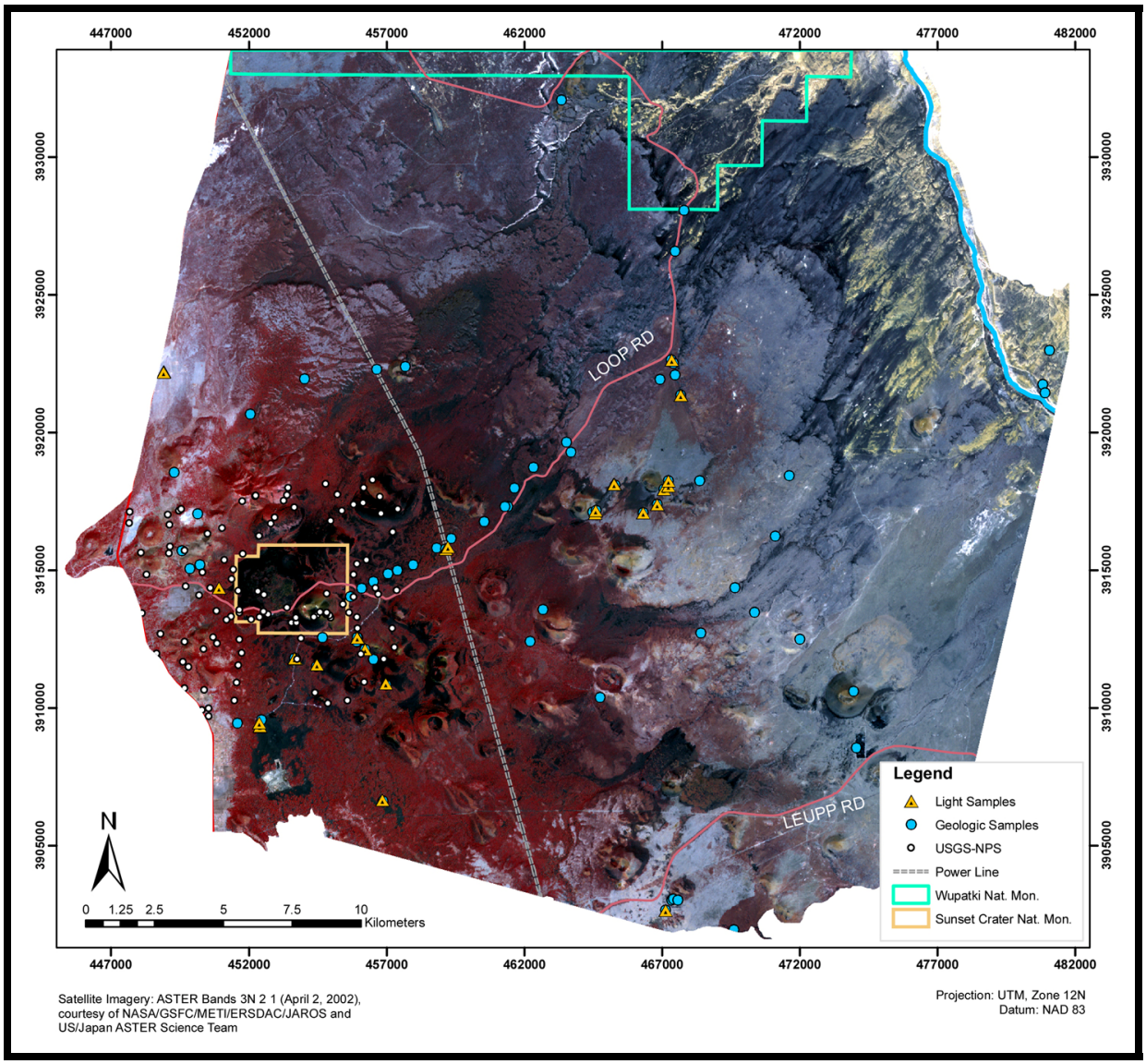

Figure 3-1. Data Collection Sites for Geologic and Optical Samples Overlain On An ASTER Image

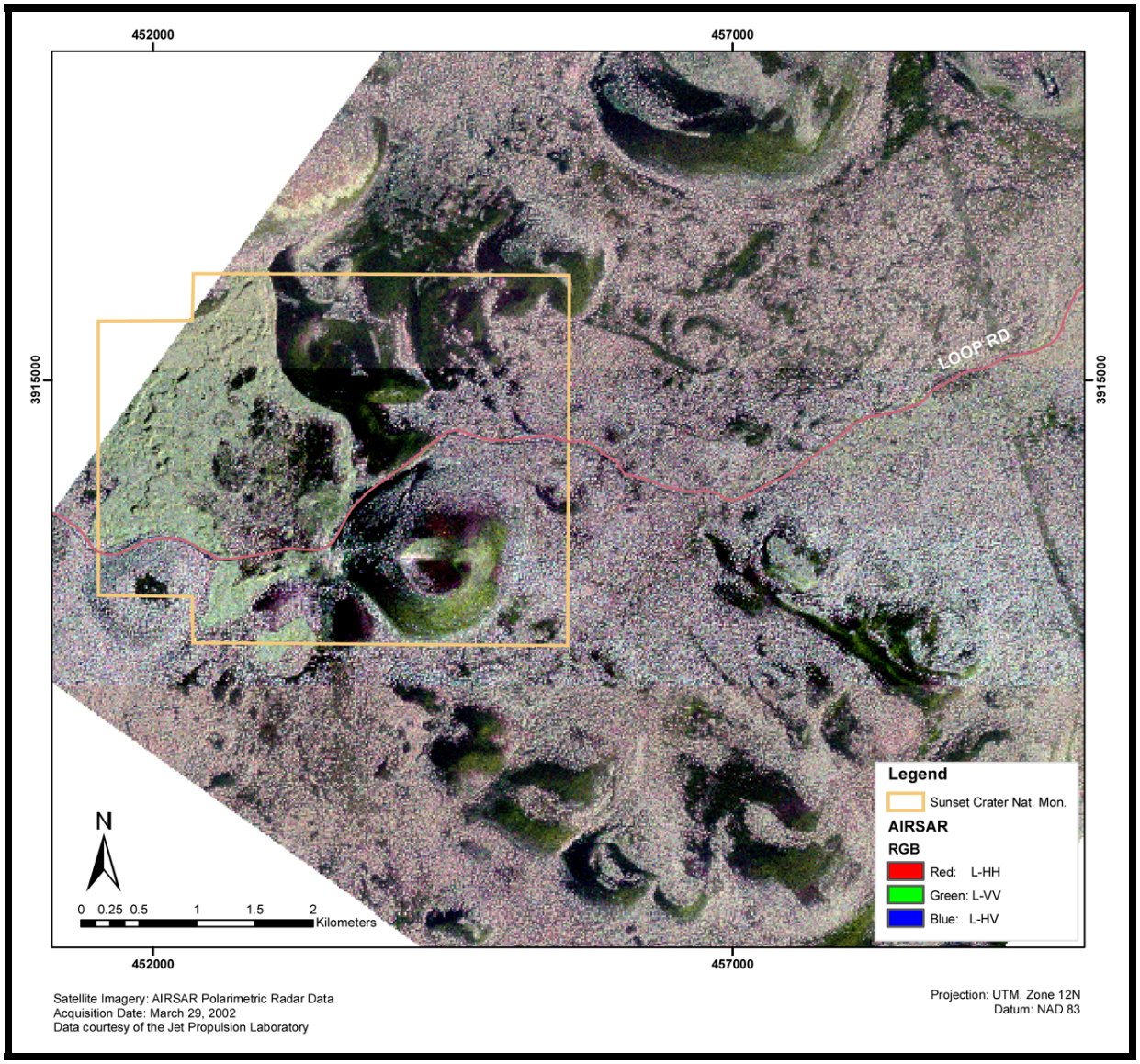

Figure 3-2. Subset of the AIRSAR Polarimetric Radar Data for Sunset Crater. The Extent of the Bonito Lava Flow (Center Left, Green) Is Clearly Separated From Tephra-Covered Regions (Black) and Vegetation (Pink, Orange).

Multisource and multisensor classification mapping is based on spectral properties and statistics of known parts (i.e., training sites). Because of the complex nature of 900 years of erosion and modification to the tephra deposit at the Sunset Crater analog site, it has been difficult to establish generic land cover classes that would aid in determining surface processes and erosion rates. The fusion of optical and radar data increases the likelihood of classifying

regions of complex lithology, vegetation, geomorphology, and soils. Based on these techniques and spectral interpretations, the following classes and endmembers describe the study area:

- Sparsely vegetated patches of black tephra (cinder)
- Lava beds (Bonito and Kana-a lava flows)
- Agglutinate (patches of welded volcanic material)
- Patches of eolian-reworked tephra
- Sedimentary formations (nonvolcanic rocks including the Kaibab and Moenkopi Formations)
- Urban and residential
- Industrial (including mining)
- Solid-waste disposal sites (e.g., municipal landfill)
- Ponderosa Pine woodland
- Ponderosa Pine/Apache Plume woodland
- Pinyon Pine/Utah Juniper woodland
- Mixed shrublands
- Grasslands

These classes and their mixed responses are displayed in the imagery. Figure 3-1 is an ASTER image of the study site and the backgrounds of Figures 2-1 and 2-2 are similar Landsat Thematic Mapper (ETM+) images. After band selection and color coding, regions of bare tephra or lava appear black. Deposits of tephra reworked by eolian processes, which appear as black wind streaks or patches, are easily identified in optical satellite data. Ponderosa Pine (Pinus ponderosa) woodlands (see Figure 1-1), which occur at higher elevations, appear green in the Landsat images and red in the ASTER image (Figure 3-1). Red to pink tints in the Landsat image are mostly associated with oxidized basalt having a high iron content. Light green to blue-gray tints are Pinyon Pine-Utah Juniper (Pinus edulis-Juniperus osteosperma) woodlands to grasslands (at lower elevations that are more arid in Arizona) (see Figures 2-5 and 2-6). These areas have a violet to red tint in the ASTER image. Bare limestone-dolostone (Kaibab Formation) and sandstone-shale (Moenkopi Formation) with eolian sand or disturbed and exposed land (e.g., borrow pits and the municipal landfill) appear yellow to white. The city of Flagstaff is in the southwest corner of the imagery.

3.5 Spectral Analyses

Spectral analysis can be used to separate primary tephra from eolian and oxidized tephra. The slope of the spectral curve provides a means to differentiate sedimentary rocks from volcanic

material with a basaltic composition (tephra and lava). The spectral curves presented in Figure 3-3 aid the overall classification process. Describing the intermixing of tephra with other lithologic and vegetation units is a major task of the spectroscopic and remote sensing work.

Quantitative and qualitative spectral analyses are being performed on tephra modified by eolian processes to investigate the effects of grain size, texture, shape, and weathering on spectral response. Reflectance spectra were collected from sieved samples. Principal component analysis (PCA) was applied to decompose data by finding maximum variances, so the complexity of tephra samples could be interpreted. Partial least squares (PLS) were used for developing a linear calibration model between grain size and spectral reflectance of the individual sieve fractions. This approach is being used to estimate grain-size distributions of other tephra samples collected from other locations in the study area. These analyses are in process and are not fully discussed in this report.

3.6 2006 Satellite Data Acquisition Campaign for ASTER

A key component of the remote sensing database is imagery from ASTER. This is an imaging instrument on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System. ASTER is a cooperative effort between NASA; Japan's Ministry of Economy, Trade and Industry; and Japan's Earth Remote Sensing Data Analysis Center. ASTER captures high spatial resolution data in 14 bands from the visible to the thermal infrared wavelengths. It is being used to obtain detailed maps of land surface temperature, reflectance, and elevation.

ASTER is an on-demand instrument, meaning that data are only acquired over a location if a request has been submitted to observe that area; however, previously acquired data can be ordered. Staff had previously proposed and were granted an ASTER data acquisition from NASA. Table 3-1 describes three overpasses requested by staff. Field work was planned in conjunction with the ASTER data acquisitions, and an intense field campaign was conducted with the intent of calibrating satellite data with field spectroscopic data. The spectral characteristics of ASTER data are valuable because the tandem day/night data set could provide improved understanding of the nature of lithologic units and geologic mapping of tephra deposits.

The final status of the ASTER data acquisitions has been unsuccessful (Table 3-1). The threshold for data acceptance is 10 percent or less for cloud coverage, but clouds affected the measurements for each overpass as observed by staff on the ground. The first data acquisition request [(DAR) 45492] was observed but not acquired. For DAR 45493, the instrument response in the short-wave infrared range was faulty, and the thermal infrared channels were strongly affected by clouds.

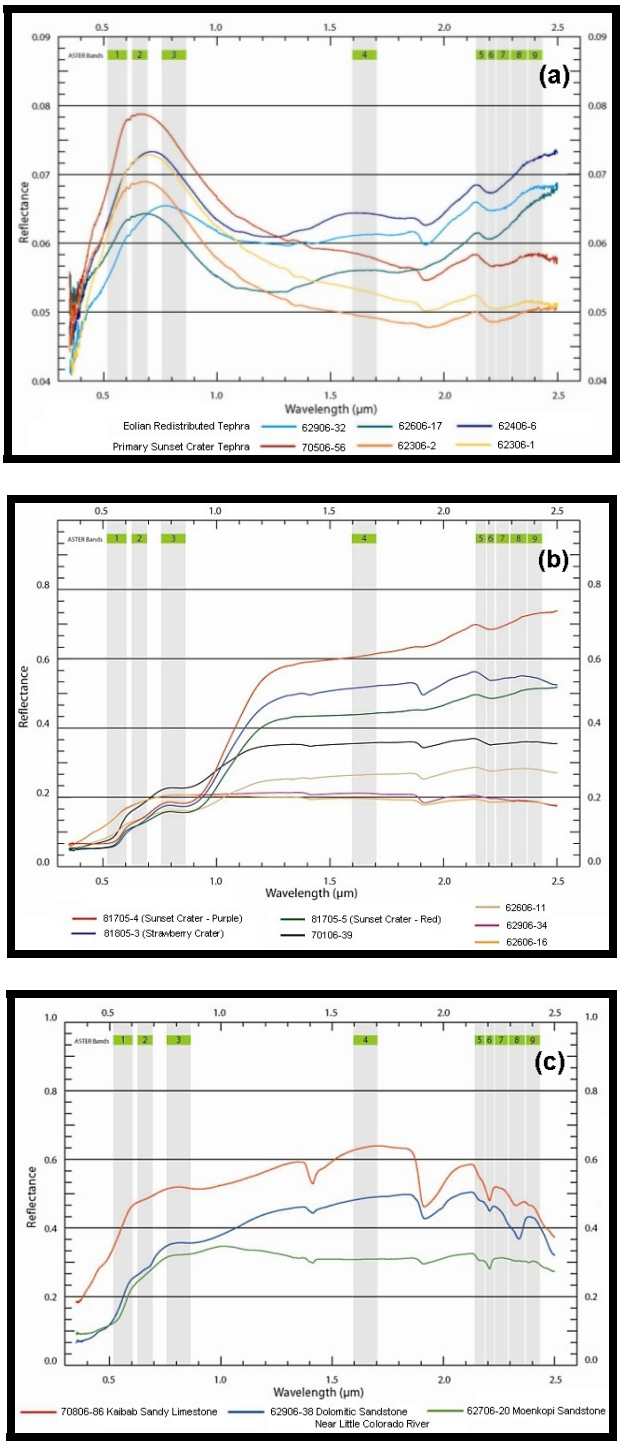

Figure 3-3. Spectral Response for (a) Primary Sunset Crater Tephra Versus Eolian Redistributed Tephra, (b) Oxidized Tephra, and (c) Sedimentary Rocks. ASTER Bands Are Shaded.

Table 3-1. Status and Characteristics of Requested ASTER* Satellite Data				
ASTER Data Acquisition Request (DAR) Number	**Date and Time**	**Flight Type**	**Mode**	**Acquisition**
45492	23 June 2006 18:19 GMT†	Day	Full Mode	Observed (Not Acquired)
45493	8 July 2006 05:34 GMT	Night	Short-Wave Infrared and Thermal Infrared	Completed (Failed Acceptance)
45496	9 July 2006 18:19 GMT	Day	Full Mode	Partially Failed

*Advanced Spaceborne Thermal Emission and Reflection Radiometer.
†Greenwich Mean Time.

A scene from DAR 45496 was acquired, but due to a slight delay in data acquisition, the target area was shifted. The captured scene covered less than one-third of the requested target area. The adjacent scene was added to the coverage after discussions with the Jet Propulsion Laboratory and the USGS. However, this adjacent scene was almost completely affected by clouds. After processing, it was found that 51 percent of the target (i.e., field) area was affected by clouds. Unfortunately, cloud cover affected most of the calibration sites for the field spectroradiometer and no further processing could be conducted. Figure 3-4 shows the cloud-covered ASTER scene (DAR 45496) and the cloud mask. Depending on the status of future observations, these data acquisition requests may be rescheduled for the dry season in 2007 or 2008.

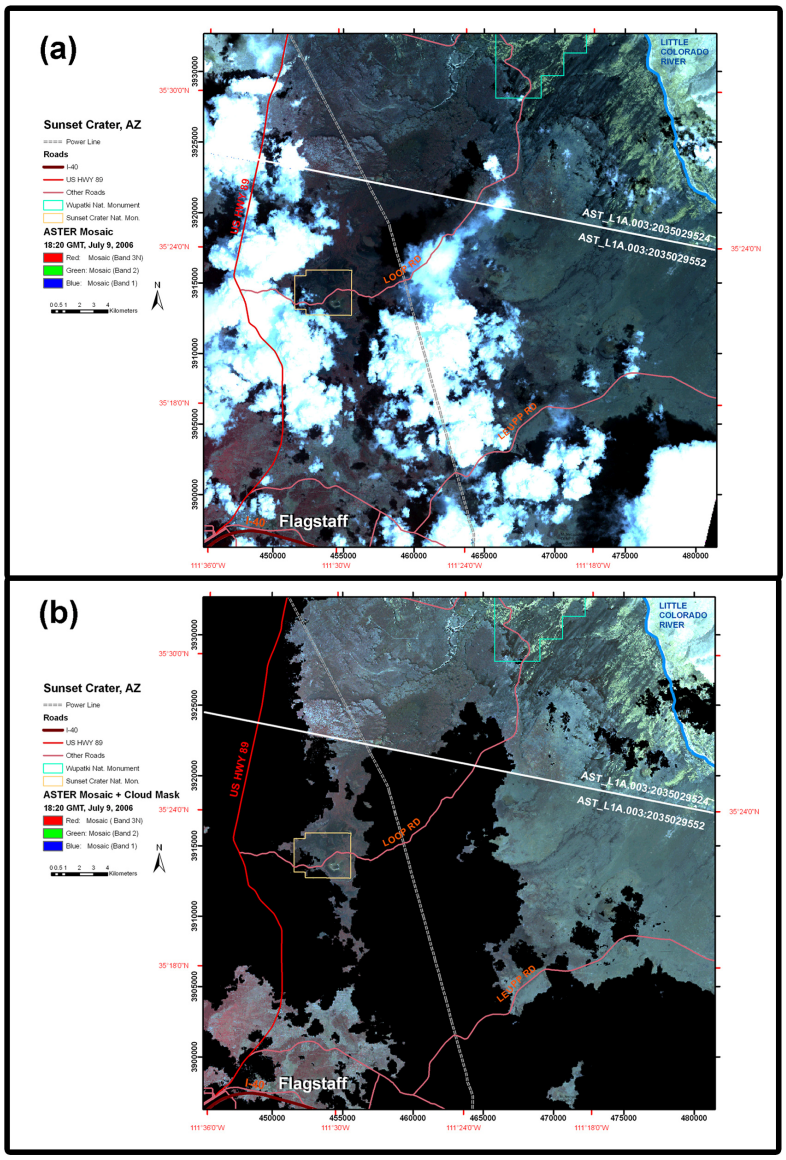

Figure 3-4. (a) Mosaic of the Two ASTER Scenes Acquired on July 9, 2006. DAR ID 45496 Is the Upper Portion of the Mosaic. (b) Same ASTER Mosaic With a Cloud Mask Applied. Processing by CNWRA Staff Determined That 51 Percent of the Study Area Is Covered by Clouds. ASTER Data Courtesy of NASA/GSFC/METI/ERSDAC/JAROS and US/Japan ASTER Science Team.

4 AIRBORNE PARTICLE CONCENTRATIONS

Wind and human activity can disturb fallen fine-grained volcanic deposits for months or years after an eruption, presenting a long-term health hazard. Airborne particle mass concentrations were measured using a personal sampler under a variety of surface-disturbing activities within different depositional environments at both volcanic and nonvolcanic sites near the Sunset Crater Volcano. Because the governing regulation of 10 CFR Part 63 specifies a postclosure individual protection standard for a reasonably maximally exposed individual, the field measurements focused exclusively on personal sampling of airborne particle concentrations. Airborne particle measurement results are not discussed at length in this status report, because they are the subject of a separate report.

4.1 Methods and Materials

Field sites were selected to be representative of two general material types (volcanic versus nonvolcanic) and three depositional environments (primarily non-reworked deposits, redistributed fluvial deposits, and redistributed eolian deposits). The surface material in the Sunset Crater region is largely volcanic in origin. However, the volcanic field sites specifically refer to regions covered by 900-year-old basaltic tephra from the Sunset Crater eruption. In addition, the designation of primarily non-reworked does not imply age or degree of weathering but rather that deposits are not in an active region of fluvial or eolian erosion and redistribution.

Separate airborne particle measurements were performed for three different levels of surface-disturbing activity. The three levels of surface-disturbing activity were

- Ambient measurements without human surface-disturbing activity
- Light disturbance measurements associated with walking or setting up equipment
- Heavy disturbance measurements associated with digging, hoeing, or collecting of surface samples

Based on combinations of ground surface material type, depositional environment, and surface-disturbing conditions, there are 18 classes of airborne particle concentration measurements (Table 4-1). Each airborne particle measurement corresponds to one of the 18 measurement classes. The locations of the measurement sites are displayed in Figure 4-1 and site descriptions are in Appendix G.

Ambient measurements used a tripod to position the personal sampler inlet at a height of 1.5 m [4.9 ft] above the ground surface. For the light and heavy disturbance measurements, the sampler was worn on an upper chest harness or on the waist by the individual performing the surface-disturbing activity. As time permitted, multiple measurements at the same site were performed on different days to provide information about variability in the field. Surface samples also were collected at each site to a depth of approximately 1 cm [0.4 in] using an inscribed template and flat trowel. Surface samples were sieved in the laboratory to yield grain-size distributions for comparison to the total and particle-size-dependent airborne particle concentrations.

Table 4-1. Measurement Classes for Airborne Particle Concentrations						
	Ground Surface Material Type and Depositional Environment					
Surface Disturbance Level	Volcanic			Nonvolcanic		
	Primarily Non-Reworked	Fluvial Redistributed	Eolian Redistributed	Primarily Non-Reworked	Fluvial Redistributed	Eolian Redistributed
Ambient	1	4	7	10	13	16
Light	2	5	8	11	14	17
Heavy	3	6	9	12	15	18

Airborne particle measurements were made with a personal airborne particle sampler and portable air pump. A single type of particle sampler (RESPICON™ Particle Sampler, Model 8522, TSI Incorporated) was used with one of two types of pumps (Model Air Pro 6000D Listed 87Y4, Bios International Corporation; Model Libra Plus LP-7, A.P. Buck Inc., only used for long sampling times for some of the ambient measurements). Figure 4-2 illustrates the particle sampler being worn during a heavy surface-disturbing activity. RESPICON™ particle samplers measure total suspended particle concentration as well as provide information on airborne particle size. They are a multistage virtual impactor, where sampled particles are separated by size with diverted air flows within the device and preferentially collected on one of three filters according to their aerodynamic diameter. Partitioning of air flow and deposition within the device stages was designed to mimic deposition in different regions of the human respiratory tract, and 50-percent cut sizes are used to characterize the sampled particle size ranges associated with each filter (TSI Incorporated, 2006). Each sampler measurement resulted in separate measurements for particles with aerodynamic diameters less than 4 μm [1.6×10^{-4} in], between 4 and 10 μm [between 1.6×10^{-4} and 3.9×10^{-4} in], and greater than 10 μm [3.9×10^{-4} in]. The total airborne particle concentration was determined by summing the particle mass collected on all three filters. Pre- and postsampling filter weights, sampling times, and air pump flow rates were used to calculate the airborne particle mass concentration.

Wind speed and other meteorological measurements were not acquired at the field sites. Meteorological data are publicly available and are recorded at the Flagstaff Pulliam Airport by the National Weather Service (U.S. Department of Commerce, National Oceanic and Atmospheric Administration).

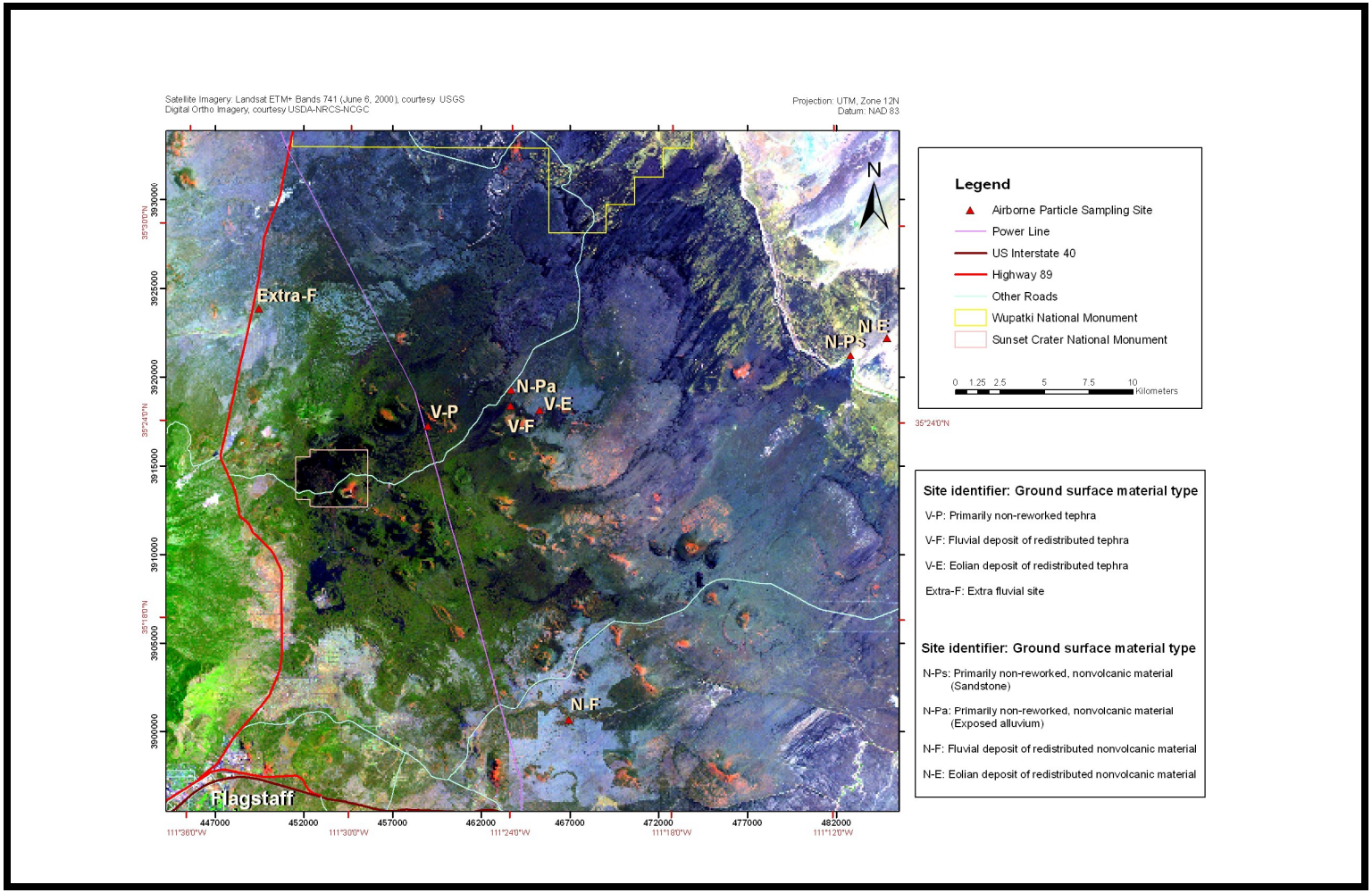

Figure 4-1. Airborne Particle Sampling Sites

Figure 4-2. Heavy Disturbance Activity on Fluvial Deposits of Redistributed Tephra. The Field Investigator Is Wearing the Model 8522 RESPICON™ Particle Sampler by TSI Incorporated.

5 SUMMARY

Field investigations at Sunset Crater volcano offer the opportunity to study a 900-year-old tephra deposit in a semiarid climate as a Yucca Mountain analog for both volcanic processes and posteruption surface processes. Field activities have focused on three related tasks: (i) geology, (ii) remote sensing and spectroscopy, and (iii) airborne particle concentrations.

The pyroclastic sheet from the Sunset Crater eruption is a widespread covering of fresh black and subordinate red tephra. Pyroclasts are typically vitreous and highly vesicular. Fallout units are unconsolidated and well sorted. Common grain sizes range from coarse scoriaceous ash to lapilli, or a grain-size range that is typical of Strombolian eruptions. Tephra dispersal can be divided into a continuous and discontinuous deposit (Amos, 1986; Colton, 1967, 1932). The continuous fall deposit mantles the preexisting landscape—even after 900 years of erosion—and extends in an east to northeasterly direction for approximately 10 km [6.2 mi] along the main axis of deposition. The area of the continuous deposit is approximately 260 km^2 [100 mi^2]. The discontinuous deposit extends to approximately a distance of 20 km [12.4 mi] to the east and northeast along the main axis of deposition. Throughout the distal regions of the deposit and in some instances beyond 20 km [12.4 mi] from the scoria cone, tephra may be present as black patches of sand-size particles reworked by eolian processes. Amos (1986) estimated a total volume of 0.75 km^3 [0.18 mi^3] {dense rock equivalent volume of 0.41 km^3 [0.10 mi^3]} from the Sunset Crater eruption. The amount of tephra present today is only a record of the minimum thickness at the time of the eruption. The presence of thick {e.g., > 1 m [3.3 ft]} tephra deposits in the proximal zone and discontinuous and/or redistributed eolian tephra deposits 20 km [12.4 mi] from the volcano indicates that substantial amounts of tephra can persist for 1,000 years in a semiarid environment.

Survey pits were dug for exploratory purposes, to measure the thickness of tephra or other geologic materials, and/or to examine the changing vertical section within the stratigraphic sequence. The Sunset Crater scoria-fall deposit has a topmost layer of bioturbated, disturbed tephra mixed with eolian fines (or potentially colluvium). This horizon is a surficial layer of scoria (cinder) with mixed sandy particles ranging between 8 to 15 cm [3.2 to 5.9 in] in thickness as measured in numerous tephra or survey pits. Granulometric analyses are being used to examine eruption characteristics and surface processes across the Sunset Crater tephra deposit. Measurements pertaining to alluvial, fluvial, and eolian deposits are being utilized to assess tephra redistribution and remobilization.

Satellite and airborne image data have served as base maps, helped identify lithologic and vegetation units, and aided the recognition of geologic characteristics, trends, and patterns. A project GIS database was constructed to store information, to perform image classification, and to aid field mapping. Mapping an area using multisensor data fusion has the benefit of mixing a variety of remote sensing data types. Optical satellite data, specifically Landsat Thematic Mapper (ETM+) and ASTER, were effective in detecting areas of eolian tephra or eolian-reworked tephra from the Sunset Crater eruption. Radar data were effective for separating lava- versus tephra-covered areas. Both geological field investigations and remote sensing studies in the area affected by the Sunset Crater eruption have revealed a complex relationship between tephra thickness, elevation, vegetation, lithology, and weathering. Field spectral profiles, digital elevation models, band ratios of optical data, and texture measurements were used as a starting point for analyses. Spectra for basaltic lava, primary tephra, eolian

tephra, and vegetation are being interpreted for distinguishing features to be used for the identification of mixtures of each of these components or endmembers. Describing the intermixing of tephra with other lithologic and vegetation units is a major task of the spectroscopic and remote sensing work.

Staff conducted field work over a range of different ground surface material types and surface-disturbing conditions to quantify the magnitude of airborne particle concentrations and to measure their sensitivity to the type of ground surface material and level of surface-disturbing activity. Field sites were selected to be representative of two general material types (volcanic versus nonvolcanic) and three depositional environments (primarily non-reworked deposits, redistributed fluvial deposits, and redistributed eolian deposits). Airborne particle measurement activities and results are only briefly presented and summarized in this status report because they are the subject of a separate reporting activity that is currently in progress. The level of surface-disturbing activity was found to be the most influential factor affecting the measured airborne particle concentrations, which increased over three orders of magnitude relative to ambient conditions. As the surface-disturbing activity level increased, the particle size distribution and the majority of airborne particle mass shifted from particles with aerodynamic diameters less than 10 μm [3.9×10^{-4} in] to particles with aerodynamic diameters greater than 10 μm [3.9×10^{-4} in]. In addition, an increased airborne particle concentration was measured when walking on an extremely fine-grained deposit. Although the limited sample size precluded detailed statistical analysis, the differences in airborne particle concentration over 900-year weathered volcanic and nonvolcanic deposits appeared to be potentially significant only under heavy surface disturbances.

This summary document is a status report, and numerous analyses are in process. Data obtained from this important analog site will help us understand some of the consequences of possible future volcanism at Yucca Mountain. This work will help reduce uncertainties and improve realism in the modeling of consequences for the potential release of radioactive material directly into the atmosphere from a volcanic eruption intersecting the potential repository. Laboratory and data analyses from field investigations at Sunset Crater will be used to update process-level modeling, to refine model parameters for performance assessment calculations, to develop and refine risk insights, and to help staff prepare for the review of the potential DOE license application.

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APPENDIX A

Appendix A. Survey (Tephra) Pits at Sunset Crater Study Site, 2004							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
5.3.04/2	Black Bottom Crater	3917541	464420	1,814	25	92+	Most pyroclasts ≤1 cm. More than 92 cm of black Sunset Crater tephra present.
5.3.04/3	Black Bottom Crater	3917511	464411	1,826	25	3+	24 cm of oxidized Black Bottom Crater tephra overlying Sunset tephra.
5.3.04/4	Black Bottom Crater	3917454	464399	1,845	28	0	43 cm of oxidized Black Bottom Crater tephra and indurated soil; no Sunset Crater tephra layer.
5.3.04/6	Black Bottom Crater	-	-	-	~19	0	100 cm of colluvium.
5.3.04/9	Black Bottom Crater	-	-	-	-	10	Tephra overlying Kana-a lava flow. Two exploratory pits of 10 cm each. Lava and lava fragments at base.
5.3.04/10	Near Black Bottom Crater	3918462	463395	1,757	0	77+	Tephra overlies Kana-a lava flow. Upper 7–10 cm of tephra contains fines.
5.3.04/12	O'Leary Basin	3921234	453896	1,929	0	68	9 cm of reworked material overlies Sunset tephra. Conducting transit traverse.

Appendix A. Survey (Tephra) Pits at Sunset Crater Study Site, 2004 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
5.3.04/13	O'Leary Basin	-	-	-	-	15	10 cm of reworked material overlies Sunset tephra.
5.3.04/13b	O'Leary Basin	3921242	453851	-	-	0	Sunset tephra absent (only colluvium present).
5.3.04/15	O'Leary Basin	-	-	-	15	30	10 cm of reworked material overlies Sunset tephra.
5.3.04/16	O'Leary Basin	3921194	453824	-	0	0	20 cm of forest duff overlies 25 cm of reworked material. End of transit traverse.
5.4.04/2	San Francisco Wash near Turkey Tanks	3900890	463362	1,878	-	-	Bar deposit (mostly tephra). Sample collected from a depth of 20 cm.
5.4.04/3	San Francisco Wash near Turkey Tanks	3900874	463277	1,874	-	18	Bank deposit. 20 cm of eolian-rich colluvium overlies the tephra. Same material beneath the tephra.
5.4.04/6	San Francisco Wash	3900483	466869	1,821	>20	63+	Bank deposit. Upper 10 cm appears slightly reworked.

Appendix A. Survey (Tephra) Pits at Sunset Crater Study Site, 2004 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
5.4.04/7	San Francisco Wash	3900715	466871	1,813	-	-	Bar deposit (mostly tephra). Sample collected from a depth of 25 cm.
5.5.04/1	Cone V30	3905989	451764	2,079	25	5	Unnamed scoria cone V30. 20 cm of reworked tephra and/or colluvium overlies intact tephra. Tephra is fine grained.
5.5.04/2	Cone V30	-	-	-	25	0	30 cm of reworked and colluvial tephra.
5.5.04/6	Cone V30	3905577	451666	2,145	~0	14	About 5 cm of reworked material overlying intact tephra. Mostly coarse upper tephra layer.
5.5.04/7	Cone V30	3905849	451655	2,083	14	23	9 cm of colluvium overlying intact tephra. Coarse tephra toward top, finer toward base.
5.5.04/8	Cone V30	3905738	451604	2,090	23	28	Coarse top layer of tephra, fine at base. Lowest 2 cm of tephra is very fine (distinct layer). 54 cm of colluvial tephra before reaching primary fall deposit. Base is hard, red, oxidized, clay-rich layer.

Appendix A. Survey (Tephra) Pits at Sunset Crater Study Site, 2004 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
5.5.04/9	Cone V30	3905703	451576	2,110	26	30	Top is 20 cm of duff overlying 25 cm of colluvium. Primary fall deposit is beneath those layers. Upper 20 cm of tephra is coarse; basal 10 cm is fine grained.
5.5.04/10	Cone V30	3905772	451600	2,075	18	33	Top is 10 cm of duff overlying 40 cm of colluvium. Primary fall deposit is beneath those layers. Upper 24 cm of tephra is coarse; basal 9 cm is fine grained.
5.5.04/11	Cone V30	3905874	451576	2,074	6	10+	At base of unnamed scoria cone V30. Eolian deposit of Sunset tephra. Base shows possible fluvial reworking. Deposit is fine grained with faint bedding (plain to lenticular).
5.5.04/12	Cone V30	3906056	451763	2,056	17	36	29 cm of colluvium overlies tephra. Lowest 2 cm of tephra is fine grained.
5.5.04/14	Cone V30	3905846	452139	2,041	13	26+	70 cm of colluvium overlies tephra.

Appendix A. Survey (Tephra) Pits at Sunset Crater Study Site, 2004 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
5.6.04/6	Cone V3913	3915631	464336	1,869	11	0	44 cm of colluvium with minor Sunset pyroclasts; no distinct Sunset tephra layer.
5.6.04/7	Cone V3913	3915643	464364	1,869	9	19	15 cm of eolian-rich colluvium overlying 5 cm (top) of fine-grained Sunset tephra and 14 cm (bottom) of coarse tephra. Base consists of coarse, yellow-colored cinders (pre-Sunset).
5.6.04/8	Cone V3913	3915663	464482	1,845	11	18	12 cm of eolian-rich colluvium overlies tephra layer. Upper 10 cm of tephra appears coarser.
5.6.04/10	Cone V3913	3915674	464660	1,818	6	8	21 cm of cohesive and noncohesive colluvium overlies tephra. Basal material still yellow-colored (pre-Sunset) cinders.
NOTE: 1 cm = 0.4 in and 1 m = 3.3 ft.							

APPENDIX B

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
8.10.05/4	Black Bottom Crater	3919333	463491	1,730	~0	0	Pit dug into alluvium for 31 cm. There is a one-pebble-thick lag or covering of redistributed Sunset scoria. Alluvium is light-colored, hard, and dry.
8.10.05/5	Black Bottom Crater	3919321	463535	1,731	~0	0	Pit dug into alluvium for 44 cm. There is a one-pebble-thick lag or covering of redistributed Sunset scoria. Alluvium is light-colored, hard, and dry.
8.10.05/8	Borrow Pit near Black Bottom Crater	3919288	463690	1,727	-	0	At Borrow Pit, measured 1 m of alluvium in pit walls.
8.12.05/2	Woodhouse Mesa-Wupatki National Monument	3927872	467856	1,489	~0	~50	Coppice dune sample collected from a depth of 12 cm. Collected along road near southern entrance of Wupatki National Monument.
8.12.05/3	Near Sunset Crater	3915990	460132	1,924	-	25+	Shallow pit dug to examine tephra characteristics. Pit shows that upper 12 cm is disturbed or reworked.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
8.15.05/4	Near Haywire Crater (between Sunset and Black Bottom Craters)	3917309	461387	1,832	-	26+	Shallow pit dug to examine tephra characteristics. Pit shows that upper 15 cm is disturbed or reworked.
8.16.05/3	Near Haywire Crater	3916566	461046	1,854	-	25+	Pit dug in the bottom of tephra-covered Kana-a Wash. Little evidence of fluvial activity. Pit shows 20 cm of upper, lightly reworked tephra. Beneath that is a layer of pristine, vesicular, blue-black tephra.
8.16.05/4	Near Haywire Crater	3916561	461046	1,855	-	78+	Pit dug in the bottom of tephra-covered Kana-a Wash. Little evidence of fluvial activity. Pit shows 15 cm of upper, fine-grained, lightly reworked tephra (with minor fluvial or eolian fines mixed in). More fine-grained, pristine, vesicular tephra is beneath the surface layer. Gradual increase in grain size to base of pit at 78 cm. Did not reach pre-Sunset substrate.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
8.16.05/7	Black Bottom Crater	3918787	463536	1,745	~0	25+	Pit dug while wearing airborne particle concentration sampler (Institute of Occupational Medicine) for heavy disturbance measurement. Near Kana-a lava flow and coppice dunes of tephra particles. About 8 cm of lightly reworked tephra. Medium grain size.
8.16.05/8	Black Bottom Crater	3918580	463590	1,746	~0	20+	Pit dug while wearing airborne particle concentration sampler (Institute of Occupational Medicine) for heavy disturbance measurement. Near Kana-a lava flow and coppice dunes of tephra particles. About 8 cm of lightly reworked tephra. Fine grain size. Two additional pits dug in this area with similar characteristics to these last two.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
V30N_1a	Unnamed scoria cone V30	3906062	451936	2,084	25	22	Tephra pit transect on north side of cone V30: 16-cm-thick top layer of colluvium (reworked Sunset and earlier cone tephra) overlying 6 cm of fine-grained primary tephra. Base of Sunset tephra reached at a depth of 22 cm.
V30N_2a	Unnamed scoria cone V30	3906069	451941	2,079	22	80	Tephra pit: upper surface layer (12 cm thick) of reworked Sunset tephra and colluvium. Middle layer (44 cm thick) of fine-grained tephra. Basal layer (24 cm thick) of coarse-grained Sunset tephra. Base of Sunset tephra reached at a depth of 80 cm.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
V30N_3a	Unnamed scoria cone V30	3906070	451945	2,078	22.5	152	Tephra pit: upper surface layer (79.5 cm thick) of reworked Sunset tephra and colluvium. Middle layer (41 cm thick) of fine-grained tephra. Basal layer (31.5 cm thick) of coarse-grained Sunset tephra. Base of Sunset tephra reached at a depth of 152 cm.
V30N_4a	Unnamed scoria cone V30	3906081	451952	2,073	24	166	Tephra pit: upper surface layer (116 cm thick) of reworked Sunset tephra and colluvium. Middle layer (21 cm thick) of fine-grained tephra. Basal layer (29 cm thick) of coarse-grained Sunset tephra. Base of Sunset tephra reached at a depth of 166 cm.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
V30N_5a	Unnamed scoria cone V30	3906102	451976	2,064	22	80	Tephra pit: upper surface layer (43 cm thick) of reworked Sunset tephra and colluvium. Middle layer (23.5 cm thick) of coarse-grained tephra. Basal layer (13.5 cm thick) of fine-grained Sunset tephra. Base of Sunset tephra reached at a depth of 80 cm.
V30N_6a	Unnamed scoria cone V30	3906123	451995	2,059	23	106	Tephra pit: upper surface layer (76 cm thick) of reworked Sunset tephra and colluvium. Middle layer (20 cm thick) of coarse-grained tephra. Basal layer (10 cm thick) of fine-grained Sunset tephra. Base of Sunset tephra reached at a depth of 106 cm.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
V30N_7a	Unnamed scoria cone V30	3906148	452042	2,045	10.5	91	Tephra pit: upper surface layer (47 cm thick) of reworked Sunset tephra and colluvium. Middle layer (31 cm thick) of coarse-grained tephra. Basal layer (13 cm thick) of fine-grained Sunset tephra. Base of Sunset tephra reached at a depth of 91 cm.
V30N_8a	Unnamed scoria cone V30	3906166	452090	2,030	7	24	Final tephra pit in this transect: 24 cm of Sunset tephra mixed with colluvium. Pre-Sunset material reached at this depth.
V30N_1b	Unnamed scoria cone V30	3906124	451775	2,111	30	26	Second tephra pit transect on north side of cone V30: 20-cm-thick top layer of colluvium (reworked Sunset and earlier cone tephra) overlying 4 cm of fine-grained primary tephra and a basal layer of 2 cm of coarse-grained tephra. Base of Sunset tephra reached at a depth of 26 cm.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
V30N_2b	Unnamed scoria cone V30	3906137	4511777	2,101	31	22.5	Tephra pit: upper surface layer (9 cm thick) of reworked Sunset tephra and colluvium. Middle layer (8.5 cm thick) of fine-grained tephra. Basal layer (5 cm thick) of coarse-grained Sunset tephra. Base of Sunset tephra reached at a depth of 22.5 cm.
V30N_3b	Unnamed scoria cone V30	3906155	451781	2,096	25	39.5	Tephra pit: upper surface layer (11 cm thick) of reworked Sunset tephra and colluvium. Middle layer (11.5 cm thick) of fine-grained tephra. Basal layer (17 cm thick) of coarse-grained Sunset tephra. Base of Sunset tephra reached at a depth of 39.5 cm.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
V30N_4b	Unnamed scoria cone V30	3906181	451783	2,086	26	109.5	Tephra pit: upper surface layer (57 cm thick) of reworked Sunset tephra and colluvium. Middle layer (22.5 cm thick) of fine-grained tephra. Basal layer (30 cm thick) of coarse-grained Sunset tephra. Base of Sunset tephra reached at a depth of 109.5 cm.
V30N_5b	Unnamed scoria cone V30	3906201	451785	2,075	25.5	138.5	Tephra pit: (i) upper surface layer (93 cm thick) of reworked Sunset tephra and colluvium; (ii) fine-grained tephra 9 cm thick; (iii) coarse-grained tephra 18.5 cm thick; and (iv) a fine-grained tephra basal layer 18 cm thick. Base of Sunset tephra reached at a depth of 138.5 cm.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
V30N_6b	Unnamed scoria cone V30	3906227	451794	2,060	21	180	Tephra pit: (i) upper surface layer (133 cm thick) of Sunset tephra with colluvium; (ii) fine-grained tephra 7 cm thick; (iii) coarse-grained tephra 24 cm thick; and (iv) a fine-grained tephra basal layer 16 cm thick. Base of Sunset tephra reached at a depth of 180 cm.
V30N_7b	Unnamed scoria cone V30	3906259	451790	2,055	17.5	198.5	Tephra pit: (i) upper surface layer (133 cm thick) of reworked Sunset tephra and colluvium; (ii) fine-grained tephra 11 cm thick; (iii) coarse-grained tephra 26 cm thick; and (iv) a fine-grained tephra basal layer 28.5 cm thick. Base of Sunset tephra reached at a depth of 198.5 cm.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
V30N_8b	Unnamed scoria cone V30	3906330	451795	2,050	13	97.5	Tephra pit: (i) upper surface layer (59 cm thick) of reworked Sunset tephra and colluvium; (ii) fine-grained tephra 10.5 cm thick; (iii) coarse-grained tephra 24.5 cm thick; and (iv) a fine-grained tephra basal layer 3.5 cm thick. Base of Sunset tephra reached at a depth of 97.5 cm.
V30N_9b	Unnamed scoria cone V30	3906339	451794	2,049	1	62	Tephra pit: (i) upper surface layer (26 cm thick) of reworked Sunset tephra and colluvium; (ii) coarse-grained tephra 22 cm thick; and (iii) a fine-grained basal layer 14 cm thick. Base of Sunset tephra reached at a depth of 62 cm.
V30S_1b	Unnamed scoria cone V30	3905735	451721	2,129	21	51	Tephra pit transect on south side of cone V30: 51-cm-thick layer of colluvium (reworked Sunset and earlier cone tephra) before reaching the pre-Sunset base.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
V30S_2b	Unnamed scoria cone V30	3905720	451718	2,116	25	34	Tephra pit: 13 cm of colluvium with little or no Sunset tephra overlies a second colluvium layer 34 cm thick consisting of reworked Sunset and earlier cone tephra. Pre-Sunset base is beneath this.
V30S_3b	Unnamed scoria cone V30	3905698	451726	2,119	24.5	32	Tephra pit: (i) upper surface layer (18 cm thick) of colluvium with little or no Sunset tephra; (ii) coarse-grained tephra 25.5 cm thick; and (iii) a fine-grained tephra basal layer 6.5 cm thick. Base of Sunset tephra reached at a depth of 50 cm.
V30S_4b	Unnamed scoria cone V30	3905682	451728	2,108	17	0	Tephra pit consists of 23 cm of colluvium with little or no Sunset tephra. Pre-Sunset base is beneath this.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
V30S_5b	Unnamed scoria cone V30	3905619	451774	2,074	23	21	Tephra pit: 20 cm of colluvium with little or no Sunset tephra overlies a second colluvium layer 21 cm thick consisting of reworked Sunset and earlier cone tephra. Pre-Sunset base is beneath this.
V30S_6b	Unnamed scoria cone V30	3905593	451787	2,066	20	14.5	Tephra pit: 4 cm of colluvium with little or no Sunset tephra overlies a second colluvium layer 14.5 cm thick consisting of reworked Sunset and earlier cone tephra. Pre-Sunset base is beneath this.
V30S_7b	Unnamed scoria cone V30	3905569	451789	2,059	13.5	8	Tephra pit consists of 32 cm of colluvium with little or no Sunset tephra overlying an 8-cm-thick layer of fine-grained Sunset tephra. Pre-Sunset base is beneath this.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
V30S_8b	Unnamed scoria cone V30	3905543	451793	2,049	14	3	Tephra pit consists of 29 cm of colluvium with little or no Sunset tephra overlying a 3-cm-thick layer of fine-grained Sunset tephra. Pre-Sunset base is beneath this.
BP-2S	Borrow Pit near Black Bottom Crater	3918522	463732	1,741	1	82	Series of tephra pits near Kana-a Wash. The upper layer is 9 cm thick and may be fluvially reworked. This overlies 82 cm of fine-grained tephra before reaching pre-Sunset material.
BP-3S	Borrow Pit near Black Bottom Crater	3918446	463672	1,747	7	143.5	Tephra pit: (i) upper surface layer (16.5 cm thick) of fluvially reworked material; (ii) approximately 18.5 cm of coarse-grained Sunset tephra; (iii) 45 cm of interbedded tephra; and (iv) 80 cm of fine-grained tephra at the base of the sequence.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
BP-4S	Borrow Pit near Black Bottom Crater	3918409	463657	1,750	5	68.5	Tephra pit with an upper layer (22.5 cm thick) that may be fluvially reworked overlying 68.5 cm of coarse-grained tephra before reaching pre-Sunset material.
BP-5S	Borrow Pit near Black Bottom Crater	3918350	463589	1,755	2.5	0	Pit with 13.5 cm of possibly fluvially-reworked material before reaching pre-Sunset material.
BP-1	Borrow Pit near Black Bottom Crater	3918592	463763	1,734	4	159	Second series of tephra pits near Kana-a Wash. Tephra pit consists of 159 cm of interbedded tephra before reaching the pre-Sunset material.
BP-2	Borrow Pit near Black Bottom Crater	3918612	463776	1,740	4	147	Tephra pit consists of 147 cm of interbedded tephra before reaching the pre-Sunset material.
BP-3	Borrow Pit (BP) near Black Bottom Crater (BBC)	3918641	463786	1,739	5	55	Tephra pit consists of 55 cm of interbedded tephra before reaching the pre-Sunset material.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
BP-4	Borrow Pit near Black Bottom Crater	3918670	463796	1,738	4	43	Tephra pit consists of 43 cm of interbedded tephra before reaching the pre-Sunset material.
BP-5	Borrow Pit near Black Bottom Crater	3918679	463800	1,736	3	18	Tephra pit consists of 18 cm of interbedded tephra before reaching the pre-Sunset material.
BP-6	Borrow Pit near Black Bottom Crater	3918695	463821	1,734	3	0	Survey (tephra) pit consisting only of pre-Sunset material. Pit depth was 40 cm.
MCW_1B	Maroon Crater	3906795	467232	1,814	1	66	Series of tephra pits dug across the west side of Maroon Crater. Tephra pit: (i) upper colluvial layer composed of reworked Sunset and Maroon tephra (2.5 cm thick); (ii) 35 cm of fine-grained Sunset tephra; (iii) 22 cm of coarse-grained tephra; (iv) 5 cm of fine-grained tephra (oxidized); and (v) a basal layer of coarse-grained tephra (4 cm thick).

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
MCW_2B	Maroon Crater	3906820	467247	1,818	20	79	Tephra pit: 91 cm of coarse- and medium-grained colluvium overlying 79 cm of coarse-grained Sunset tephra. Pit depth 170 cm.
MCW_3B	Maroon Crater	3906840	467262	1,829	28	39	Tephra pit: (i) upper colluvial layer composed of reworked Sunset and Maroon tephra (19 cm thick); (ii) 7 cm of medium-grained Sunset tephra; (iii) 6.5 cm of fine-grained tephra; (iv) 14 cm of medium-grained tephra; (v) 6 cm of medium-grained tephra (oxidized); and (vi) a basal layer of coarse-grained, glassy tephra (5.5 cm thick).
MCW_4B	Maroon Crater	3906844	467266	1,831	32	8	Tephra pit: (i) upper colluvial layer composed of reworked Sunset and Maroon tephra (10 cm thick); (ii) 5 cm of medium-grained tephra (oxidized); and (iii) a basal layer of fine-grained, glassy tephra (3 cm thick).

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
MCW_1a	Maroon Crater	3907104	466981	1,811	27.5	36	Second series of tephra pits dug across the west side of Maroon Crater. Tephra pit: (i) upper colluvial layer composed of reworked Sunset and Maroon tephra (9 cm thick); (ii) graded coarse to fine (alternating layers) tephra, 18 cm thick; (iii) 7 cm of medium-grained tephra (gray color); (iv) 6 cm of medium-grained tephra (oxidized); and (v) a basal layer of coarse-grained tephra (5 cm thick).
MCW_2a	Maroon Crater	3907102	466991	1,820	27	14	Tephra pit: (i) upper colluvial layer composed of reworked Sunset (black) and Maroon (red) tephra (16 cm thick); (ii) 4 cm of medium to coarse vesicular (primary) Sunset tephra; (iii) 7 cm of medium-grained tephra (oxidized); and (iv) a basal layer of medium-grained tephra (3 cm thick).

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
MCW_3a	Maroon Crater	3907103	467002	1,826	31	3	Tephra pit with an upper colluvial layer composed of reworked Sunset and Maroon tephra (8 cm thick) and 3 cm of glassy, medium- to coarse-grained Sunset tephra. Maroon scoria lies beneath this thin Sunset layer.
MCW_4a	Maroon Crater	3907107	467008	1,833	30	0	Tephra pit with an upper colluvial layer composed of reworked Sunset and Maroon tephra (30 cm thick) and a lower colluvial layer (30 cm thick) composed of coarser, mixed scoria. Brown soil/colluvium (20 cm) underlies these units.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
MCW_5a	Maroon Crater	3907105	467019	1,840	29.5	0	Tephra pit with an upper colluvial layer composed of reworked Sunset and Maroon tephra (36 cm thick) and a lower layer (8 cm thick) composed of red and black scoria with fine-grained, fresh-appearing glassy material (Sunset) in matrix. Brown soil/colluvium (25 cm) underlies these layers.
MCW_6a	Maroon Crater	3907113	467028	1,838	30	0	Pit with 63 cm of brown, fine-grained colluvium with minor Sunset mixed in.
MCE_1b	Maroon Crater	3907372	467725	1,860	5	17	Series of tephra pits dug across the east side of Maroon Crater. Tephra pit with an upper colluvial layer (14 cm thick) and 17 cm of coarse-grained tephra before reaching the pre-Sunset base.
MCE_2b	Maroon Crater	3907424	467767	1,852	5	0	Survey (tephra) pit consisting of 68 cm of colluvium.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
MCE_3b	Maroon Crater	3907464	467782	1846	7	25	Tephra pit: (i) upper colluvial layer composed of reworked Sunset and Maroon tephra (26.5 cm thick); (ii) 17 cm of coarse-grained Sunset tephra; (iii) 4.5 cm of medium-grained tephra (oxidized); and (iv) a basal layer of coarse-grained tephra (3.5 cm thick).
MCE_4b	Maroon Crater	3907494	467797	1839	2	0	Pit consisting of 39 cm of colluvium.
MCE_5b	Maroon Crater	3907838	467976	1784	4.5	11.5	Tephra pit: (i) upper colluvial layer composed of reworked Sunset and Maroon tephra (10.5 cm thick); (ii) 7.5 cm of medium-grained tephra (oxidized); and (iii) a basal layer of coarse-grained tephra (4 cm thick).
MCE_1a	Maroon Crater	3907056	467380	1857	25	0	Second series of tephra pits dug across the east side of Maroon Crater. Tephra pit consists of 47 cm of brown-colored colluvium.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
MCE_2a	Maroon Crater	3907522	467375	1853	12	36	Tephra pit: (i) upper colluvial layer composed of reworked Sunset and Maroon tephra (20 cm thick); (ii) alternating beds of fine-to-coarse, glassy Sunset tephra (24 cm thick); (iii) 6 cm of medium-grained tephra (oxidized); and (iv) a basal layer of glassy, coarse-grained tephra (6 cm thick).
MCE_3a	Maroon Crater	3907534	467378	1855	12	72	Tephra pit: (i) upper layer consists of alternating beds of fine-to-coarse Sunset tephra (weathered, 39 cm thick); (ii) alternating beds of fine-to-coarse, glassy Sunset tephra (20 cm thick); (iii) 5 cm of medium-grained tephra (oxidized); and (iv) a basal layer of glassy, coarse-grained tephra (8 cm thick).
MCE_4a	Maroon Crater	3907552	467382	1851	21	0	Pit consists of 42 cm of brown-colored colluvium.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
MCE_5a	Maroon Crater	3907568	467389	1850	20	0	Tephra pit consists of an upper colluvial layer (22 cm thick) with some Sunset material incorporated and a lower layer (22 cm thick) of brown-colored colluvium.
MCE_6a	Maroon Crater	3907586	467394	1838	14	31	Tephra pit: (i) upper unit consists of at least four alternating layers of fine-to-coarse Sunset tephra (17 cm thick); (ii) 6 cm of medium-grained tephra (oxidized); and (iii) a basal layer of glassy, coarse-grained tephra (8 cm thick).

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
MCE_7a	Maroon Crater	3907607	467399	1830	14	19	Tephra pit: (i) consists of an upper colluvial layer (15 cm thick) with some Sunset material incorporated; (ii) repeating layers of fine-to-coarse tephra (9 cm thick); (iii) 5 cm of medium-grained tephra (oxidized); and (iv) a basal layer of glassy, coarse-grained tephra (5 cm thick). Pre-Sunset base is a red, scoriaceous gravel.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
MCE_8a	Maroon Crater	3907632	467407	1824	7	18.5	Tephra pit: (i) upper colluvial layer 20.5 cm thick (well developed); (ii) 30 repeating sequences (possibly reworked) of fine-to-coarse Sunset tephra (77 cm thick: basal 20 cm are gray, top 57 cm are black); (iii) 2 cm of medium-grained tephra (glassy); (iv) 7.5 cm of coarse-grained tephra (glassy); (v) 2 cm of fine-grained tephra (glassy); (vi) 5 cm of medium-grained tephra (oxidized); and (vii) a basal layer of glassy, coarse-grained tephra (2 cm thick).
MCE_9a	Maroon Crater	3907649	467415	1812	21	0	Pit (156 cm deep) consists of repeating layers of colluvium, interbedded with Maroon scoriaceous layers.

Appendix B. Survey (Tephra) Pits at Sunset Crater Study Site, 2005 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
MCE_10a	Maroon Crater	3907689	467433	1799	4	47	Tephra pit: (i) upper colluvial layer 25 cm thick; (ii) 19.5 cm of fine-grained tephra; (iii) 19 cm of coarse-grained tephra; (iv) 6.5 cm of medium-grained tephra (oxidized); and (v) a basal layer of coarse-grained tephra (2 cm thick).
MCE_11a	Maroon Crater	3907734	467455	1789	7	22	Tephra pit: (i) upper colluvial layer 21 cm thick; (ii) 10 cm of coarse-grained tephra; (iii) 2 cm of fine-grained tephra; (iv) 6.5 cm of medium-grained tephra (oxidized); and (v) a basal layer of coarse-grained tephra (3.5 cm thick).
MCE_12a	Maroon Crater	3907752	467470	1783	4	11	Tephra pit: (i) upper colluvial layer 10.5 cm thick; (ii) 4 cm of medium-grained tephra; (iii) 4.5 cm of medium-grained tephra (oxidized); and (iv) a basal layer of coarse-grained tephra (2.5 cm thick).

NOTES: 1 cm = 0.4 in and 1 m = 3.3 ft.

Field station identifiers may show variance with the use of blank spaces, hyphens, dashes, the underscore character, or other alphanumeric characters.

APPENDIX C

Appendix C. Survey (Tephra) Pits at Sunset Crater Study Site, 2006							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
6.6.06/4	Near Sunset Crater and Black Mountain	3917248	458841	1,951	~0	89+	Pit designated 60606 and dug along "Powerline Road," 5.5 km from vent. Light-colored, reworked upper layer with a thickness of 15 to 17 cm. Beneath the reworked material is a layer of fine- to medium-grained tephra with a thickness of 45 cm. Beneath this layer to the base is a stratum of slightly coarser tephra (with more 1-cm-sized pyroclasts). Dug to a depth of 89 cm and four samples collected.
6.9.06/3	San Francisco Wash	3901075	467503	1,807	-	15	Fluvially reworked Sunset tephra 15 cm thick. This is a bar deposit between boulders in San Francisco Wash. There is reddish (old, non-Sunset) material mixed in.

Appendix C. Survey (Tephra) Pits at Sunset Crater Study Site, 2006 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
6.9.06/4	San Francisco Wash	3901072	467497	1,808	-	14	Fluvially reworked Sunset tephra from another bar deposit in the dry wash. Tephra layer thickness was 14 cm and there is reddish (old, non-Sunset) material mixed in.
6.9.06/10	Black Bottom Crater	3918637	463312	1,759	~0	-	Tephra thickness measurements around coppice dunes. Dunes have a maximum height of 2 m. Two pits were dug into interdune corridors. Eolian reworked tephra measured 18 and 10 cm in thickness. A layer of primary tephra is beneath that.

Appendix C. Survey (Tephra) Pits at Sunset Crater Study Site, 2006 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
6.12.06/10	Black Bottom Crater	3918538	463462	1,753	~0	-	Tephra thickness measurements around coppice dunes. Largest dunes have a maximum height of 1.5 to 2.5 m. Two pits were dug into interdune corridors. First eolian reworked tephra measurement was 58 cm without reaching substrate. Second pit reached substrate of primary tephra at 22 cm in thickness.
6.12.06/13	Black Bottom Crater	3917767	463171	1,785	~0	0	Pit dug into alluvium for 77 cm. Alluvium appeared silty (fine grained) and homogeneous with minor caliche.
6.12.06/14	Black Bottom Crater	3917755	463275	1,782	~0	0	Alluvium pit. Depth of small gully of 25 cm plus depth of pit of 80 cm for a measured alluvium thickness here of 105 cm. Silty, homogeneous, light-colored alluvium; sample collected.

Appendix C. Survey (Tephra) Pits at Sunset Crater Study Site, 2006 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
6.13.06/3	Near Sunset Crater	3914040	458099	2,017	<5	49+	Tephra pit dug near Forest Service Road 244 amongst Ponderosa Pine. Surface layer (4 cm) of loose cinder. This is part of a 26-cm-thick reworked zone (roots present). Beneath this layer to the base of the pit at 49 cm is a coarse layer of primary tephra. Two samples collected.
6.13.06/6	Black Bottom Crater	3918508	463883	1,742	~0	75+	Tephra pit. Upper layer with light-colored material (possibly eolian) is 9 cm thick. Some roots present. Beneath this is a homogeneous layer mixed with fine- and medium-grained tephra. The coarser pyroclasts appear to be reworked because they are rounded (thus may not be primary or *in-situ*). This layer extends to base of pit at 75 cm.

Appendix C. Survey (Tephra) Pits at Sunset Crater Study Site, 2006 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
6.13.06/7	Black Bottom Crater	3918337	463797	1,757	6	28	Tephra pit. upper layer with light-brown-colored material (possibly eolian) is 14 cm thick. Some roots present. Beneath this is a 14-cm-thick layer of sharp, jagged (pristine) tephra. Contact is not distinct. Beneath this is a light-brown, fine-grained horizon that should be the pre-Sunset surface. Some $CaCO_3$ on the scoria, possibly due to this horizon.

Appendix C. Survey (Tephra) Pits at Sunset Crater Study Site, 2006 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
6.13.06/8	Black Bottom Crater	3917763	464936	1,737	~0	69	Tephra pit: upper layer of fine-grained tephra, 9 cm thick, with some light-brown material. Numerous interspersed pyroclasts ranging from 0.5 to 1.5 cm in diameter. Beneath this layer, from 9 to 24 cm, is a similar layer but without the light-brown eluvium. Jagged, primary tephra from 24 to 69 cm. Reddish-orange, claylike material (pre-Sunset) reached at 69 cm.

Appendix C. Survey (Tephra) Pits at Sunset Crater Study Site, 2006 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
6.13.06/9	Black Bottom Crater	3917627	464897	1,740	~0	30+	Tephra pit: upper layer of fine-grained tephra, 12–15 cm thick, with some light-brown material. Beneath this layer, from 12–15 to 24 cm, is a similar layer but without the light-brown eluvium. Jagged, primary tephra reached at 24 cm. This pit appears to have significant eolian-reworked tephra and lacks interspersed pyroclasts ranging from 0.5 to 1.5 cm in diameter. Some cinders show $CaCO_3$ coating. Did not dig to pre-Sunset surface.

Appendix C. Survey (Tephra) Pits at Sunset Crater Study Site, 2006 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
6.13.06/10	Black Bottom Crater	3917903	465063	1731	~0	45+	Tephra pit: upper 10 cm is fine grained and contains light brown fines. From 10 to 45 cm (base of pit), the tephra appears to be slightly reworked and is still fine grained with occasional coarser pyroclasts. Did not dig to pre-Sunset surface.
6.15.06/2	Near Woodhouse Mesa, northeast of Black Bottom Crater	3923083	467417	1596	~0	0	Alluvium pit. Dug through 1.1 m of light brown, silt-to-clay size alluvial material before reaching a basal caliche layer (two other nearby exploratory pits confirmed this).
6.15.06/7	Northeast of Strawberry Crater and outside of Wupatki National Monument	3931584	462883	1615	-	15+	Shallow pit. Tephra is a mix of eolian reworked and primary, draped over Kaibab Formation (Doney Mountain is nearby). Sample collected.

Appendix C. Survey (Tephra) Pits at Sunset Crater Study Site, 2006 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
546 (6.28.06_1)	Near Sunset Crater and Haywire Crater	3914724	455910	2122	9	125+	Tephra pit off National Forest Road 546. Five major horizons or layers present: (i) surface layer of tephra and colluvium, 0–9 cm thick; (ii) reworked tephra and colluvium with a reddish color, depth of 9–13.5 cm; (iii) fine- to medium-grained tephra, depth of 13.5–18.5 cm; (iv) medium- to coarse-grained tephra with roots present, depth of 18.5–68.5 cm; and (v) coarse-grained tephra, depth of 68.5–125 cm (base of pit, did not reach pre-Sunset material). Five samples collected.

Appendix C. Survey (Tephra) Pits at Sunset Crater Study Site, 2006 (continued)							
Field Station	**Location**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)**	**Slope (deg.)**	**Sunset Tephra Thickness (cm)**	**Comments and Description**
TankPit (6.28.06_2)	North of Black Bottom Crater	3919679	463472	1790	0	0	Alluvium pit dug north of Loop Road near the water tank. Three layers present: (i) surface colluvium, depth of 0–3 cm; (ii) fine-grained alluvium with reddish-colored soil, depth of 3–24 cm; and (iii) alluvium with large limestone (caliche) cobbles, depth of 24–100 cm.

NOTES: 1 cm = 0.4 in and 1 m = 3.3 ft.

Field station identifiers may show variance with the use of blank spaces, hyphens, dashes, the underscore character, or other alphanumeric characters.

APPENDIX D

Appendix D. Sieved Samples from Sunset Crater Study Site						
Sample ID	**Location**	**Field Station**	**Northing (UTM)**	**Easting (UTM)**	**Description or Comment**	**Bulk Density (kg/m^3)**
50304-2	Black Bottom Crater	5.03.04/10	3918462	463395	Sunset Crater tephra on Kana-a lava flow. Sample collected from beneath 7–10 cm of loose surface material.	1,027
50404-1	San Francisco Wash	5.04.04/2	3900890	463362	Bar deposit (mostly tephra) from San Francisco Wash near Turkey Tanks. Sample collected from a depth of 20 cm.	816
50404-2	San Francisco Wash	5.04.04/3	3900874	463277	Bank deposit (of tephra) from small tributary of San Francisco Wash near Turkey Tanks. Sample collected from beneath 20 cm cover of eolian-rich material.	588
50404-4	San Francisco Wash	5.04.04/7	3900715	466871	Bar deposit (mostly tephra) from San Francisco Wash. Sample collected from a depth of 25 cm.	943
50604-1	Woodhouse Mesa-Wupatki National Monument	5.06.04/11	3927280	467613	Coppice dune 18 km from vent along Sunset Crater-Wupatki road. Sample collected from a depth of 15 cm into dune.	1,140

Appendix D. Sieved Samples from Sunset Crater Study Site (continued)						
Sample ID	**Location**	**Field Station**	**Northing**	**Easting**	**Description or Comment**	**Bulk Density (kg/m^3)**
81205-1	Woodhouse Mesa-Wupatki National Monument	8.12.05/2	3927872	467856	Coppice dune sample collected from a depth of 12 cm. Collected along road near southern entrance of Wupatki National Monument.	1,385
81605-2	Black Bottom Crater	8.16.05/9a	3918352	463594	Small unnamed wash near Black Bottom Crater. Sample of tephra and fluvial sediment collected in channel at top of wash (top = start of drainage).	1,232
81605-3	Black Bottom Crater	8.16.05/9b	3918636	463801	Small unnamed wash near Black Bottom Crater. Sample of tephra and fluvial sediment collected in channel at bottom of wash (bottom = end of drainage).	1,309
BP-1A	Borrow pit near Black Bottom Crater	82205_1A	3918592	463763	Repeating sequences (at least 21) of coarse to fine reworked Sunset tephra; thickness of layers decreases up section. Sample collected from 31–40 cm depth (0 = surface).	1,083
BP-1B	Borrow pit near Black Bottom Crater	82205_1B	3918592	463763	Repeating sequences (at least 21) of coarse to fine reworked Sunset tephra; thickness of layers decreases up section. Sample collected from 116–127 cm depth (0 = surface or top).	1,024

Appendix D. Sieved Samples from Sunset Crater Study Site (continued)						
Sample ID	**Location**	**Field Station**	**Northing**	**Easting**	**Description or Comment**	**Bulk Density (kg/m^3)**
BP-1C	Borrow pit near Black Bottom Crater	82205_1C	3918592	463763	Repeating sequences (at least 21) of coarse to fine reworked Sunset tephra; thickness of layers decreases up section. Sample collected from 152–159 cm depth (159 = bottom of pit).	1,132
BP-3S	Borrow pit near Black Bottom Crater	82205_3S	3918446	463672	Bedded Sunset tephra (several of the fine-grained beds are frosted with postdepositional mineralization). Sample collected from 42–50 cm depth (160 = bottom of pit).	984
60606-1	Near Sunset Crater and Black Mountain	6.6.06/1	3917248	458841	Tephra pit dug along “Powerline Road,” 5.5 km from vent. Light-colored, reworked upper layer (roughly the A-horizon) with a thickness of 15 to 17 cm. Beneath the reworked material is a layer of fine- to medium-grained tephra with a thickness of 45 cm. Beneath this layer to the base is a stratum of slightly coarser tephra (with more 1-cm-sized pyroclasts). First sample (60606-1) of uppermost 8 cm (0–8 cm, 0 = surface or top).	881

Appendix D. Sieved Samples from Sunset Crater Study Site (continued)						
Sample ID	**Location**	**Field Station**	**Northing**	**Easting**	**Description or Comment**	**Bulk Density (kg/m^3)**
60606-2	Near Sunset Crater and Black Mountain	6.6.06/1	3917248	458841	Same tephra pit as 60606-1. Second sample (60606-2) taken from a depth of 8–16 cm.	903
60606-3	Near Sunset Crater and Black Mountain	6.6.06/1	3917248	458841	Same tephra pit as 60606-1. Third sample (60606-3) taken from a depth of 16–24 cm.	846
60606-4	Near Sunset Crater and Black Mountain	6.6.06/1	3917248	458841	Same tephra pit as 60606-1. Fourth sample (60606-4) taken from a depth of 81–89 cm.	760
60906-1	San Francisco Wash	6.9.06/3	3901075	467503	Fluvially reworked Sunset tephra. This is a bar deposit between boulders in San Francisco Wash. There is reddish (old, non-Sunset) material mixed in. Sample collected from 0–8 cm (0 = surface).	1,268
60906-2	San Francisco Wash	6.9.06/4	3901072	467497	Fluvially reworked Sunset tephra from another bar deposit in the dry wash. There is reddish (old, non-Sunset) material mixed in. Sample collected from 1–9 cm (0 = surface).	1,225

Appendix D. Sieved Samples from Sunset Crater Study Site (continued)						
Sample ID	**Location**	**Field Station**	**Northing**	**Easting**	**Description or Comment**	**Bulk Density (kg/m^3)**
60906-4	Black Bottom Crater near Kana-a lava flow	6.9.06/9	3918637	463312	Coppice dune sample extracted near surface halfway up a 1-m-high dune.	1,430
546-1	Near Sunset Crater and Haywire Crater	6.28.06_1	3914724	455910	Tephra pit off National Forest Road 546. Sample collected from 0–9 cm (0 = surface). Colluvium present.	886
546-2	Near Sunset Crater and Haywire Crater	6.28.06_1	3914724	455910	Same tephra pit as 546-1. Sample collected from 9–13.5 cm (0 = surface). Reddish soil present.	676
546-3	Near Sunset Crater and Haywire Crater	6.28.06_1	3914724	455910	Same tephra pit as 546-1. Sample collected from a depth of 13.5–18.5 cm. Fine- to medium-grained tephra.	702
546-4	Near Sunset Crater and Haywire Crater	6.28.06_1	3914724	455910	Same tephra pit as 546-1. Sample collected from within a thick horizon 18.5–68.5 cm (0 = top). Medium- to coarse-grained tephra. Roots present.	806
546-5	Near Sunset Crater and Haywire Crater	6.28.06_1	3914724	455910	Same tephra pit as 546-1. Sample collected from within a thick horizon 68.5–125 cm (0 = top). Coarse-grained tephra.	648

Appendix D. Sieved Samples from Sunset Crater Study Site (continued)						
Sample ID	**Location**	**Field Station**	**Northing**	**Easting**	**Description or Comment**	**Bulk Density (kg/m^3)**
V30 S 3B (E)	Unnamed scoria cone V30	V30S_3b (8.19.05)	3905698	451726	Tephra pit on south side of "Landfill Cone" (V30). Sample collected from within an 18-cm-thick surface layer (Layer E) of colluvium with little or no Sunset tephra.	940
V30 S 3B (B)	Unnamed scoria cone V30	V30S_3b (8.19.05)	3905698	451726	Tephra pit on south side of "Landfill Cone" (V30). Sample collected from within a 25.5-cm-thick horizon (Layer B) of coarse-grained Sunset tephra.	613
V30 S 3B (A)	Unnamed scoria cone V30	V30S_3b (8.19.05)	3905698	451726	Tephra pit on south side of "Landfill Cone" (V30). Sample collected from a depth of 43.5–50 cm (50 cm = base of tephra), which is fine-grained Sunset tephra (Layer A).	799
V30 N 3A (D)	Unnamed scoria cone V30	V30N_3a (8.19.05)	3906070	451945	Tephra pit on north side of "Landfill Cone" (V30). Sample collected from within a 79.5-cm-thick surface horizon (Layer D) of colluvium (reworked Sunset and earlier V30 tephra).	883

Appendix D. Sieved Samples from Sunset Crater Study Site (continued)						
Sample ID	**Location**	**Field Station**	**Northing**	**Easting**	**Description or Comment**	**Bulk Density (kg/m^3)**
V30 N 3A (C)	Unnamed scoria cone V30	V30N_3a (8.19.05)	3906070	451945	Tephra pit on north side of "Landfill Cone" (V30). Sample collected from within a 41-cm-thick horizon (Layer C) of fine-grained Sunset tephra.	781
V30 N 3A (B)	Unnamed scoria cone V30	V30N_3a (8.19.05)	3906070	451945	Tephra pit on north side of "Landfill Cone" (V30). Sample collected from within a 31.5-cm-thick horizon (Layer B) of coarse-grained Sunset tephra.	644
V30 N 6B (D1)	Unnamed scoria cone V30	V30N_6b (8.19.05)	3906227	451794	Tephra pit on north side of "Landfill Cone" (V30). Sample collected from a depth of 24–30 cm (0 = top), which is a horizon (Layer D) of fine Sunset tephra with some colluvium.	956
V30 N 6B (D2)	Unnamed scoria cone V30	V30N_6b (8.19.05)	3906227	451794	Tephra pit on north side of "Landfill Cone" (V30). Sample collected from a depth of 70–80 cm (0 = top), which is a second and coarser horizon (Layer D) of Sunset tephra with some colluvium.	827

Appendix D. Sieved Samples from Sunset Crater Study Site (continued)						
Sample ID	**Location**	**Field Station**	**Northing**	**Easting**	**Description or Comment**	**Bulk Density (kg/m^3)**
V30 N 6B (B)	Unnamed scoria cone V30	V30N_6b (8.19.05)	3906227	451794	Tephra pit on north side of "Landfill Cone" (V30). Sample collected from a depth of 146–150 cm, which is a horizon (Layer B) of coarse-grained Sunset tephra.	730
V30 N 6B (C)	Unnamed scoria cone V30	V30N_6b (8.19.05)	3906227	451794	Tephra pit on north side of "Landfill Cone" (V30). Sample collected from a depth of 148–155 cm, which is a horizon (Layer C) of fine-grained Sunset tephra.	808
V30 N 6B (A)	Unnamed scoria cone V30	V30N_6b (8.19.05)	3906227	451794	Tephra pit on north side of "Landfill Cone" (V30). Sample collected from a depth of 170–174 cm (0 = top), which is a horizon (Layer A) of fine-grained Sunset tephra.	858
MCW-1B (Coarse B)	Maroon Crater	MCW_1b (8.24.05)	3906795	467232	Tephra pit on west side of Maroon Crater. Sample collected from a depth of 1–5 cm (0 = top), which is a layer of coarse-grained Sunset tephra (Coarse B).	786
MCW-1B (Fine B)	Maroon Crater	MCW_1b (8.24.05)	3906795	467232	Tephra pit on west side of Maroon Crater. Sample collected from a depth of 6–11 cm (0 = top), which is a layer of fine-grained Sunset tephra (Fine B). Oxidized.	774

Appendix D. Sieved Samples from Sunset Crater Study Site (continued)						
Sample ID	**Location**	**Field Station**	**Northing**	**Easting**	**Description or Comment**	**Bulk Density (kg/m^3)**
MCW-1B (Coarse A)	Maroon Crater	MCW_1b (8.24.05)	3906795	467232	Tephra pit on west side of Maroon Crater. Sample collected from a depth of 30–37 cm, which is a layer of coarse-grained Sunset tephra (Coarse A).	770
MCW-1B (Fine A)	Maroon Crater	MCW_1b (8.24.05)	3906795	467232	Tephra pit on west side of Maroon Crater. Sample collected from a depth of 45–50 cm, which is a layer of fine-grained Sunset tephra (Fine A).	984
MCE-7A	Maroon Crater	MCW_7a (8.24.05)	3907607	467399	Tephra pit on east side of Maroon Crater. Sample collected from a depth of 27–37 cm (0 = top), which is a layer of medium- to coarse-grained Sunset tephra and colluvium.	842
MCE-9A	Maroon Crater	MCW_9a (8.24.05)	3907649	467415	Tephra pit on east side of Maroon Crater. Repeated layers of red (oxidized) scoria with colluvium. Sample collected from a depth of 40–47 cm (0 = top). Mostly Maroon Crater tephra with little or no Sunset tephra.	820

NOTES: 1 cm = 0.4 in, 1 m = 3.3 ft, and 1 Kg/m^3 = 0.0624 lb/ft^3.

Field station identifiers may show variance with the use of blank spaces, hyphens, dashes, the underscore character, or other alphanumeric characters.

APPENDIX E

Appendix E. Geologic Samples Collected in 2005 for Spectroscopic Analysis				
Sample	**Date**	**Northing (UTM)**	**Easting (UTM)**	**Comments**
MN81505-1	8/15/2005	3917309	461387	Bare tephra
MN81505-2	8/15/2005	3917309	461387	Fresh (primary, pristine) tephra collected beneath 15 cm of alluvium and reworked material
MN81505-3	8/15/2005	3917309	461387	Forest duff (Ponderosa Pine)
MN81505-4	8/15/2005	3917309	461292	Weathered basaltic lava and lichen
MN81505-5	8/15/2005	3919284	463697	Alluvium
MN81505-6	8/15/2005	3926594	467463	Old basaltic lava
MN81505-7	8/15/2005	3926594	467463	Moenkopi Formation (red sandstone/shale)
MN81505-8	8/15/2005	3928072	467792	Eolian tephra
MN81505-9	8/15/2005	3932065	463348	Kaibab Formation (sandy limestone/dolostone)
MN81705-1	8/17/2005	3909451	451575	Reworked tephra
MN81705-2	8/17/2005	3909576	452462	Reworked tephra
MN81705-3	8/17/2005	3912559	454676	Tephra near the southern base of the Sunset Crater scoria cone
MN81705-4	8/17/2005	3912411	455926	Altered tephra (from fumarolic activity); red
MN81705-5	8/17/2005	3912424	455905	Altered tephra (from fumarolic activity); purple
MN81705-6	8/17/2005	3912546	455960	Altered tephra (from fumarolic activity); orange
MN81805-1	8/18/2005	3922296	456643	Rhyodacite flow at Deadman Mesa
MN81805-2	8/18/2005	3922297	456644	Rhyodacite flow at Deadman Mesa (obsidian)
MN81805-3	8/18/2005	3922401	457670	Strawberry Crater tephra
MN81805-4	8/18/2005	3917988	482236	Moenkopi Formation (red sandstone/shale)
MN81805-5	8/18/2005	3920706	482136	Fluvial sand (Little Colorado River basin)
MN81805-6	8/18/2005	3920707	482137	Basalt
MN81805-7	8/18/2005	3920708	482138	Tephra in Little Colorado River basin
MN81805-8	8/18/2005	3895860	456733	Kaibab Formation (sandy limestone/dolostone) at Cosnino Road railroad cut
NOTES: 1 cm = 0.4 in.				

APPENDIX F

Appendix F. Geologic Samples Collected in 2006 for Spectroscopic Analysis						
Sample	**Date**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)†**	**Lithology***	**Comments**
MN62206-1	6/22/2006	3910843	456994	2,239	Primary tephra (Qsp)	Qsp is basaltic tephra from the Sunset Crater eruption. At this location the tephra is blanketing an unnamed scoria cone north of Little Cinder Basin. Site revisited 6/25/06. It seems that Qsl has a higher reflectance than Qts.
MN62306-2	6/23/2006	3911505	454440	2,133	Primary tephra (Qsp)	This sample location is west of the first sample location and tephra is blanketing an unnamed scoria cone.
MN62306-3	6/23/2006	3906630	456866	2,041	Primary tephra (Qta)	Qta is basaltic tephra that was deposited by cone V46 (pre-Merriam age) with later Sunset tephra deposition. This sample location is southeast of Cinder Lake and looks similar to Cinder Lake except there is an abundance of vegetation. The topography is relatively flat.
MN62406-4	6/24/2006	3922652	467338	1,609	Primary tephra (Qbo)	This site is east of the Borrow Pit and the lithology is primary pre-Sunset basaltic tephra. At the surface there is a mixture of Sunset tephra, pre-Sunset tephra, and Moenkopi.
MN62406-5	6/24/2006	3921353	467681	1,618	Mixed tephra	This site is on a slope at the edge of a basalt lava flow. The tephra is mostly primary, but has some evidence of eolian deposition.
MN62406-6	6/24/2006	3918082	465291	1,728	Eolian tephra (Qe)	This site is an eolian deposit (sand dune) of Sunset tephra east of Black Bottom Crater.
MN62506-7	6/25/2006	3904282	452285	2,087	Primary cinder (Qtc)	This site is on the eastern slope of Old Caves Crater, or V28 and V29. There is some Sunset tephra that was blown down slope after its deposition. The upper slope where the sample was taken from is primarily red cinder (Qtc) and a mix of alluvium and soil.

Appendix F. Geologic Samples Collected in 2006 for Spectroscopic Analysis (continued)						
Sample	**Date**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)†**	**Lithology***	**Comments**
MN62506-8	6/25/2006	3912566	455944	2,144	Primary tephra (Qsl)	This site is southeast of Sunset Crater at the top of a small unnamed cinder/scoria cone. The tephra is weathered and red and it is the latest pyroclastic material from Sunset Crater. This deposit covers the primary cinder deposit of the crater. Revisited 6/25/06.
MN62506-9	6/25/2006	3912564	455927	2,137	Primary tephra (Qsl)	This sample is of fresh Qsl down slope from MN62506-8.
MN62506-10	6/25/2006	3913582	462683	1,967	Primary cinder (Qtc)	This location is on the west flank of a pre-Sunset cinder cone. The sample is a primary cinder cone deposit.
MN62606-11	6/26/2006	3917958	467058	1,703	Primary cinder (Qmc)	This location is east of Black Bottom Crater. It is a small scoria cone next to a much larger asymmetrical scoria cone (V173). The sample is a red-colored primary cone deposit.
MN62606-12	6/26/2006	3918063	467224	1,673	Eolian tephra (Qe)	This location is east of MN62606-11. The deposit is eolian tephra from Sunset with minor mixing.
MN62606-13	6/26/2006	3918252	467233	1,675	Primary tephra (Qmp)	This location is east of V173 and the deposit is primary tephra from V173.
MN62606-14	6/26/2006	3917397	466826	1,698	Primary tephra (Qtb)	This location is west of V172 and the deposit is primary tephra from V172.
MN62606-15	6/26/2006	3917102	466320	1,706	Primary tephra (Qsp)	This location is west of MN62606-14 and is primary Sunset tephra (large tephra clasts).
MN62606-16	6/26/2006	3917115	464487	1,804	Primary cinder (Qtc)	This location is on the southeast flank of Black Bottom Crater (V93). The sample is of red cinder and is the primary cinder cone deposit.
MN62606-17	6/26/2006	3917181	464617	1779	Eolian tephra (Qe)	This location is east of MN62606-16 and is an eolian deposit of Sunset tephra mixed with minor red cinder from Black Bottom.

Appendix F. Geologic Samples Collected in 2006 for Spectroscopic Analysis (continued)						
Sample	**Date**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)†**	**Lithology***	**Comments**
MN62706-18	6/27/2006	3919315	482534	1432	Mixed tephra (Qe)	This is a mixed eolian deposit of Sunset tephra and Moenkopi on top of a basalt flow (Qmb) from V127 or V128.
MN62706-19	6/27/2006	3919319	482549	1432	Basalt flow (Qmb)	Primary basalt flow (Qmb) from V127 or V128 on the west side of the road, south of Great Falls.
MN62706-20	6/27/2006	3921293	482765	1413	Primary Moenkopi Fm. (TRps)	Moenkopi Formation weathers at this location into small, platy pieces with an underlying sandy, primitive soil. Small coppice dunes (Moenkopi in origin) around vegetation clumps. Here Moenkopi is interbedded with finer-grained mudstone. Sampled pieces of Moenkopi.
MN62706-21	6/27/2006	3921122	482753	1412	Alluvium (Qal)	Overflow channel of Little Colorado River upstream from Grand Falls. Mixed alluvium with eolian coppice dunes around vegetation clumps. Sampled alluvium.
MN62706-22	6/27/2006	3921172	482714	1407	Alluvium (Qal)	Main channel of the Little Colorado River (dry). Mudcracks up to 60 cm in length, average ~25–30 cm; triangular and rectangular shaped, some polygonal. Cracks up to 25 cm deep. Numerous photographs.
MN62706-23	6/27/2006	3922241	484880	1444	Non-volcanic eolian (Qe)	Dunes have accumulated up against terrace gravel (Qtg) forming topographic high.
MN62706-24	6/27/2006	3921615	484688	1,431	Non-volcanic eolian (Qe)	Primarily non-volcanic eolian dunes with some eolian Sunset tephra (Qsp) giving dunes darker color in some areas. Dunes are unobstructed allowing for more movement and less vegetation than MN62706-23.

Appendix F. Geologic Samples Collected in 2006 for Spectroscopic Analysis (continued)						
Sample	**Date**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)†**	**Lithology***	**Comments**
MN62706-25	6/27/2006	3910615	473958	2,067	Primary cinder (Qmc)	This site is at the top of Merriam Crater (V128) on the north side approximately 20 m down into the crater. The sample is primary cinder cone deposit.
MN62706-26	6/27/2006	3912498	472003	1,680	Bedded tuff/debris flow	This site is west of Merriam Crater (V128) and is a lithified bedded tuff or debris flow deposit. Deposit made up of volcanics, Moenkopi, and limestone. Clasts angular to subangular and poorly sorted. Largest boulder (Moenkopi) >1 m. Layers 10–30 cm thick.
MN62706-27	6/27/2006	3916238	471101	1649	Eolian tephra (Qe)	This is an eolian deposit of Sunset tephra up against a basaltic lava flow from V170 or V171.
MN62906-31	6/29/2006	3902661	467118	1,867	Basalt flow (Qtb)	This site is mapped as primary basalt (Qtb) that may be subdued by pyroclastic sheet or alluvium. Mixed Sunset and pre-Sunset sampled with primitive, light brown soil underneath.
MN62906-32	6/29/2006	3903041	467353	1,857	Eolian tephra (Qe)	This site is eolian Sunset tephra blown against the base of V120, forming a crescent on the southeast base of the cone. Strong vegetation difference from the eolian at base of cone to vegetation on the primary deposit.
MN62906-33	6/29/2006	3903084	467419	1,864	Primary cinder (Qtc)	This location is approximately 1/4 up the south-southeast flank of V120 in primary cinder deposit slightly covered with reworked Sunset tephra. Darker than red top of crater, not as dark as MN62906-32.
MN62906-34	6/29/2006	3903035	467576	1,893	Primary cinder (Qtc)	Higher up on V120 than MN62906-33, approximately 1/2 up the cone. Deposit is red, primary cinder with some very large basalt up to 1.5 m in diameter.

Appendix F. Geologic Samples Collected in 2006 for Spectroscopic Analysis (continued)						
Sample	**Date**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)†**	**Lithology***	**Comments**
MN62906-35	6/29/2006	3901954	469599	1,797	Eolian tephra (Qe)	Qe deposit on the west side of a wash that flows into San Francisco wash and east of an outcrop of basalt. Eolian deposit is lighter in color than most eolian tephra, possibly from mixing with alluvium from the wash.
MN62906-36	6/29/2006	3922981	481059	1,430	Moenkopi (Trps)	Sampled mixed eolian from Moenkopi and Sunset tephra.
MN62906-37	6/29/2006	3921758	480824	1,407	Moenkopi (Trps)	Moenkopi and Kaibab sedimentary rocks outcropping along a wash flowing into the Little Colorado River. Sample of yellow limestone (Kaibab) taken from the north side of the wash. Limestone on the south side of the wash was pink, most likely from dust from the Moenkopi.
MN62906-38	6/29/2006	3921441	480903	1,408	Moenkopi (Trps)	Sampled large piece of Moenkopi at the edge of the gorge of the Little Colorado River.
MN70106-39	7/1/2006	3915201	450222	2,180	Primary cinder (Qtc)	Primary cinder deposit on V38 west of Sunset Crater. Small sample taken with a few pieces of larger cinder.
MN70106-40	7/1/2006	3915058	449847	2,242	Primary cinder (Qtc)	Approximately 15 m down from top of Crater V37; cinder mostly large and red mixed with some Sunset tephra.
MN70306-47	7/3/2006	3912134	456214	2,149	Primary tephra (Qsp)	This location is on primary Sunset tephra (Qsp) in the sand bluestem vegetation class as mapped by U.S. Geological Survey.
MN70306-48	7/3/2006	3911781	456510	2,147	Primary tephra (Qsp)	Cinder class mapped by U.S. Geological Survey in the Cinder Hills ORV area; tephra heavily reworked by ORVs. Small surficial sample taken near shrub so not very disturbed.

Appendix F. Geologic Samples Collected in 2006 for Spectroscopic Analysis (continued)						
Sample	**Date**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)†**	**Lithology***	**Comments**
MN70306-49	7/3/2006	3914057	455691	2,117	Primary tephra (Qsp)	This location is within the first isopach of southwest-northeast transect. Approximately 50 m form the Sunset Crater park boundary on the northeast side of the Crater.
MN70306-50	7/3/2006	3918553	449287	2,153	Andesite (porphyritic) flow (Qoaf)	At this location a surface sample of the soil formed on Qoaf was taken. This location is just south of V47 and north of Qorr near V523.
MN70306-52	7/3/2006	3920677	452042	2,009	Primary tephra (Qsp)	At this location a tephra pit was dug with 30 cm of tephra.
MN70306-53	7/3/2006	3921950	454026	1,912	Rhyodacite flow (Qor)	Deadman's Mesa (Qor) mantled with alluvium and only a very thin lag of Sunset tephra.
MN70506-54	7/5/2006	3914348	456096	2,106	Primary tephra (Qsp)	Transect: between first (12 m) and second (10 m) isopach.
MN70506-55	7/5/2006	3914591	456528	2,085	Primary tephra (Qsp)	Transect: between second (10 m) and third (8 m) isopach.
MN70506-56	7/5/2006	3914885	457058	2,056	Primary tephra (Qsp)	Transect: between third (8 m) and fourth (6 m) isopach. There is an increasing amount of Pinyon Pine, but still not prevalent; few grasses.
MN70506-57	7/5/2006	3915008	457400	2,048	Primary tephra (Qsp)	Transect: between fourth (6 m) and fifth (5 m) isopach.
MN70506-58	7/5/2006	3915204	457958	2,028	Primary tephra (Qsp)	Transect: between fifth (5 m) and sixth (4 m) isopach.
MN70506-59	7/5/2006	3915805	458814	2,000	Primary tephra (Qsp)	Transect: first sample collected between sixth (4 m) and seventh (3 m) isopach.
MN70506-60	7/5/2006	3916166	459350	1,987	Primary tephra (Qsp)	Transect: second sample collected between sixth (4 m) and seventh (3 m) isopach.
MN70506-61	7/5/2006	3916773	460551	1,891	Primary tephra (Qsp)	Transect: between seventh (3 m) and eighth (2 m) isopach.

Appendix F. Geologic Samples Collected in 2006 for Spectroscopic Analysis (continued)						
Sample	**Date**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)†**	**Lithology***	**Comments**
MN70506-62	7/5/2006	3917987	461634	1,802	Primary tephra (Qsp)	Transect: between tenth (0.8 m) and eleventh (0.6 m) isopach.
MN70506-63	7/5/2006	3918739	462334	1,782	Primary tephra (Qsp) on basalt flow (Qmb)	Transect: between tenth (0.8 m) and eleventh (0.6 m) isopach. Tephra pit dug; basalt outcrops in area.
MN70506-64	7/5/2006	3919656	463533	1,782	Alluvium (Qal)	Transect: between 11th and 12th isopach, near where Ronnie and John dug alluvium pit
MN70506-65	7/5/2006	3921936	466922	1,632	Basalt flow (Qtwb)	Transect: basalt flow (mapped Qtwb) with alluvium and thin layer of Sunset tephra.
MN70506-66	7/5/2006	3922087	467475	1,617	Eolian tephra (Qe)	Transect: Qe blown against basalt ridge.
MN70506-67	7/5/2006	3922511	467412	1,614	Basalt flow (QTwb)	Transect: thin layer of tephra (maximum 10 cm).
MN70506-68	7/5/2006	3918428	471619	1,654	Basalt flow (Qtwb)	Last point of transect (south of other points due to access). Soil formed on basalt flow; sampled soil and some basalt.
MN70606-70	7/6/2006	3918250	468365	1,677	Mixed eolian (Qe) on basalt flow	Mixed Sunset tephra and non-Sunset eolian; lighter in color than pure Sunset eolian.
MN70606-71	7/6/2006	3914367	469654	1,701	Eolian Tephra (Qe)	Eolian (primarily Sunset tephra) blown against basalt outcrop.
MN70606-72	7/6/2006	3913474	470368	1,708	Basalt flow (Qmb) and eolian tephra (Qe)	Primary and eolian tephra sampled together from the same location to help determine the difference between the two.
MN70606-73	7/6/2006	3912723	468413	1,745	Alluvium (Qal)	Alluvium.
MN70606-74	7/6/2006	3910381	464743	1,909	Primary tephra (Qsp)	Uphill from road; marked Qsp on geologic map. Steep slope.
MN70606-75	7/6/2006	3912431	462211	2,007	Primary tephra (Qsp)	Sampled primary Sunset tephra (Qsp).

Appendix F. Geologic Samples Collected in 2006 for Spectroscopic Analysis (continued)						
Sample	**Date**	**Northing (UTM)**	**Easting (UTM)**	**Elevation (m)†**	**Lithology***	**Comments**
MN70706-83	7/7/2006	3910682	448473	2,169	Andesite flow (Qta)	Thin lag of Sunset tephra on primary andesite flow (Qta) from San Francisco Peaks Volcanic Center. Heavily mantled with alluvium. Qta occurs only in the western section of the study area. Sampled surface with thin lag of Sunset.
MN70706-84	7/7/2006	3915711	449577	2,218	Basalt flow (Qtb)	Sample of loose, orange soil taken from the top of basalt flow from V38.
MN70806-85	7/8/2006	3908562	474051	1,720	Basalt flow (Qmb)	Quarry south of Merriam and north of North Sheba Crater (V131). Area mapped as basalt flow (Qmb), but quarry appears to be mostly tephra. Sampled surface of pile on edge of quarry.
MN70806-86	7/8/2006	3897476	450553	2,050	Kaibab Formation	Sampled pieces of the Kaibab Formation (dolostone/limestone) at a roadcut on Santa Fe Avenue east of Flagstaff.

* Description of map/lithologic units is from Moore, R.B. and E.W. Wolfe. "Geologic Map of the Eastern San Francisco Volcanic Field, Arizona." U.S. Geological Survey Miscellaneous Investigations Series Map I–953. Scale 1:50,000. 1976.

†1 m = 3.3 ft. and 1 cm = 0.4 in.

APPENDIX G

Appendix G. Site Descriptions of Surface Samples Used In the Measurement of Airborne Particle Concentrations		
Site Identifier	**Ground Surface Material Type**	**Description**
V-P	Volcanic, Primarily Non-reworked	Primarily non-reworked implies an *in-situ* deposit or tephra that has not been transported by erosional processes from the place of original deposition. Non-reworked or pristine tephra is glassy and vesicular representing volcanic fragments that have fallen to the ground in a solid condition.
V-F	Volcanic, Fluvial Channel* Volcanic, Fluvial Banks*	Samples collected from the channel and banks of a small wash (ephemeral stream). Friction and impact during transport by running water may abrade and mechanically break tephra particles. Tephra may be mixed with other materials. The channel deposit was not well sorted.
V-E	Volcanic, Eolian	Coppice dune environment where wind or eolian processes produce fine-grained, well-sorted, and well-rounded tephra grains. Clay content (illite, mica, and kaolinite) of about 4 percent by weight is greater than the negligible clay content in pristine, non-reworked tephra.
N-Pa	Nonvolcanic, Primarily Non-reworked (alluvium)†	Unconsolidated and unsorted sediment of exposed alluvial pebbles, sand, and silt derived from basaltic volcanism that predates the Sunset Crater eruption. Alluvium in the Sunset Crater area can be composed of nonvolcanic material from the Moenkopi and Kaibab Formations, volcanic material of a nonbasaltic composition including San Francisco Mountain and andesitic to rhyolitic lava domes, and basalt. The amount of ferromagnesian components (plagioclase, augite, and olivine) of about 70 percent by weight in the alluvium is similar to the total amount in pristine Sunset Crater tephra. The alluvium, however, had a higher quartz and calcite content (together about 10 percent by weight), compared to negligible amounts in pristine Sunset Crater tephra. Lower amounts of amorphous glass (about 15 percent by weight) were also found in the alluvium.

Appendix G. Site Descriptions of Surface Samples Used In the Measurement of Airborne Particle Concentrations (continued)		
Site Identifier	**Ground Surface Material Type**	**Description**
N-Ps	Nonvolcanic, Primarily Non-reworked (sandstone)	Calcareous sandstone of the Moenkopi Formation primarily composed of quartz and calcite (over 80 percent by weight) with lesser amounts of clay (predominantly kaolinite with smaller amounts of illite and mica), potassium feldspar, dolomite, and hematite.
N-F	Nonvolcanic, Fluvial	Fluvially redistributed deposit of pebbles, sand, and silt from San Francisco Wash, an ephemeral stream that drains a larger area including limestone and dolostone from the Kaibab Formation exposed to the southwest. In addition to fragments of the Kaibab Formation, the sample also consists of detrital quartz and feldspar, fragments of the Moenkopi Formation, and some basaltic lava fragments that predate the Sunset Crater eruption. Sunset Crater tephra is a minor component.
N-E	Nonvolcanic, Eolian	Sand and silt redistributed from eolian processes. Dune samples were mainly composed of quartz with lesser amounts of potassium feldspar and plagioclase. Tephra from either the Merriam Crater or Sunset Crater eruption is a minor component.
Extra-F	Extra nonvolcanic fluvial deposit	Fluvially redistributed material composed of fine-grained sand, silt, and clay dropped from suspension after stream flow events. Although time limitations restricted scouting of areas around this extra measurement site, the mainly silt-sized deposit seemed localized to where an unpaved forest route road crossed Deadman Wash, northwest of Sunset Crater. The fluvial deposit originates from the San Francisco Mountain drainage system, located west of Sunset Crater and U.S. Interstate 40. Compared to the basaltic tephra of Sunset Crater, the San Francisco Mountain area consists mainly of andesite of a much older igneous origin. Other material (e.g., glacial deposits) may also be present in the drainage system and available for fluvial transport.

*Surface samples of channel and bank deposits at the fluvial volcanic site were collected and processed separately. The fluvial channel was approximately 3-m [10-ft] wide with banks about 2-m [7-ft] high.

†The term “primarily non-reworked” is used to indicate that the deposit is not in an active region of fluvial or eolian erosion and redistribution.