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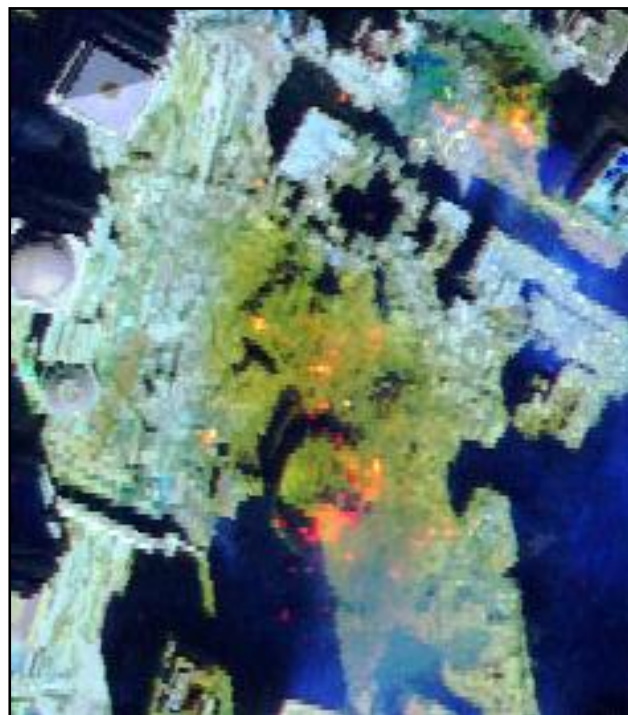
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Environmental Studies of the World Trade Center area after the September 11, 2001 attack.

Version 1.1

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Executive Summary

This web site describes the results of an interdisciplinary environmental characterization of the World Trade Center (WTC) area after September 11, 2001.

Information presented in this site was first made available to the World Trade Center emergency response teams on September 18, 2001 (Thermal hot spot information), and September 27, 2001 (maps and compositional results).

The Airborne Visible / Infrared Imaging Spectrometer (AVIRIS), a hyperspectral remote sensing instrument, was flown by JPL/NASA over the World Trade Center (WTC) area on September 16, 18, 22, and 23, 2001 ([Link to the AVIRIS JPL data facility](#)). A 2-person USGS crew collected samples of dusts and airfall debris from more than 35 localities within a 1-km radius of the World trade Center site on the evenings of September 17 and 18, 2001. Two samples were collected of indoor locations that were presumably not affected by rainfall (there was a rainstorm on September 14). Two samples of material coating a steel beam in the WTC debris were also collected. The USGS ground crew also carried out on-the-ground reflectance spectroscopy measurements during daylight hours to field calibrate AVIRIS remote sensing data. Radiance calibration and rectification of the AVIRIS data were done at JPL/NASA. Surface reflectance calibration, spectral mapping, and interpretation were done at the USGS Imaging Spectroscopy Lab in Denver. The dust/debris and beam-insulation samples were analyzed for a variety of mineralogical and chemical parameters using Reflectance Spectroscopy (RS), Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), chemical analysis, and chemical leach test techniques in U.S. Geological Survey laboratories in Denver, Colorado.

Results of these studies to date lead to several important conclusions:

- The dusts released from the WTC building collapse are largely composed of particles of glass fibers, gypsum, concrete, paper, and other miscellaneous materials commonly used in building construction.
- Laboratory analyses (RS, SEM, XRD) have detected chrysotile asbestos only in trace levels (less than 1 weight percent) in over two thirds of the dust and airfall debris samples. To date, no amphibole asbestos minerals have been detected in any of the dust samples. For definitions of asbestos, [CLICK HERE](#) (use the back button on your browser to return here).
- Laboratory analyses of the material coating a steel beam in the WTC debris have detected the presence of chrysotile asbestos (a serpentine mineral) at levels as high as 20% (by volume) of the coating material. No amphibole asbestos has been detected in this beam coating material.
- AVIRIS mineral maps do not show widespread distribution of chrysotile or amphibole asbestos at the few-percent detection limit of the instrument at the ground surface. AVIRIS mapping keyed to the detection of minerals that may occur in asbestiform habits has identified isolated pixels or pixel clusters (each pixel is approximately 2m x 2m) in the area around the WTC. In these areas, potentially asbestiform minerals might be present in concentrations of a few percent to tens of percent. Some spectral absorption strengths in the AVIRIS data are similar to those observed in spectra of the chrysotile asbestos-bearing beam coating. The absorption features mapped by AVIRIS only indicate the presence of serpentine mineralogy and not if the serpentine has asbestos form. Non-asbestiform serpentine minerals can occur naturally in rocks and such rocks may have been used in building materials. The AVIRIS maps could indicate areas of higher concentrations of asbestos or simply areas of non-asbestiform mineralogy and would need field sampling and laboratory analysis to confirm the presence of any asbestos. The AVIRIS maps show the surface materials only and not any buried materials.
- AVIRIS mineral maps show a few isolated pixels of amphibole minerals, but these pixels are isolated with no clusters like those seen in the chrysotile pixels. The few mapped amphibole pixels are at a statistical noise level in the WTC area similar to the pixel noise level mapped throughout the city. The absorptions mapped by AVIRIS only indicate the presence of amphibole mineralogy, which can occur naturally (non-asbestiform) in rocks that are used in building materials, and field sampling of those pixels would be necessary to confirm the presence of asbestos. The AVIRIS maps of serpentine chrysotile and amphibole mineralogy are consistent with laboratory analyses of the field samples.
- Laboratory analyses and the AVIRIS mapping results indicate the dusts are variable in composition, both on a fine scale within individual samples and on a coarser spatial scale based on direction and distance from the WTC. Replicate mineralogical and chemical analyses of material from the same

sample reveal variability that presumably is due to the heterogeneous mixture of different materials comprising the dusts. The spatial variability is observed at large scales of tens of meters to centimeter and smaller scales. AVIRIS mapping suggests that materials with higher iron content settled to the south-southeast of the building 2 collapse center. Chrysotile may occur primarily (but not exclusively) in a discontinuous pattern radially in west, north, and easterly directions perhaps at distances greater than 3/4 kilometer from ground zero.

- Although only trace levels of chrysotile asbestos have been detected in the dust and airfall samples studied to date, the presence of up to 20 volume % chrysotile in material coating steel beams in the WTC debris, and the potential areas indicated in the AVIRIS mineral maps indicates that asbestos can be found in localized concentrations.
- Chemical leach tests of the dusts and airfall debris samples indicate that the dusts can be quite alkaline. When reacted with rain water or wash water from cleanup efforts, the dusts can produce slightly alkaline to very alkaline solutions, due to partial dissolution of concrete, gypsum, and glass fiber particles. Indoor dust samples generated the highest pH levels (11.8) in the leach tests, indicating that dusts that have not been exposed to rainfall since September 11th are substantially more alkaline than those that have been leached by rainfall.
- At least some heavy metals and metalloids (such as aluminum, chromium, antimony, molybdenum, and barium) are readily leached from the dusts into rain or wash water. Indoor dust samples showed greater proportions of leachable metals than outdoor dust samples. These metals may also be potentially bioavailable if the dusts are accidentally inhaled or ingested. Chemical leach tests of the material coating steel girders in the WTC debris indicate that the coatings can contain soluble chromium.
- AVIRIS data collected on September 16, 2001, revealed a number of thermal hot spots in the region where the WTC buildings collapsed. Analysis of the data indicated temperatures greater than 800°F in these hot spots (some over 1300°F) . Over 3 dozen hot spots of varying size and temperature were present in the core zone of the WTC. By September 23, most of these fires that were observable from an aircraft had been eliminated or reduced in intensity.
- Our finding that trace levels of asbestos are present in the dust samples is consistent with results of other studies carried out by the U.S. Environmental Protection Agency (www.epa.gov). Our results provide further clarification by showing that 1) elevated concentrations of asbestos may be present in beam coatings and possible localized area as indicated by the AVIRIS maps, and 2) asbestos in the dusts and beam coating materials is composed only of chrysotile asbestos and does not contain amphibole asbestos. A significant body of research conducted over the last twenty years by toxicologists, epidemiologists and mineralogists has indicated that chrysotile asbestos is less

carcinogenic than the amphibole asbestos minerals (Ross, 1999; Skinner et al., 1988; Van Oss et al., 1999; McDonald, 2001). This conclusion, however, has not been universally accepted by the scientific community. A recent and thorough discussion of these ongoing issues can be found in Nolan, et al. (2001).

- Results of our mineralogical characterization studies, chemical leach tests, and AVIRIS mapping provide further support for the EPA and New York Department of Public Health recommendations that cleanup of dusts and the WTC debris should be done with appropriate respiratory protection and dust control measures. These results include: the presence of up to 20 volume % chrysotile in material coating steel beams in the WTC debris (which could be unintentionally released into the air as dust during cleanup); the small areas in the AVIRIS mineral maps indicating that asbestos might be found in localized concentrations in the dusts; the highly alkaline nature of the dusts; and, the presence of potentially bioavailable metals in the dusts.
- For information on the health aspects of the dusts, readers are referred to web sites of the EPA: (<http://www.epa.gov>) and New York department of Public Health: (<http://www.nyc.gov/html/em/health.html>, and <http://www.nyc.gov/html/doh/html/alerts/911.html>)

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Introduction

The information in this report describes the results of an interdisciplinary environmental characterization of the World Trade Center (WTC) area following requests from other Federal agencies after the attack on September 11, 2001. The scientific investigation included two main aspects: 1) imaging spectroscopy mapping of materials to cover a large area around the WTC and 2) laboratory analysis of samples collected in the WTC area.

Spectroscopy is a tool that detects chemical bonds in molecules (solid, liquid or gas) through absorption (or emission) features in the spectrum of the material. Imaging spectroscopy obtains a spectrum for every spatial pixel in an image format. Data from the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) were collected over the WTC area by NASA/JPL for this study. The results of the imaging spectroscopy mapping are shown below.

The analytical techniques applied to this study include X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) with elemental analysis by Energy Dispersive Spectroscopy (EDS), laboratory Reflectance Spectroscopy (RS), leachable metals, and X-

Ray Fluorescence Spectroscopy (XRF).

For definitions of asbestos, [CLICK HERE](#) (use the back button on your browser to return here).

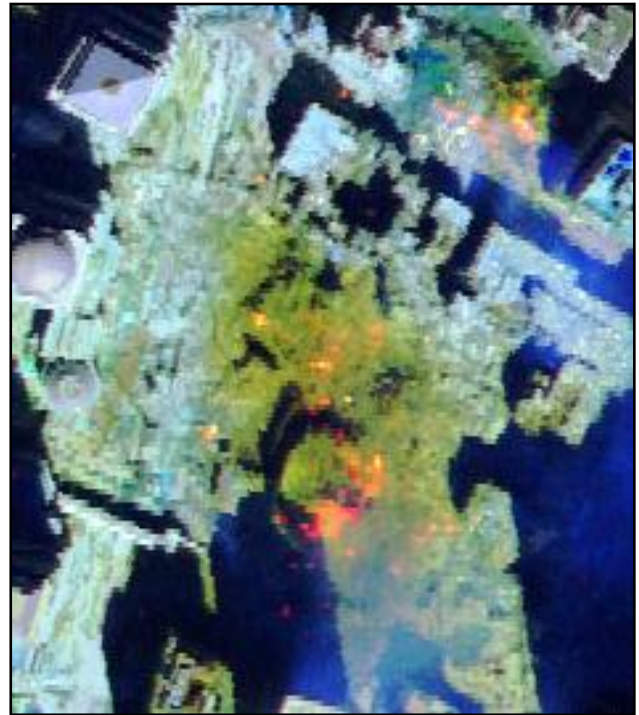
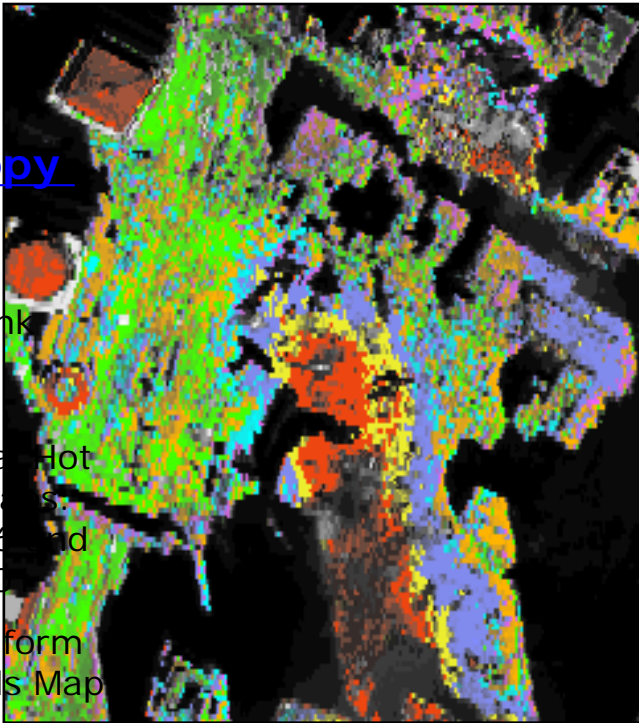
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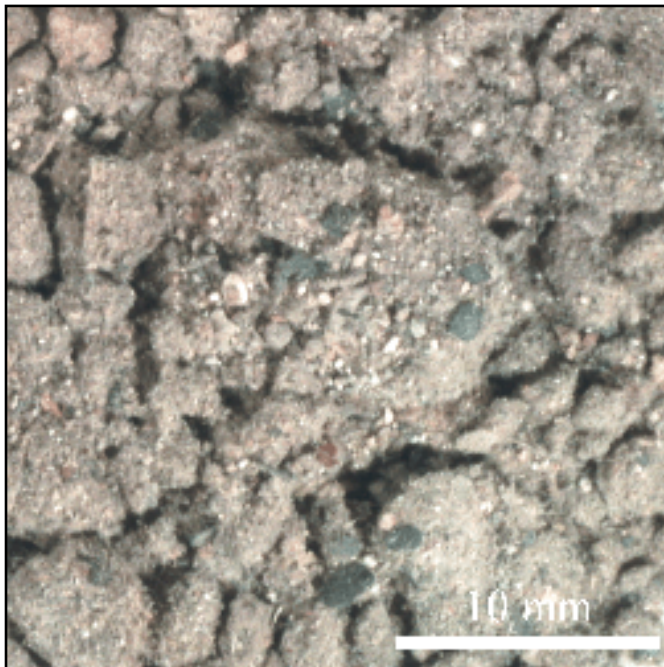
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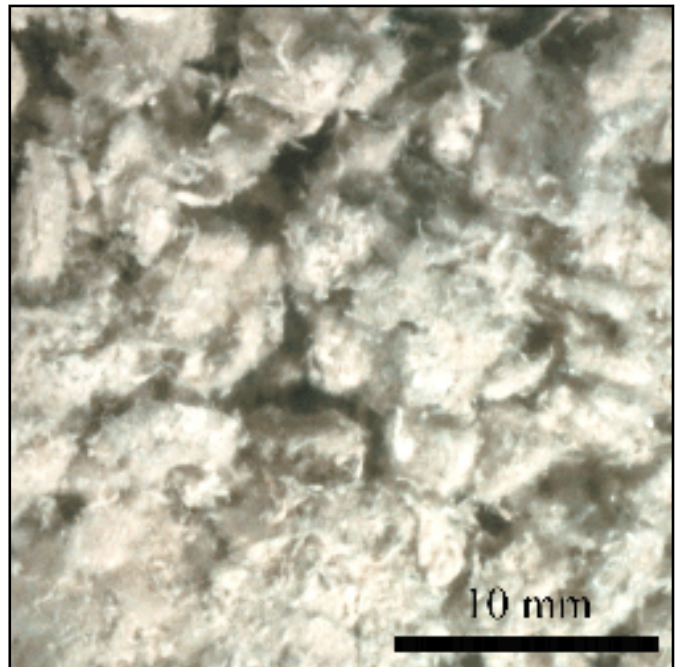
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[Sample Collection in the WTC Area](#)



Ground sampling consisted of collecting debris from 35 locations in the WTC area, including 33 dust, 2 concrete, and 2 steel



beam insulation samples.

Optical photographs of a typical dust sample on the left (sample WTC01-27) and what appeared to be an insulation coating from a steel beam on the right (WTC01-8). The coating contains as much as 20% chrysotile asbestos. Scale bar is 10 millimeters.

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Laboratory Studies of Samples

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The objective of the laboratory analysis was to characterize the samples for potential environmental impacts and to provide feedback to imaging spectral analysis and field confirmation of the imaging spectroscopy results. In certain cases the laboratory studies provide better detection levels than airborne imaging spectroscopy, thus providing complimentary information that allowing a more robust characterization of the entire site.

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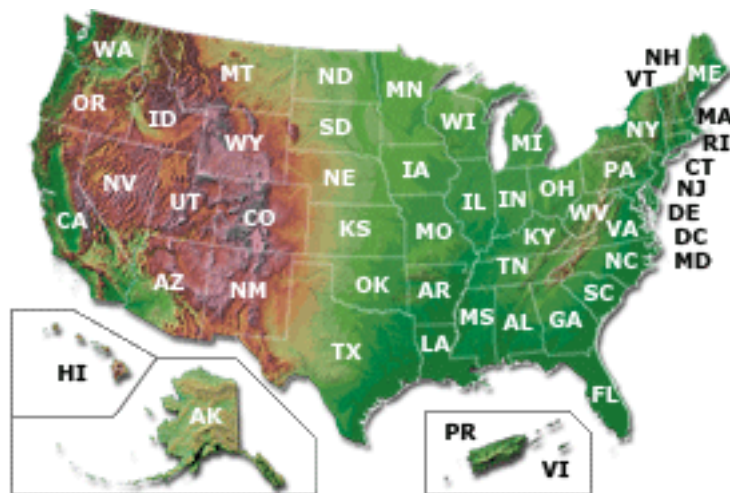
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A Fish Tale
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Proportions

Gulf sturgeon can grow to 8 feet
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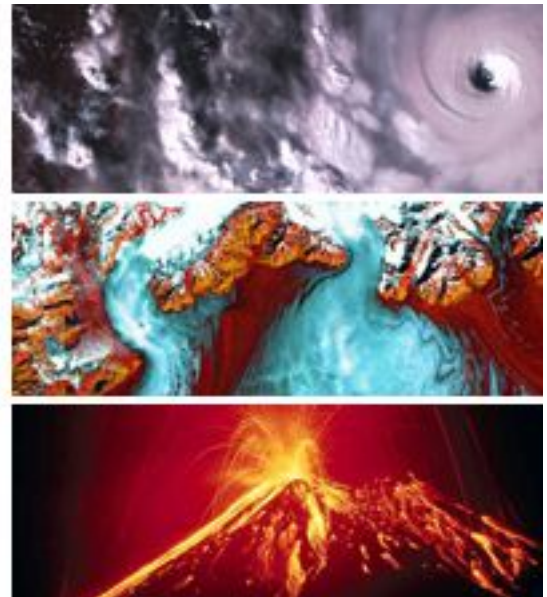
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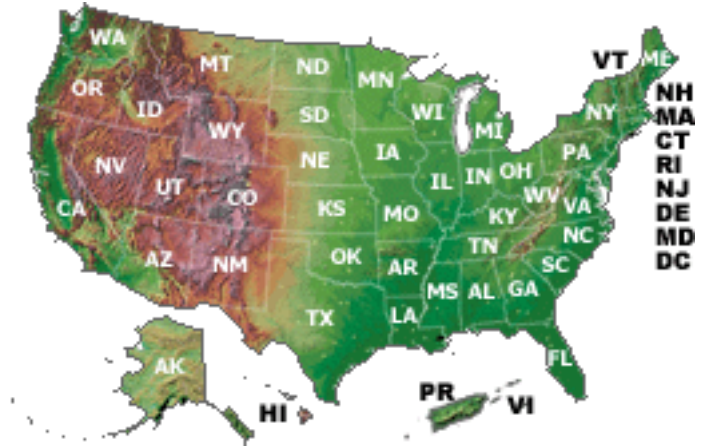
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The USGS joined more than 400 science organizations exhibiting products and services at the National Science Teachers Association (NSTA) National Convention, April 6-8, in Anaheim, Calif. See above link for photographs and more information.

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scientific research, in addition to employment and career development.

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Asbestos

Asbestos is a commercial term that represents several different silicate minerals which separate into long thin fibers, are heat resistant, and are chemically inert. Over the years, asbestos has been used in numerous commercial applications including fire proofing materials, ceiling tiles, floor tiles, insulation, brake linings, and many more. Since the nineteen seventies, the use of asbestos in commercial products has greatly diminished due to health concerns and demonstrated links to diseases such as asbestosis, mesothelioma and lung cancer.

Asbestos can be divided into two major classes of minerals, serpentines and amphiboles.

Chrysotile (includes the minerals clinochrysotile and orthochrysotile) is the only asbestos mineral of the serpentine group and has been the most widely used commercially. Chrysotile is a sheet silicate comprised of bundles of extremely small, tightly rolled sheets that form tubes or rods. Chrysotile has been more widely used than amphibole asbestos because it is usually more flexible, forms longer thinner fibers, and can easily be woven into cloth. Chrysotile is not as chemically inert as the asbestiform amphibole minerals.

All other asbestos belongs to the amphibole family of minerals. Amphiboles are chain silicates that include over fifty different minerals, most of which do not crystallize in asbestiform varieties. Of the few amphiboles recognized to crystallize in asbestiform varieties, those that have been used commercially are grouped into five materials that are referred to both in commercial and regulatory nomenclature as; **amosite** (includes the asbestiform varieties of the amphibole minerals cummingtonite and grunerite), **crocidolite** (asbestiform variety of the mineral riebeckite), **tremolite** (asbestiform variety of the mineral tremolite), **actinolite** (asbestiform variety of the mineral actinolite), and asbestiform **anthophyllite**. Other amphiboles can occur in asbestiform varieties, but these minerals have generally not been used in commercial products and are often not cited in the regulatory literature.

Listed below are the nominal (pure) chemical formulas for the most common asbestos minerals. It is rare, however, to find pure compounds in natural materials. Considerable chemical substitution often occurs in these minerals, particularly the amphiboles. As examples, some amount of sodium (Na) and potassium (K) often substitutes for calcium (Ca), and aluminum (Al) and titanium (Ti) can substitute for silicon (Si).

Common Asbestos Minerals

Serpentine

chrysotile $(\text{Mg,Fe})_3\text{Si}_2\text{O}_5(\text{OH})_4$

Amphiboles

tremolite $\text{Ca}_2(\text{Mg,Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$

actinolite $\text{Ca}_2(\text{Mg,Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$

cummingtonite $(\text{Mg,Fe}^{2+})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$

grunerite $(\text{Mg,Fe}^{2+})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$

riebeckite $\text{Na}_2(\text{Mg,Fe}^{2+})_3\text{Fe}^{3+}_2\text{Si}_8\text{O}_{22}(\text{OH})_2$

anthophyllite $(\text{Mg,Fe}^{2+})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$

A significant body of research conducted over the last twenty years by toxicologists, epidemiologists and mineralogists suggests that the amphibole asbestos minerals are more toxic than chrysotile (Ross, 1999; Skinner et al., 1988; Van Oss et al., 1999; McDonald, 2001). This conclusion, however, has not been universally accepted by the scientific community. A recent and thorough discussion of this ongoing debate can be found in Nolan, et al. (2001).

Definitions:

Asbestiform: The physical form or appearance of minerals that consists of long, thin and sometimes flexible fibers or needle-like structures.

Chain Silicate: A class of silicate minerals that form in structural chains. In some of these minerals the chains can separate easily along parallel crystallographic planes and can form fibrous or needle-like structures. Amphiboles and pyroxenes are members of the chain silicate family.

Mineral: A naturally occurring material with a specific chemical composition or range of compositions, and a specific crystalline structure.

Sheet Silicate: A class of silicate minerals that form in structural sheets and often break easily along one crystallographic plane so as to form extremely thin flat plates. Members of this mineral group include micas, clays, and serpentine.

* The above definitions are descriptive and are not intended to be used in the technical evaluation of materials containing asbestos.

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Imaging Spectroscopy Mapping Results for the World Trade Center Area

The AVIRIS instrument measures upwelling spectral radiance in the visible through short-wavelength infrared. The instrument has 224 spectral channels (bands) with wavelengths from 0.37 to 2.5 microns (micrometers) with sufficient spectral resolution to characterize diagnostic spectral features in materials. AVIRIS was flown at 2 altitudes in the WTC area for this study to give pixel sizes of approximately 2 and 4 meters.

The AVIRIS instrument was flown by NASA/JPL over the World Trade Center (WTC) area on Sept 16, 18, 22, and 23, 2001, after the attack on the WTC. This page shows results of analysis of the Sept 16 data. Collection of data on Sept 18 and 22 was hampered by clouds. Analysis of the Sept. 23 data includes an assessment of the change in thermal hot spots.

The 13 Gigabytes of September 16th data were sent to the USGS in Denver on September 17-18th. Atmospheric absorptions, instrument response and the solar

spectrum were removed using ground calibration that employs spectra of large, uniform areas in new Jersey outside the WTC debris zone. The areas were spectrally calibrated with real-time feedback from a field crew (Gregg Swayze and Todd Hoefen) on site with portable field spectrometers (Sept. 17-19).

The calibration measurements, field site, and AVIRIS coverage of the New York area are detailed within the next link. This is a data page and includes registered images with map coordinates for context. This page does not need to be read to follow the analysis and conclusions of this report, but is included for others trying to work with the AVIRIS data. Click here for the [field spectral measurements, registered images, and calibration site information.](#)

Once calibrated, the data were analyzed for the presence of specific spectral features to identify materials expressed in the spectrum at each pixel in the image. The methods employed, from calibration, to imaging spectroscopy analysis (the Tetracorder analysis system), to verification of results follows the procedures and methods established in Clark and Roush (1984), Clark et al., (1990b, 1991, 1995, 2001), Clark 1999, King et al., (2000), and Swayze et al., (2000). Reference spectra for the mapping are from Clark et al., (1993), Clark (1999), measurements made for the above studies, and this study.

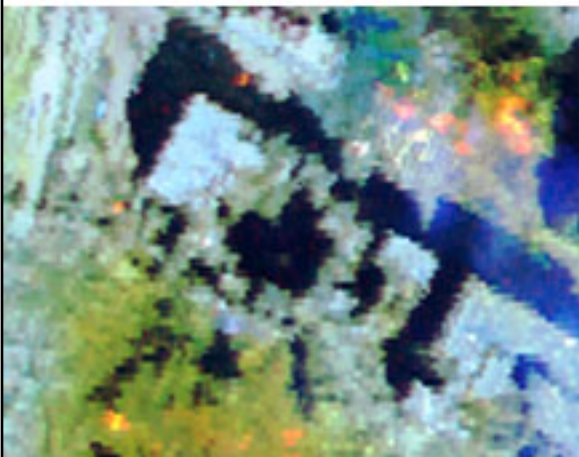
Because AVIRIS measures reflected sunlight it cannot detect materials deeper than can be seen with the human eye. For most solid materials this optical penetration is measured in millimeters.

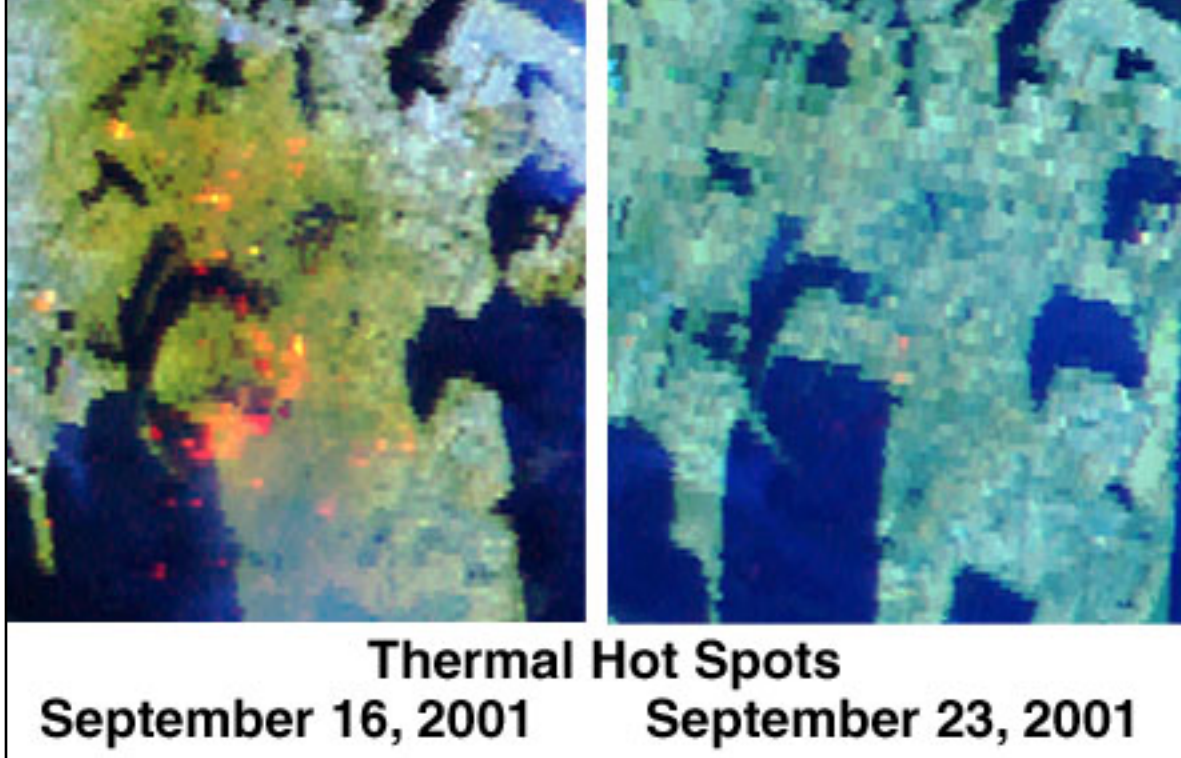
The materials maps below from AVIRIS and the USGS Tetracorder analysis (Clark et al., 2001) describe results from the imaging spectroscopy analysis. Click on the thumbnails or text below for full resolution image maps and explanatory text.

[Click here to go to the AVIRIS mapping. At the end of each page will be a link to the next mapping page. You can jump to specific mapping pages by clicking on the links below, or from the index.](#)

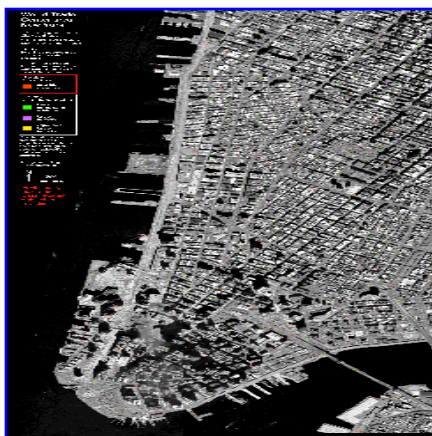
Thermal hot-spot maps. Images of the World Trade Center site show significant thermal hot spots on Sept. 16, 2001. By Sept. 23, 2001, most of the hot spots had cooled or the fires had been put out. The thermal images show the relative ground temperature at the World Trade Center for Sunday Sept 16, 2001 using infrared wavelengths sensitive to high temperatures. Red, orange, and yellow spots are regions of high thermal emission (high temperatures) with the yellow areas being the hottest and red the coolest.

World Trade Center area, New York

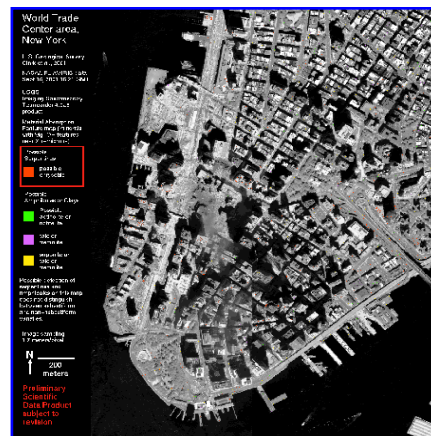




A key concern has been whether asbestos minerals, such as chrysotile, which may have been used in the WTC construction, were released into the environment as dusts by the WTC collapse. AVIRIS remote sensing images do not show widespread distribution of chrysotile or amphibole asbestos at the detection limit of the instrument. However, there is an indication of an east-west spread of possible chrysotile mineralogy.

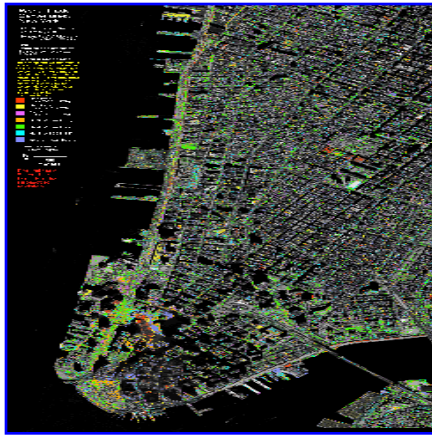


Serpentine and Amphibole minerals map.

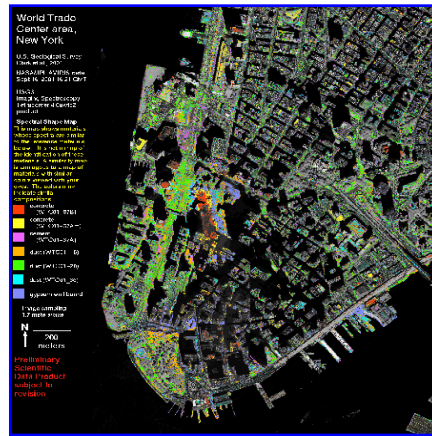


Serpentine and Amphibole minerals map, same as at right, but zoomed in to lower Manhattan.

Maps of the dust and debris materials are shown. This map shows the asymmetric distribution of materials after the building collapsed.



Dust/Debris plume map.



Dust/Debris plume map, same as at right, but zoomed in to lower Manhattan.

Iron-bearing Material Map: ferric- and ferrous-bearing materials are shown. This map shows the asymmetric distribution of materials after the building collapsed.

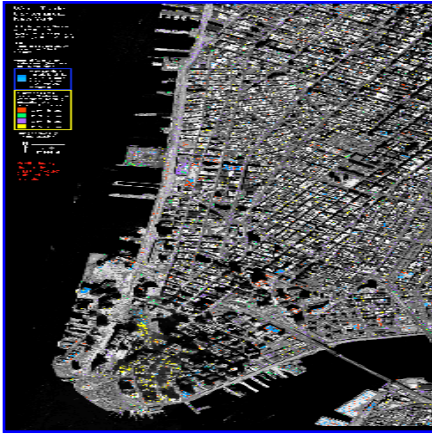


Ferrous, ferric iron absorption features map.

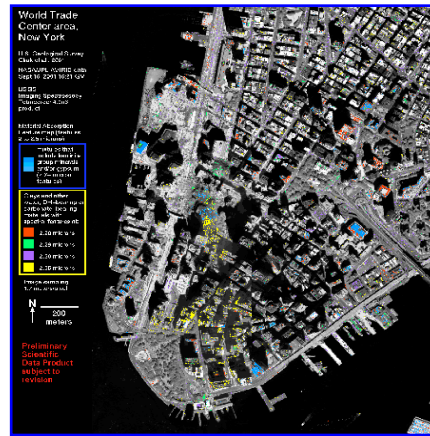


Ferrous, ferric iron absorption features map, same as at right, but zoomed in to lower Manhattan.

The material map of clays and other materials with hydroxyl vibrational absorption features shows the asymmetric distribution of materials after the building collapsed, in agreement with the ferric and ferrous absorption map above.

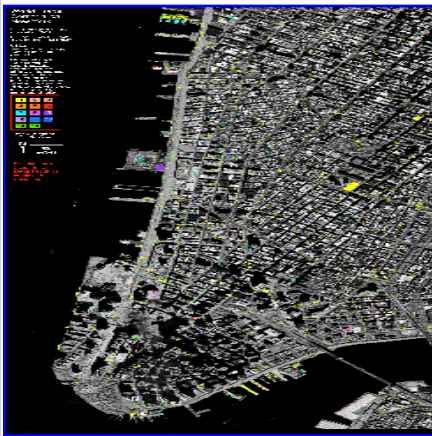


Vibrational absorption features map.

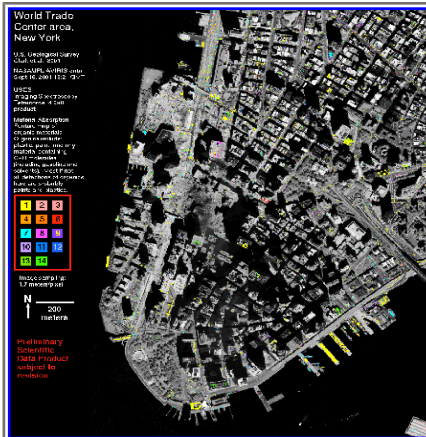


Vibrational absorption absorption features map, same as at right, but zoomed in to lower Manhattan.

The organic material map can includes paint, plastics, many types of solvents, gasoline, and other materials containing C-H bonds.

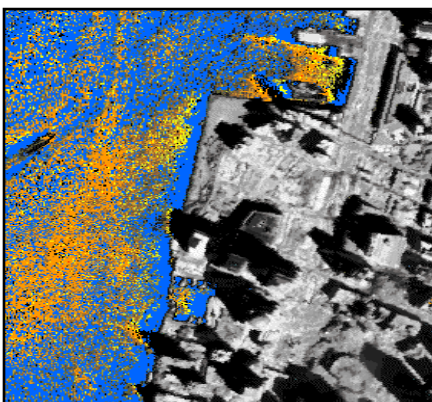


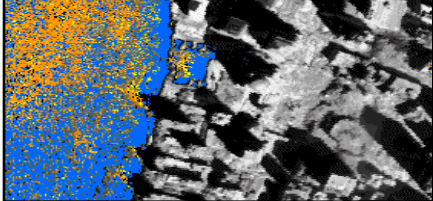
Organic materials absorption map.



Organic materials absorption map, same as at right, but zoomed in to lower Manhattan.

Sediment Map: Sediment in the water in the New York area is common. The maps show possible sources (yellow and orange) where material from the World Trade Center may be entering the river.





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[Link to the AVIRIS JPL data facility\)](#)

For information about AVIRIS, contact:

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AVIRIS Experiment Scientist

rog@spectra.jpl.nasa.gov

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Open-File Report 01-0429: AVIRIS Calibration Sites and Spectra[About USGS](#) / [Science Topics](#) / [Maps, Products & Publications](#) / [Education](#) / [FAQ](#)

Here are the calibration site image and corresponding spectral data files as measured on the ground using an Analytical Spectral Devices ASD-FR field-spectrometer. (*Use of trade names is for descriptive purposes only and does not constitute endorsement but the USGS.*) Several dozen field spectra were collected, averaged, and the results smoothed in areas where atmospheric absorption and instrument artifacts occurred.

Calibration Site on Mall Parking Garage Roof.

Roof is composed of two ages of concrete;
older concrete form the darker strips.

581051E 4508566N NAD27

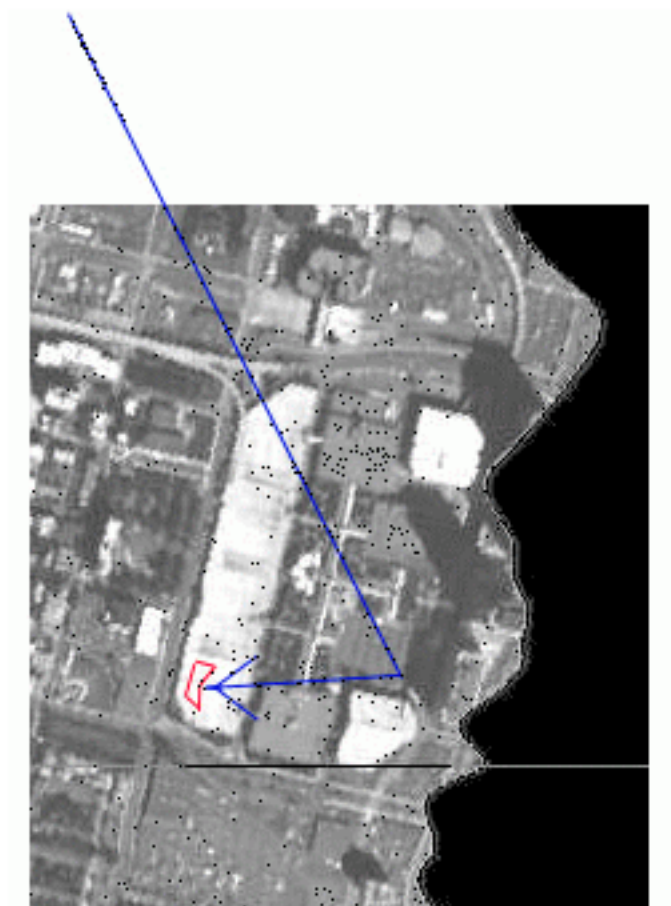


Figure 1. Parking Garage Roof (West Bank of the Hudson River, NJ).

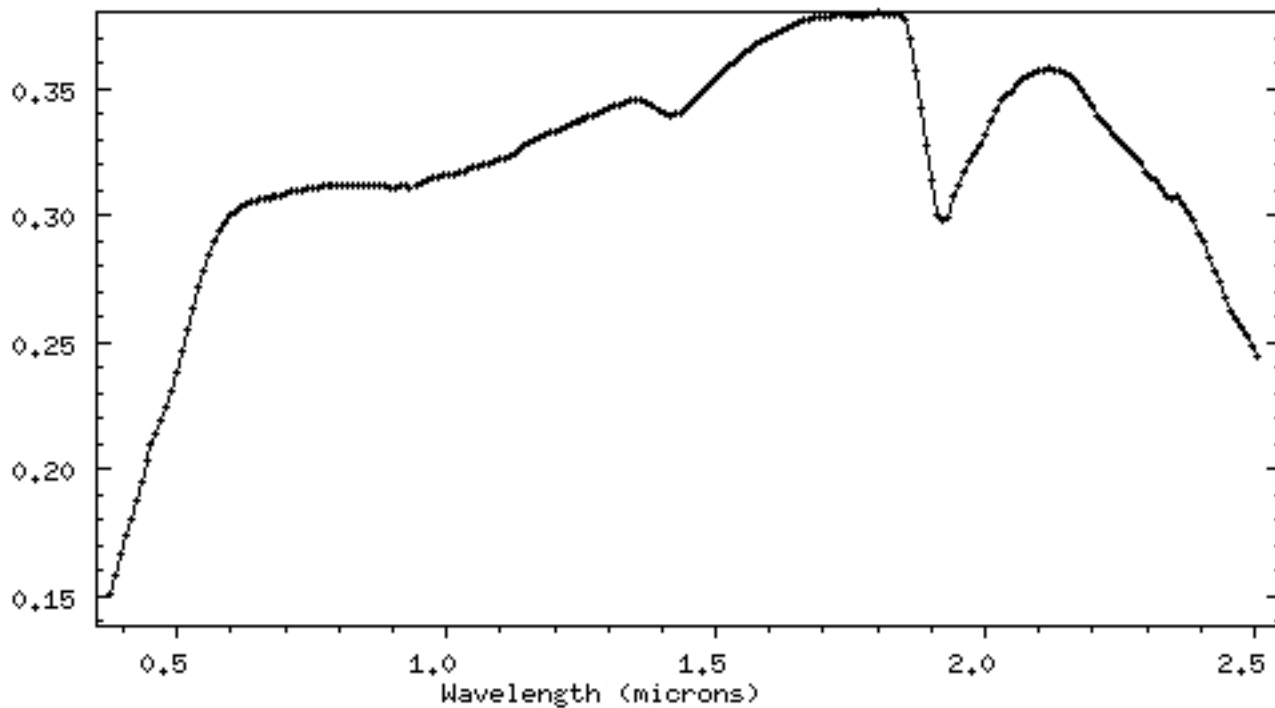
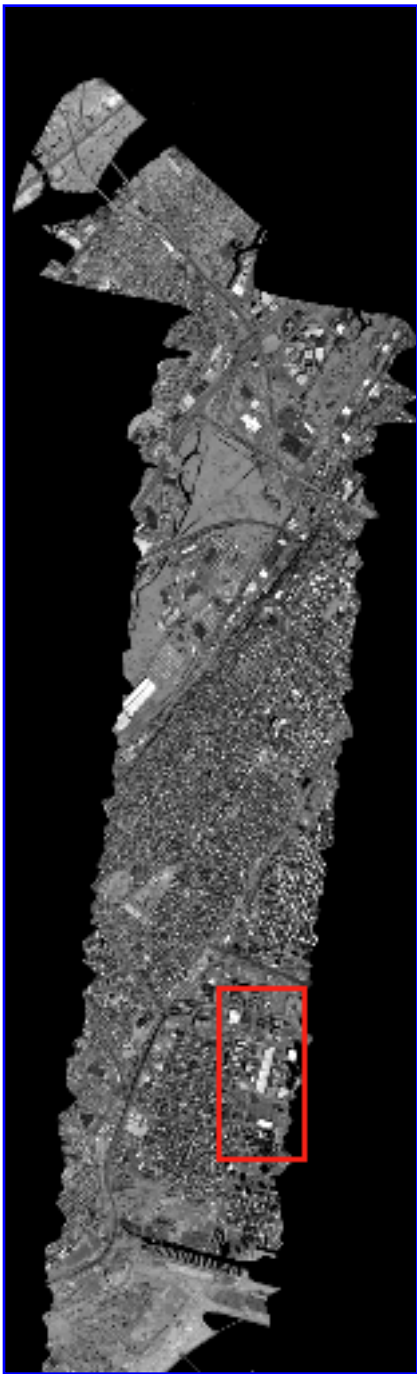


Figure 2. Spectrum Plot of Parking Garage Roof, NJ.

Click here for the [ASD spectrometer ASC-II data of the Parking Garage Roof, NJ, 717 channels](#) (field spectra averaged). Note: wavelengths are in Column 1, reflectance data are in Column 2.

Click here for the [ASD spectrometer ASC-II data of the Parking Garage Roof, NJ, 224 channels](#) (field spectra averaged and convolved to 2001 AVIRIS wavelengths). Note: wavelengths are in Column 1, reflectance data are in Column 2.

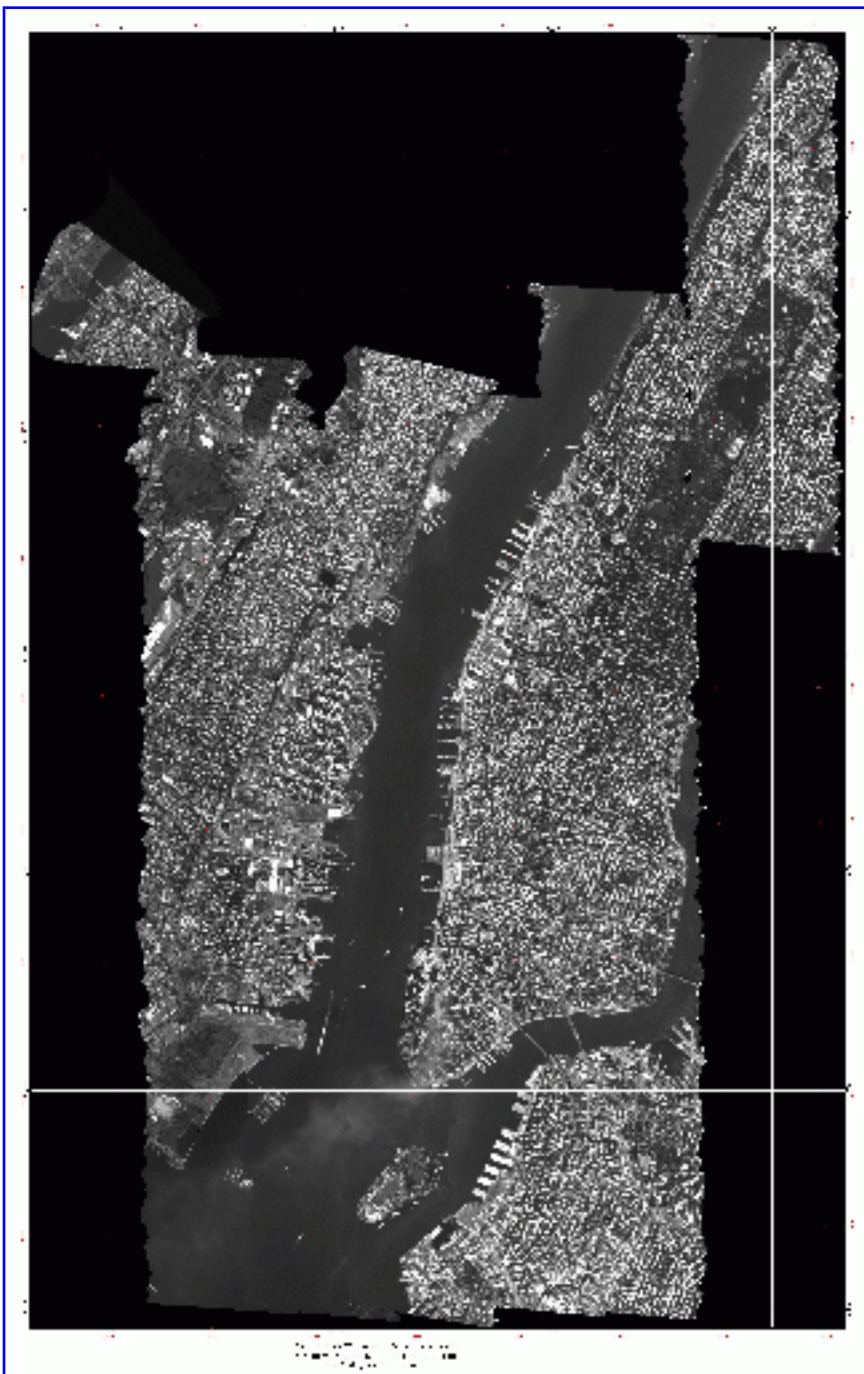
Here is the full Run 2 image (channel 150) showing the field calibration site within the red box at the lower right.



[Larger 1747 KB image](#)

Figure 3. Calibration site: AVIRIS Run 2, Sept. 16, 2001.

Here is the full flight coverage mosaic of AVIRIS (12,500 feet) for Sept. 16, 2001 (except for Run 8, where the WTC material is being disposed).



[Larger 6010 KB image](#)

Figure 4. AVIRIS run02-run07 (W to E) Mosaic

3.3 meter pixels, 0 degrees rotation

WGS-84/NAD83 datum

Joe Boardman, AIG

[Back to Imaging Spectroscopy Mapping Results](#)

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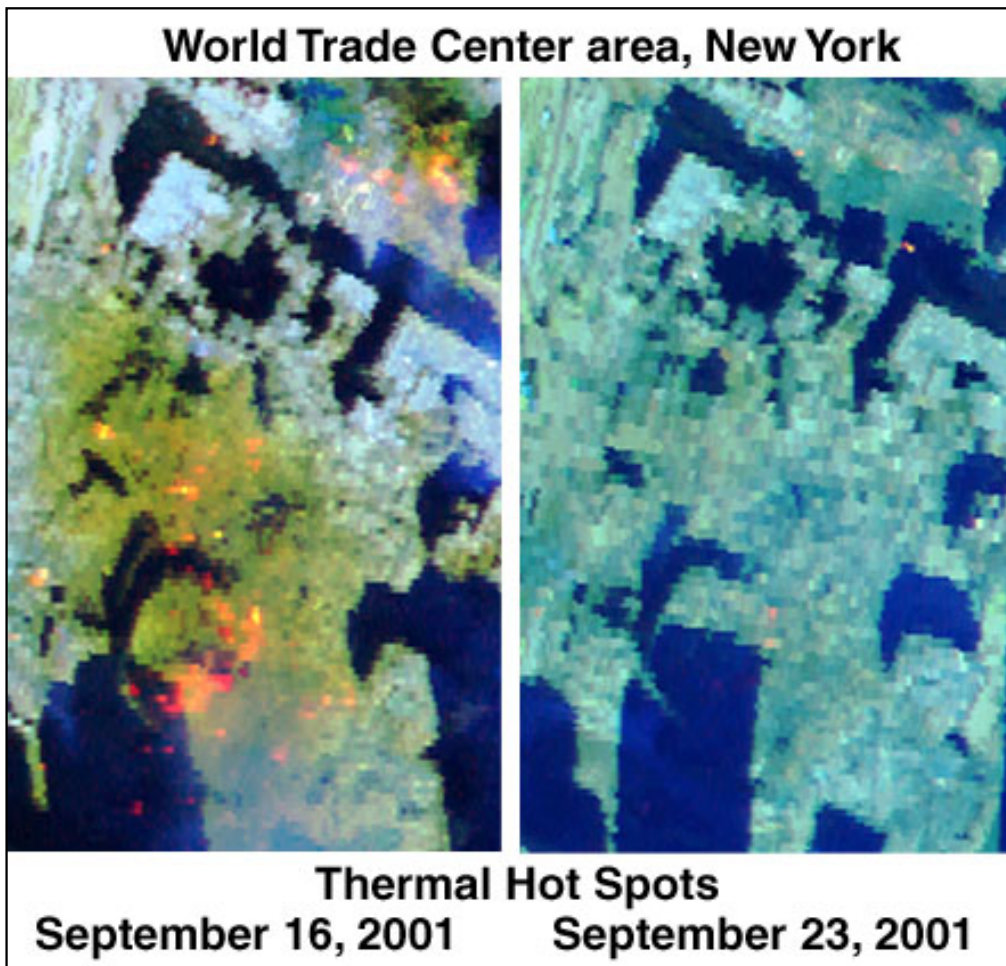
Images of the World Trade Center Site Show Thermal Hot Spots on September 16 and 23, 2001.

Results of Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) remote sensing data and interpretations show the distribution and intensity of thermal hot spots in the area in and around the World Trade Center on September 16 and 23, 2001. Data collected on the 16th were processed, interpreted and released to emergency response teams on the 18th of September, 2001. The September 23 data were processed, interpreted and the results released on October 12, 2001. The images of the World Trade Center site show significant thermal hot spots on Sept. 16, 2001. By Sept. 23, 2001, most of the hot spots had cooled or the fires had been put out.

The AVIRIS instrument is a National Aeronautics and Space Administration (NASA) remote sensing instrument that measures upwelling spectral radiance in the visible through short-wavelength infrared. The instrument has 224 spectral channels (bands) with wavelengths from 0.37 to 2.5 microns (micrometers).

In response to requests from the EPA through the USGS, NASA flew AVIRIS on a De Havilland Twin Otter over lower Manhattan at mid-day on September 16 and 23, 2001. For these deployments, the Twin Otter was flown at altitudes of 6,500 and 12,500 feet. The spectral data for the maps shown here were measured at 6,500 feet and have a spatial resolution (pixel spacing) of approximately 6 feet (2 meters).

AVIRIS records the near-infrared signature of heat remotely. The accompanying maps are false color images that show the core affected area around the World Trade Center. Initial analysis of these data revealed a number of thermal hot spots on September 16 in the region where the buildings collapsed 5 days earlier. Analysis of the data indicates temperatures greater than 800°F. Over 3 dozen hot spots appear in the core zone. By September 23, only 4, or possibly 5, hot spots are apparent, with temperatures cooler than those on September 16 (Thermal Figure 1).



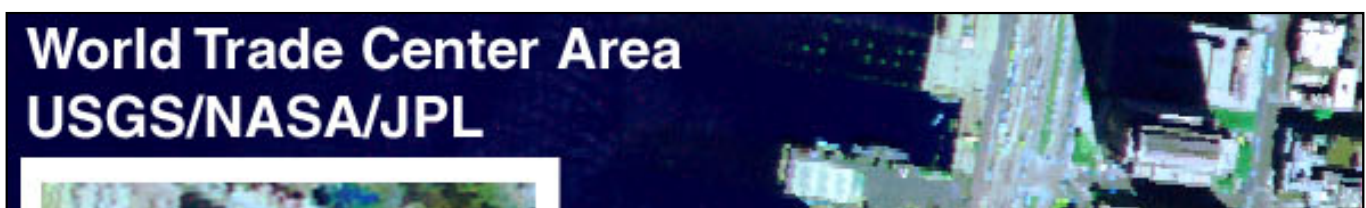
Thermal Figure 1. Hot spots show as orange and yellow areas. Dozens of hot spots are seen on September 16, but most had cooled or the fires had been put out by September 23.

The images (larger area shown below) also show vegetated areas as green. Water appears blue, and the smoke from the fires appears as a light blue haze. White and lighter blue areas are rooftops, roads, and concrete as well as dust and debris from the collapsed buildings. Dust, probably more than a millimeter thick, appears in shades of brown around the core WTC area on the 16th.

On the September 16th, 2001 image (Thermal Figure 2), large areas around the World Trade Centers show brownish colors, indicating the debris. On September 20, 2001 there was a significant rain storm that washed away some of the dusty debris. Reduction of the distribution of dust/debris is apparent in the September 23 image (Thermal Figure 3), and can be attributed to the cleanup effort along with the rain.

There are other red/orange spots that show in the images in the area south of the World Trade Center zone. These are hot spots from chimneys or heating exhaust vents and are normal and not other uncontrolled fires.

The AVIRIS data were processed at the Jet Propulsion Laboratory (JPL) in Pasadena California where the data are calibrated to radiance and corrected for aircraft yaw, pitch, and roll. Acquisition and calibration of AVIRIS data at JPL are under the direction of Robert O. Green. The data were then transmitted to the U.S. Geological Survey (USGS), Imaging Spectroscopy Group in Denver, Colorado, under the direction of Dr. Roger N. Clark. Atmospheric and ground calibrations were applied to derive apparent surface reflectance and maps were then made of surface materials. The USGS imaging spectroscopy group includes Dr. Gregg Swayze, Eric Livo, and Todd Hoefen.

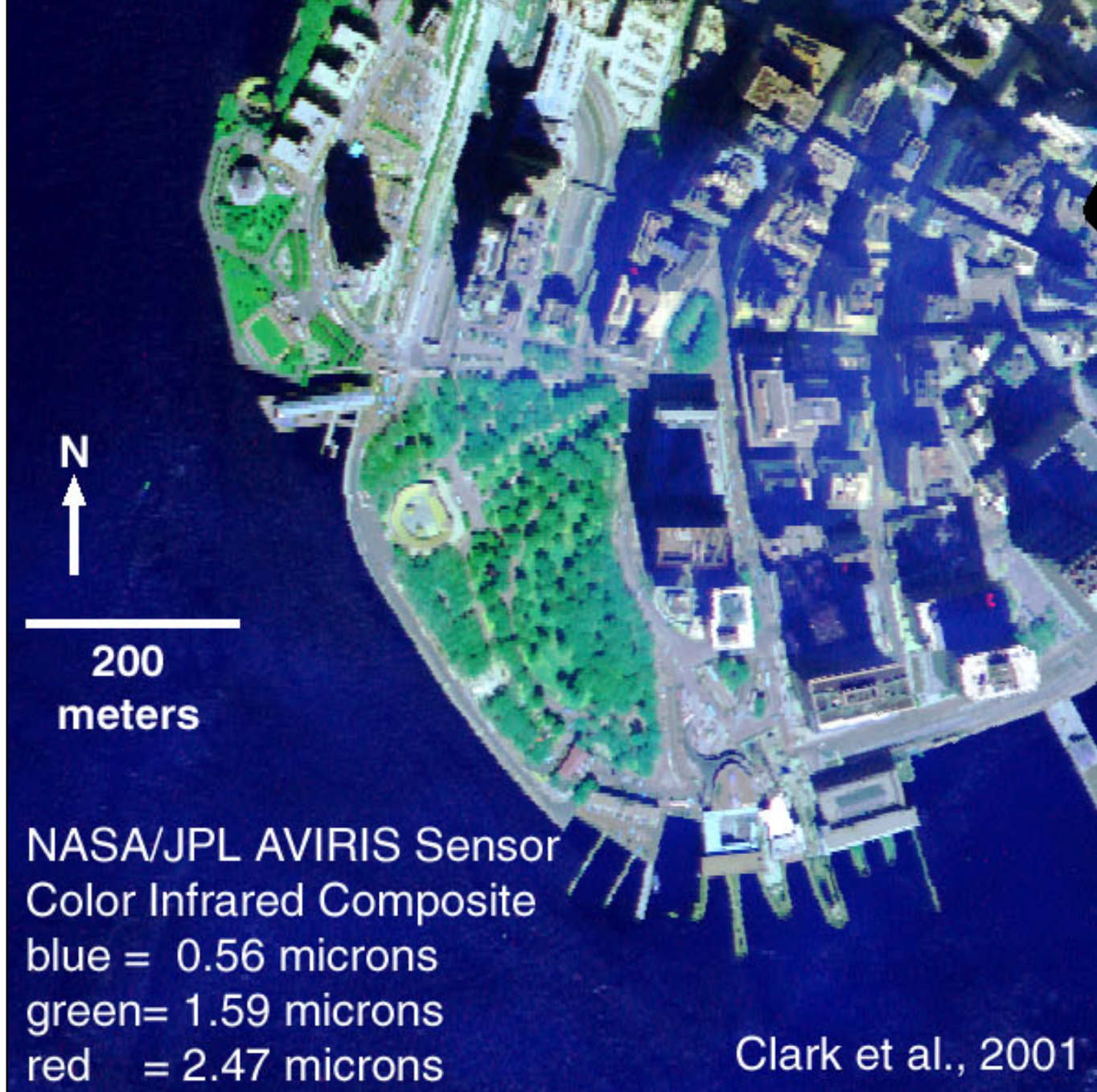




Core Zone:
orange/red
areas are
thermal
hot spots

Sept. 16, 2001
mid-day





Thermal Figure 2. AVIRIS image from September 16, 2001. Hot spots show as orange and yellow areas. Yellow is hotter than red (because of color mixing in the way the 3-color image was produced).

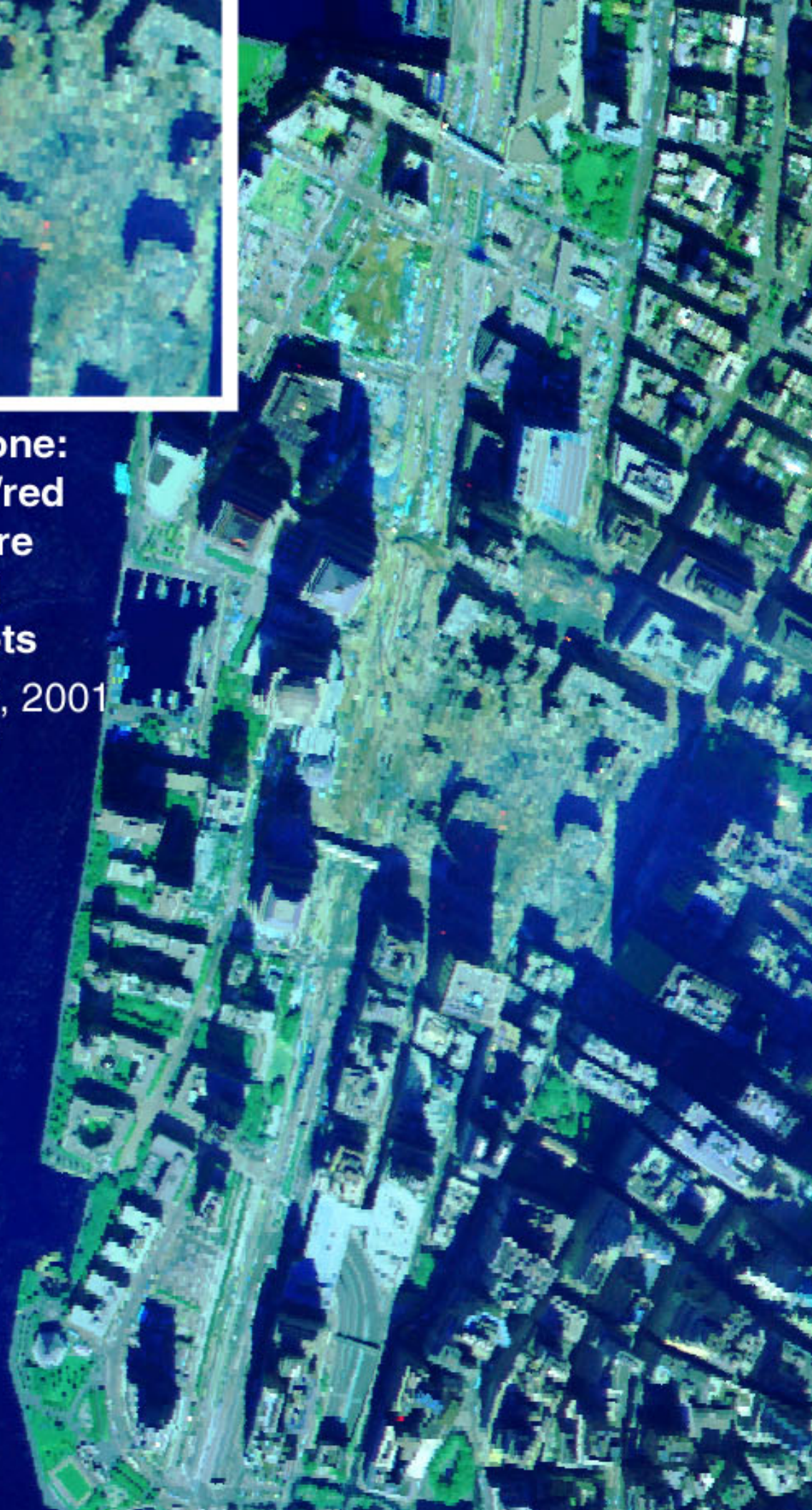
World Trade Center Area USGS/NASA/JPL

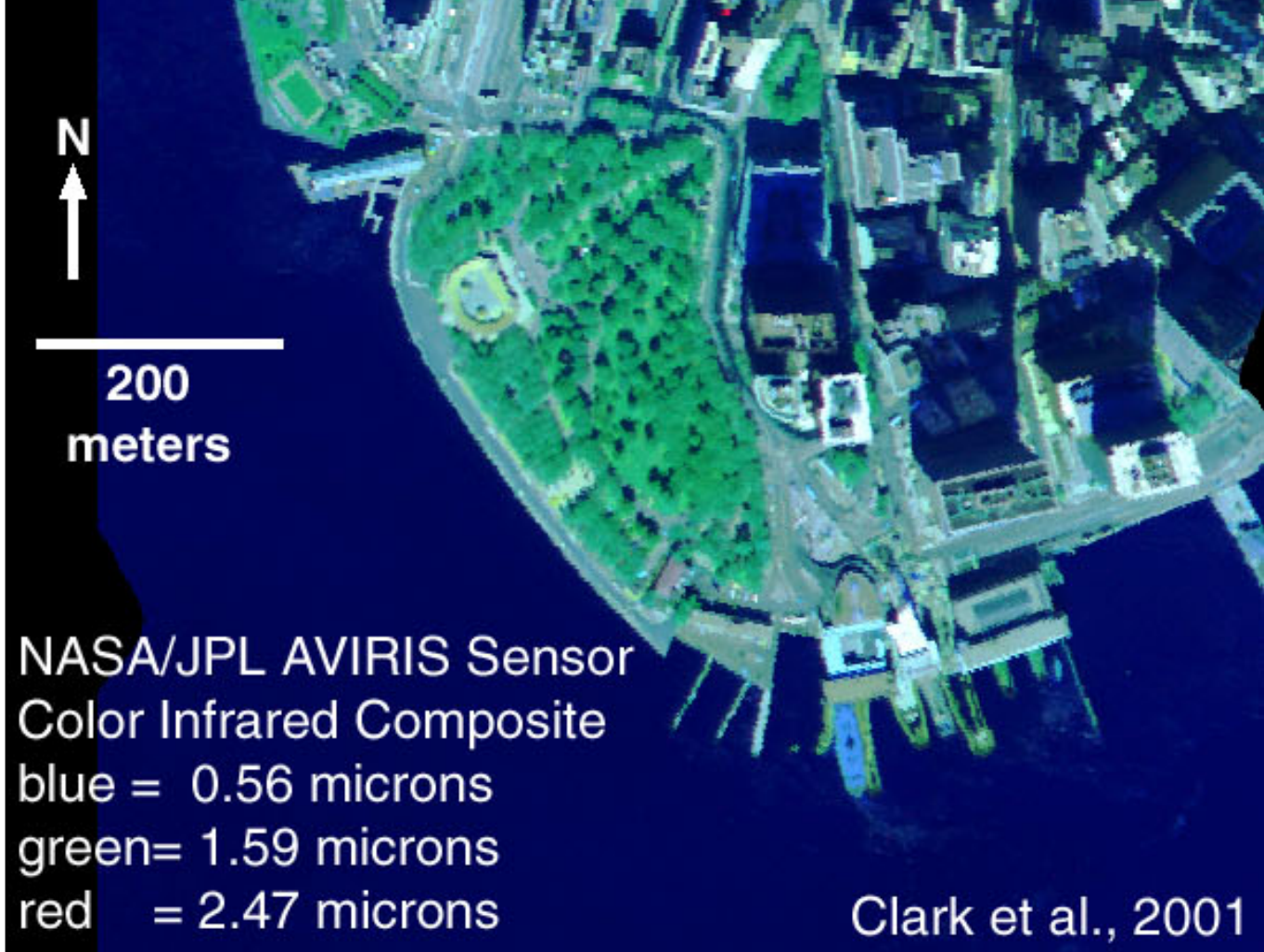




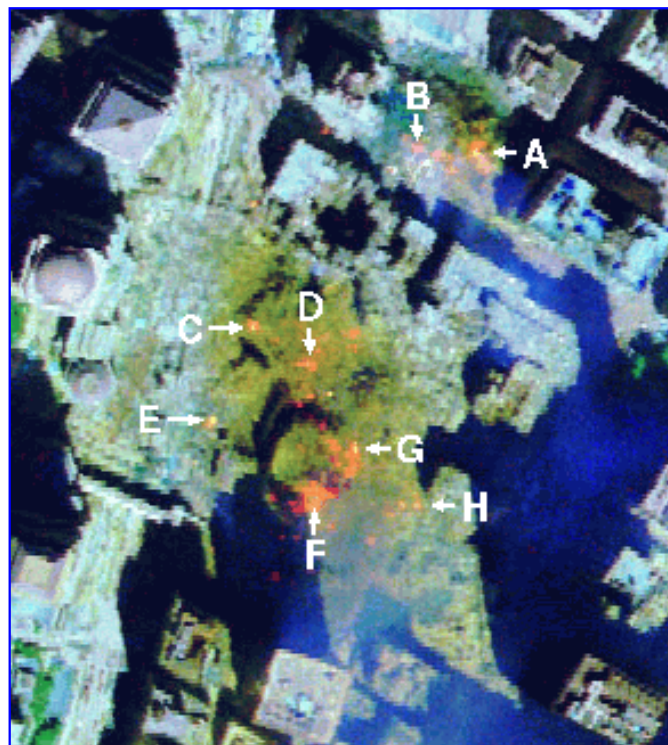
**Core Zone:
orange/red
areas are
thermal
hot spots**

Sept. 23, 2001
mid-day





Thermal Figure 3. AVIRIS image from September 23, 2001. Only a couple of hot spots remain in view.



[Larger 254 KB image](#)

Thermal Figure 4. Index for the locations of some of the hot spots observed on September 16, 2001.

Temperature of the Hot Spots

Remote measurement of the temperature is difficult because the source of the thermal emission can be less than the field of view of the measuring instrument. In that case a thermal sensor has an ambiguous solution: a hotter temperature of a smaller area or lower temperature of a larger area can result in the same total received thermal radiation.

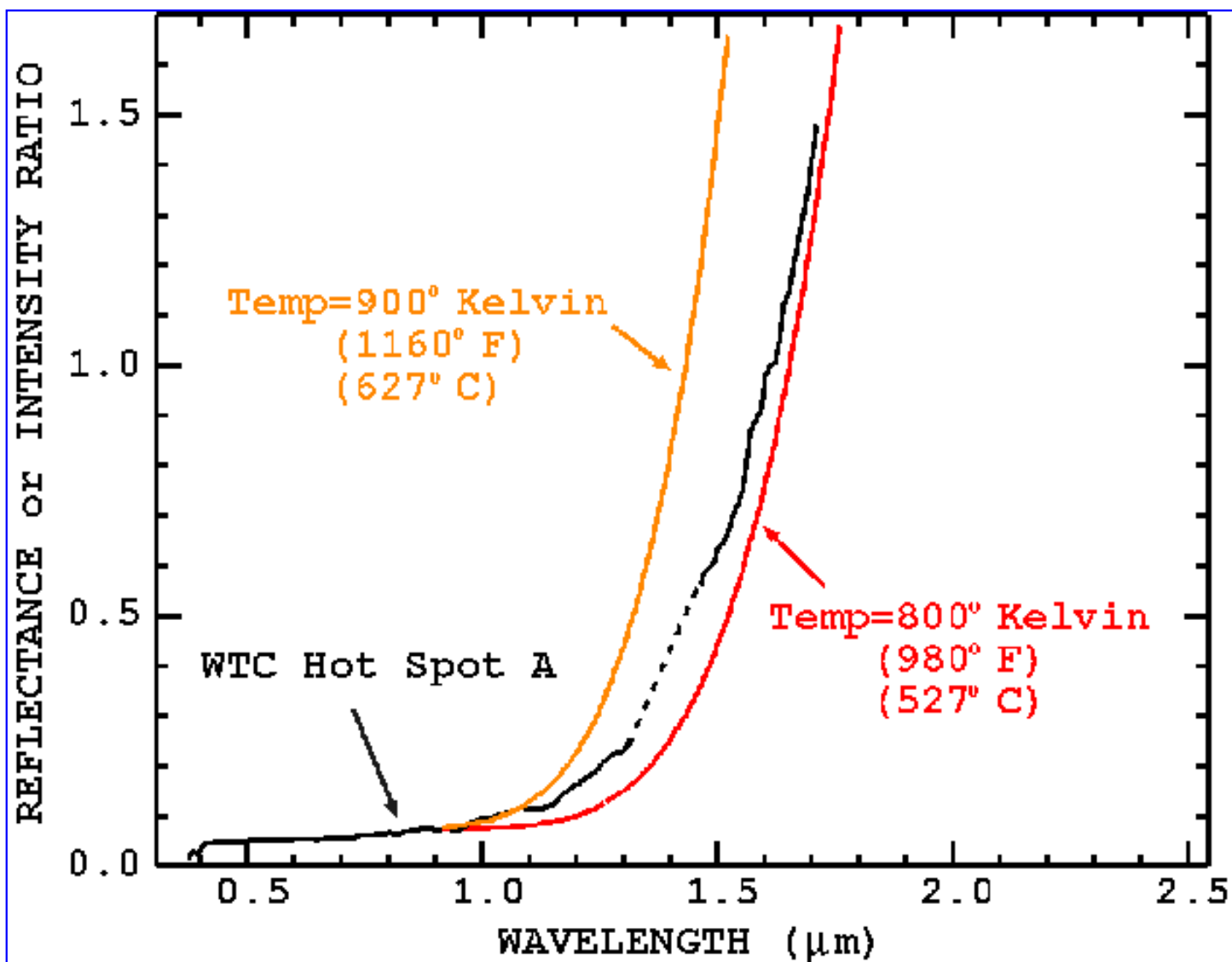
A spectrometer, however, overcomes the ambiguity problem above, because the shape of the thermal spectrum can be used to derive a unique temperature, and the intensity gives the area of the emitting source. If a large enough spectral range is covered, a range of temperatures and the area of each can be derived. In the near infrared spectral range of AVIRIS, reflected solar radiation also contributes to the signal. The solution to the generalized problem involving all these effects is given in Clark (1979). We derived temperatures using two methods: calibrated radiance, and derived reflectance following Clark's (1979) methods. In derived reflectance, thermal radiation is the Planck response divided by the solar spectrum. This has several effects: 1) the data are corrected for atmospheric absorption and scattering, 2) the reflected solar component can be readily assessed and compensated for, and 3) the ratio of the Black-Body response by the solar spectrum produces a very steep curve that is readily distinguishable from reflected sunlight and reflectance of surface materials.

Simple temperature derivation from derived reflectance is illustrated in Thermal Figure 5a and b. Here the hot spot is assumed to fill the pixel. The thermal response of hot spot A (from Thermal Figure 4) shows the AVIRIS response higher than the 800 kelvin curve. The 800 Kelvin temperature is a lower limit to the temperature. While the upper limit might be the 900 Kelvin curve, we see the slopes do not match. As temperatures increase, the peak in Black Body emission moves to shorter wavelengths and the slope of the curve decreases at positions on the short wavelength side of the peak (the case here). Hot spot C (Thermal Figure 5b) shows similar effects. For hot spots covering the full area of the pixel, the temperature must be greater than 700 Kelvin. At about 1.3 microns, the model at 800 Kelvin matches the AVIRIS data, but the 800 Kelvin curve has a higher slope. This indicates the hot spot is smaller than the size of the pixel, but hotter than 800 Kelvin.

Solutions that include reflected solar radiation, hot spot temperature and hot spot area are shown in Thermal Figures 6a and b. Hot spot A, which from Thermal Figure 5 has a temperature greater than 800 Kelvin, is found to have a 1000 Kelvin temperature in a spot covering ~15% of a pixel, or 0.56 square meter. Similarly, hot spot C is found to have a 900 kelvin temperature over 20% of a pixel, or 0.8 square meter.

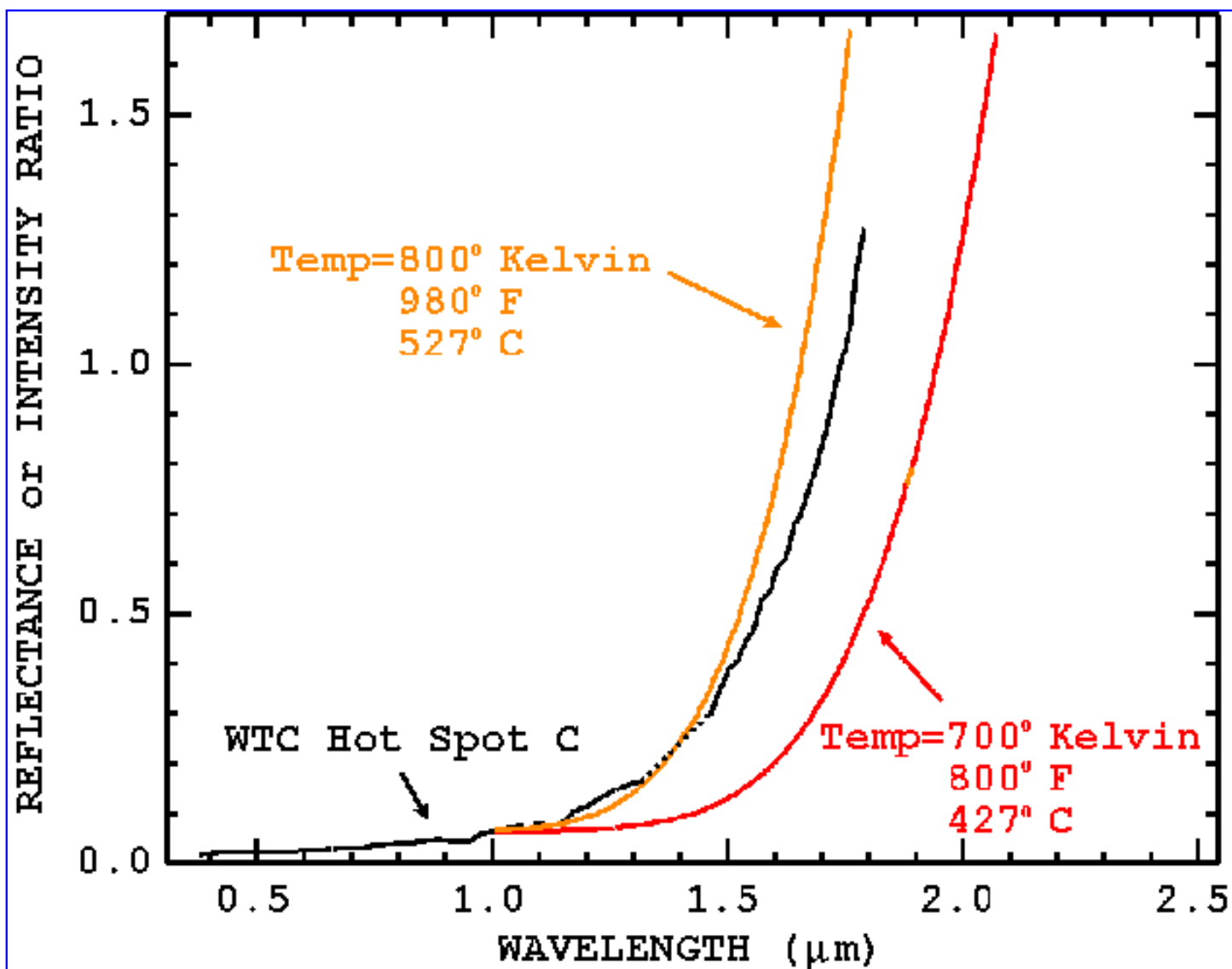
The sensitivity of the solution of area and temperature is illustrated in Thermal Figure 7. An excellent fit is obtained for hot spot C with a 900 Kelvin spot filling 20% of the pixel. At 1000 Kelvin, only 8% is required but the fit is noticeably worse. For temperatures in the 800-1000 Kelvin range, temperature accuracy is estimated to be ± 30 Kelvin and the area $\pm 5\%$. For smaller spots, like spot G in Table 1, the temperature accuracy is similar, but the accuracy on such small areas is approximately $+5\%$, -0.5% . For example, decreasing the temperature to 1000 Kelvin (from 1020 Kelvin) on spot G increases the fractional area to about 5%.

Positions, temperatures and equivalent areas for hot spots A-H are given in Table 1 and the geometrically rectified location map is shown in Thermal Figure 8.



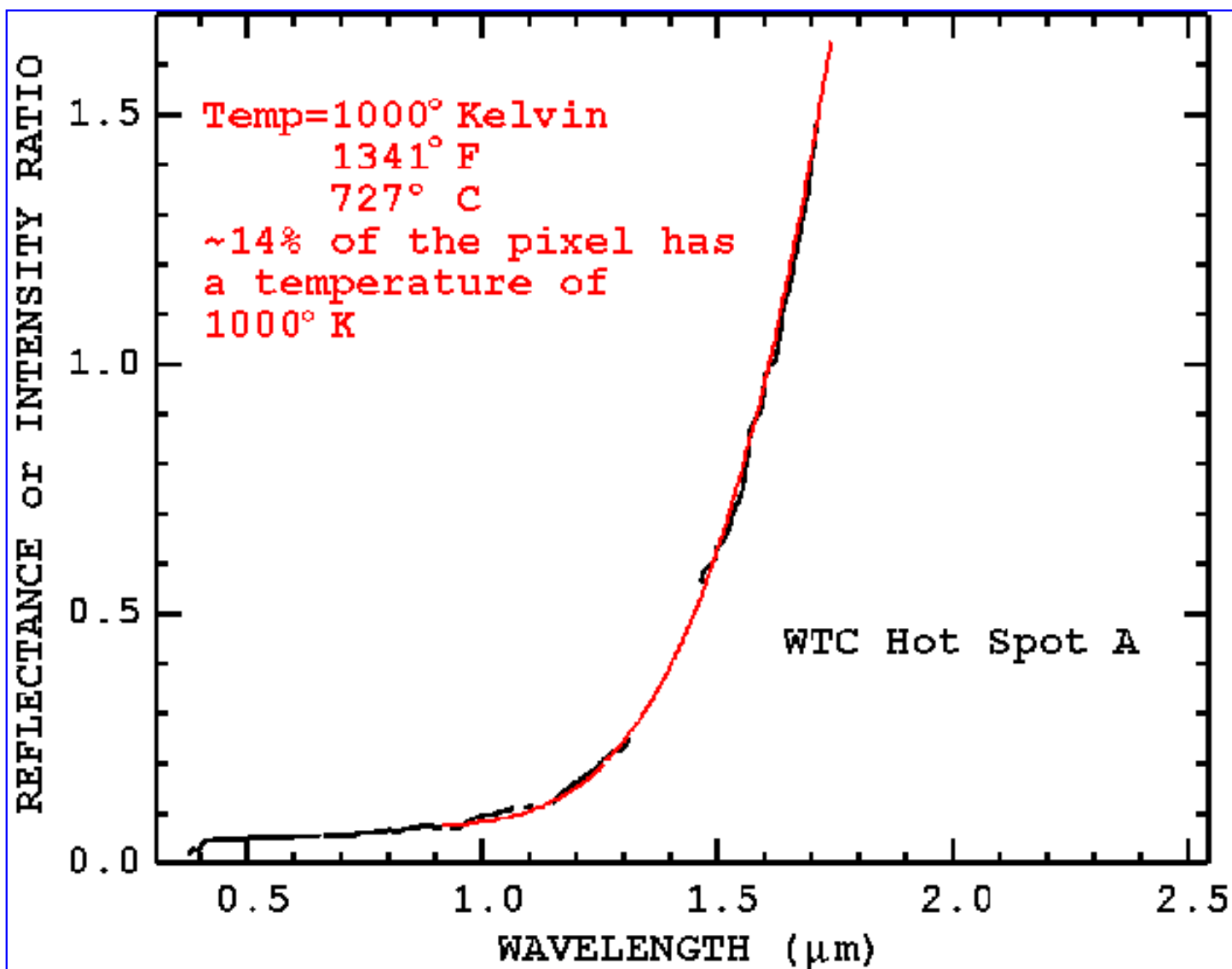
[Larger 16 KB image](#)

Thermal Figure 5a.



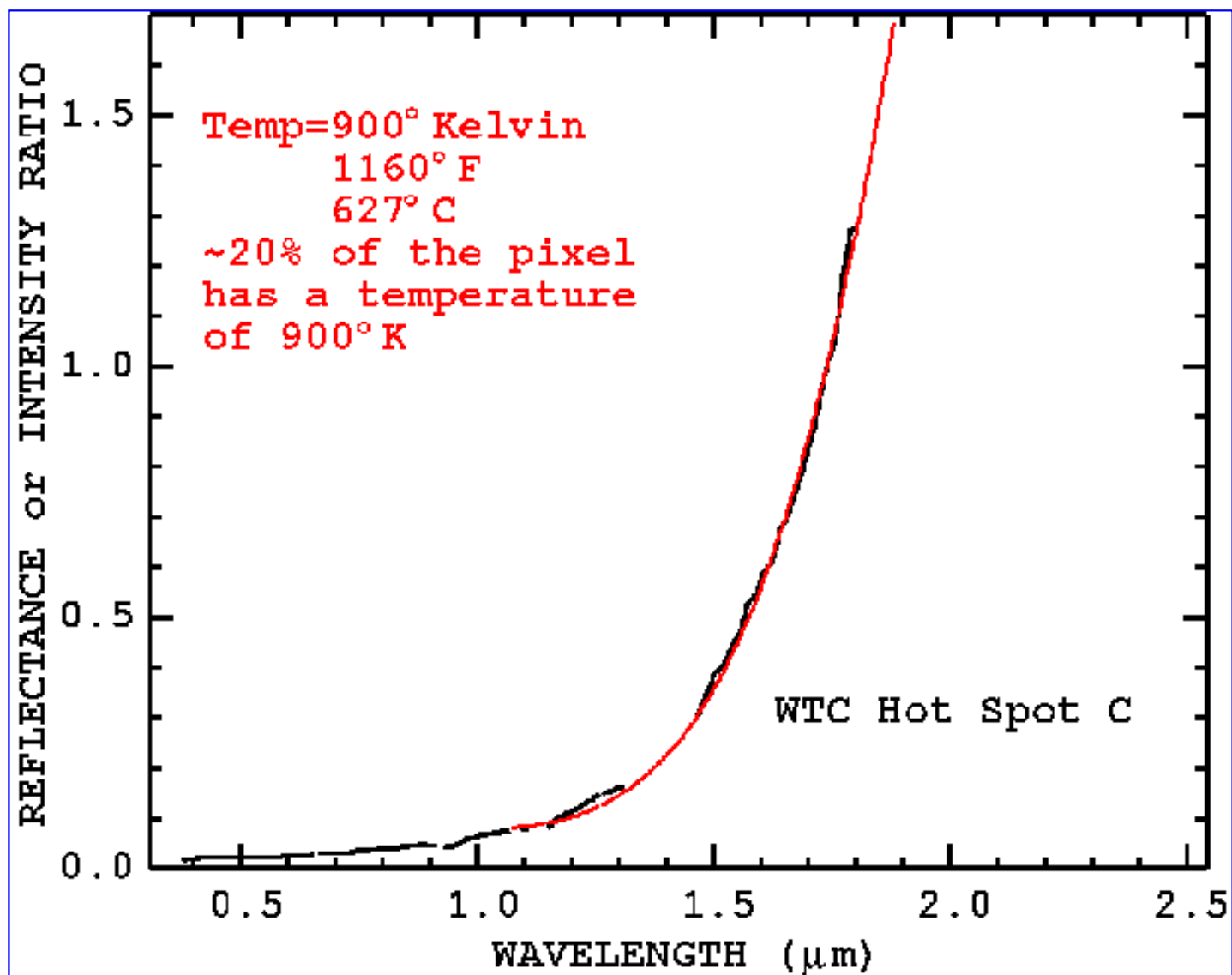
[Larger 15 KB image](#)

Thermal Figure 5b



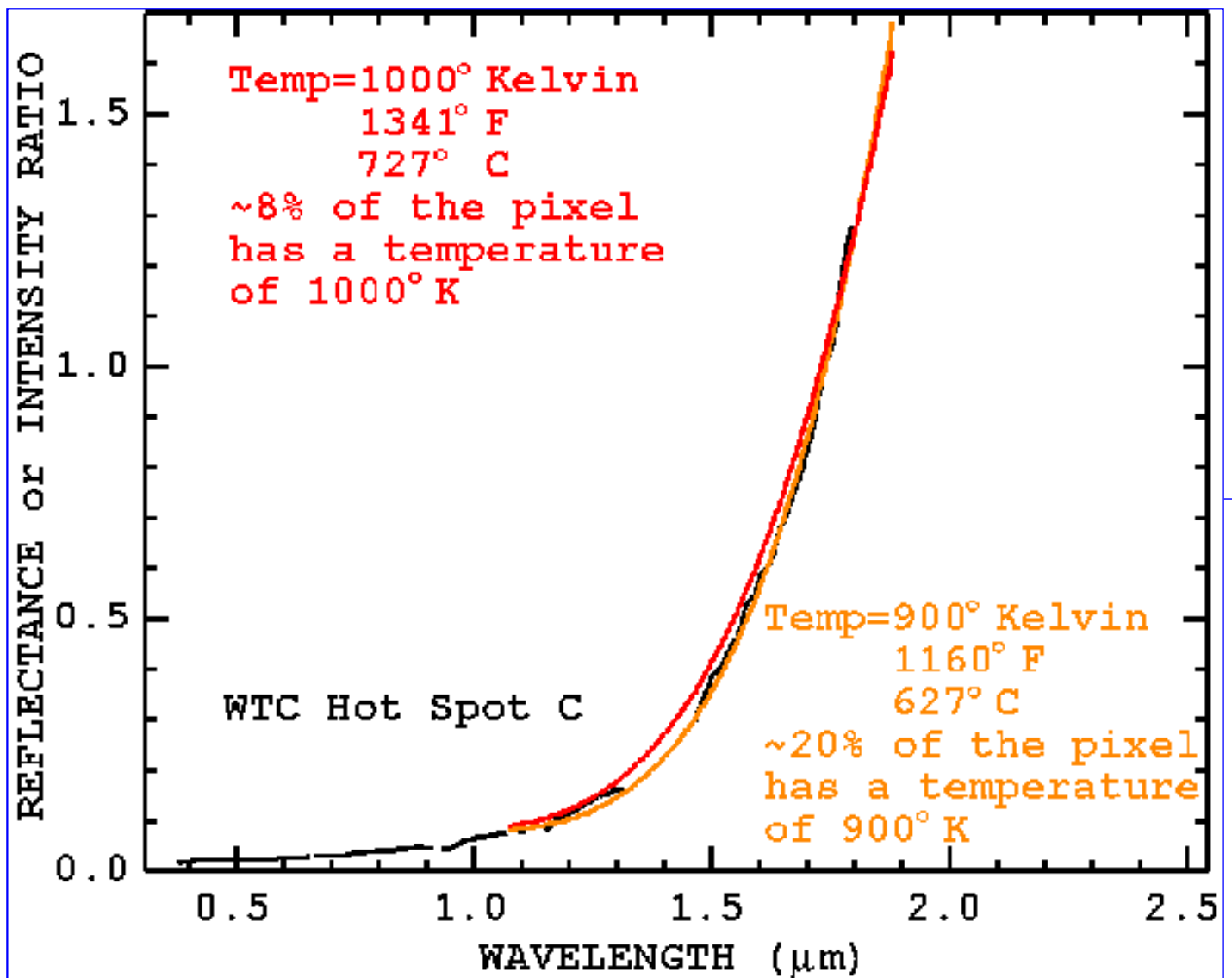
[Larger 13 KB image](#)

Thermal Figure 6a



[Larger 13 KB image](#)

Thermal Figure 6b



[Larger 16 KB image](#)

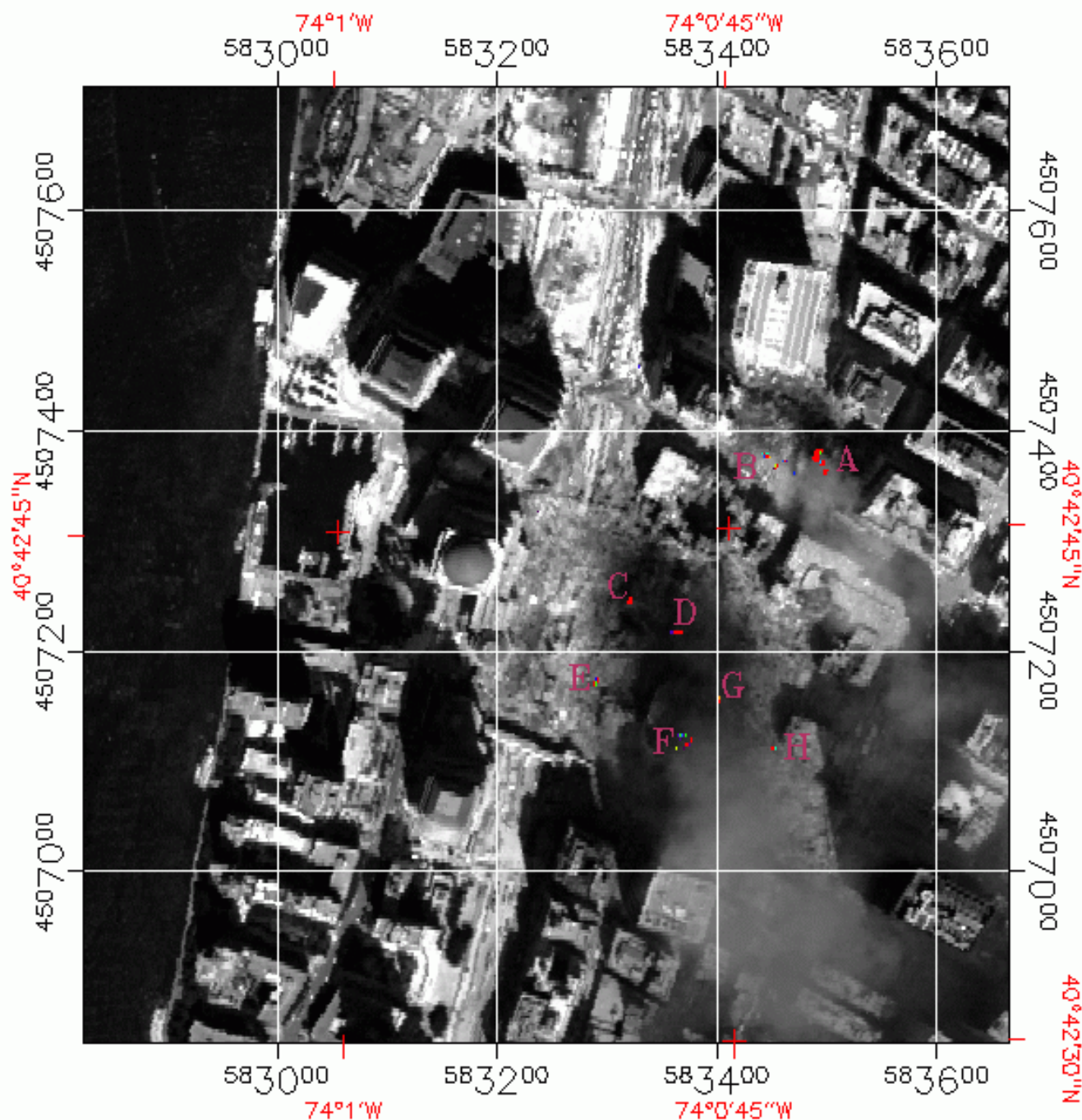
Thermal Figure 7.

Table 1 Thermal Hot Spot Data

Hot Spot	Location		Temperature	Area	
	N Latitude	W Longitude	(Kelvin)	% FOV	sq meter
A	40° 42' 47.18"	74° 00' 41.43"	1000	15	0.56
B	40° 42' 47.14"	74° 00' 43.53"	830	2	0.08
C	40° 42' 42.89"	74° 00' 48.88"	900	20	0.8
D	40° 42' 41.99"	74° 00' 46.94"	790	20	0.8
E	40° 42' 40.58"	74° 00' 50.15"	710	10	0.4
F	40° 42' 38.74"	74° 00' 46.70"	700	10	0.4
G	40° 42' 39.94"	74° 00' 45.37"	1020	1	0.04


H	40° 42' 38.60"	74° 00' 43.51"	820	2	0.08
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Positions are in degrees-minutes-decimal seconds, datum WGS84.
Position accuracy is estimated to be approximately +/- 6 meters (18 feet).



AVIRIS Hot Spot Mapping 09/16/2001
Color Coded Hot Spots on B/W Image Background
UTM projection, zone 18
NAD-83/WGS-84 datum, 1.7 meter pixels

lower temp. scale higher


lower temp. scale higher

[Click here for 180 KB geo-tif image](#)

Thermal Figure 8. Geometrically rectified image of the WTC core region showing hot spot locations.

Additional temperature analysis: ftp://popo.jpl.nasa.gov/pub/outgoing/WTC_AVIRIS_HOT.htm

[NEXT PAGE of Report: Asbestiform Minerals Map](#)

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Images of the World Trade Center site show weak patterns of materials with spectral absorptions indicating the possible presence of asbestiform minerals.

Spectral reflectance mapping keyed to minerals that can have asbestiform varieties shows only scattered possible occurrences at the surface around the World Trade Center area. Spectroscopy identifies mineralogy by detecting absorptions, due to molecular bonds, at a characteristic wavelength and with a diagnostic band shape. The grain size of a mineral affects the intensity and, to some extent, the shape of its spectral absorptions, but spectroscopy may not be sensitive to whether a mineral has an asbestiform shape (long needle-like shapes with diameters less than a micrometer). Research is underway to see if spectroscopy can, at some level, be used to differentiate asbestiform from nonasbestiform mineral shapes. To read about [asbestos mineralogy and definitions](#), [click here](#). Use the back key on your browser to return here.

To the extent that the top few millimeters contain mineralogy that is representative of the underlying material, spectral mineral maps can be used to assess potential asbestos distribution in the WTC debris. It is also possible that asbestos-bearing debris is buried beneath the surface and that AVIRIS was not be able to detect it.

Building materials can contain trace serpentine and amphibole minerals that are naturally occurring but not asbestiform. During the era when the WTC was built, industrial asbestos was reportedly used. Therefore, detection of asbestiform mineralogy warrants further investigation.

The map, A-Figure 1a, b, shows possible weak absorption features indicative of minerals that may occur with asbestiform morphology. The map shows relatively isolated pixels indicating areas that may warrant further investigation (colored pixels). The detection limits are still under study, but are probably in the few percent range for these data. Note that in shadows, there is not enough light for spectroscopic determination of surface mineralogy, so it is unknown if these locations have asbestos-bearing debris. Laboratory Spectroscopy of the WTC samples (discussed in detail in the laboratory spectroscopy section, and in the integration of results section) show, in all but one case (sample WTC01-08), only very weak, if any, spectral features from chrysotile because the occurrence of chrysotile asbestos is present in trace abundances less than about 1 %. Such abundances are not detectable by AVIRIS. Thus, it is not surprising that the AVIRIS map shows little asbestiform mineralogy. The lack of large contiguous clusters of colored pixels at the WTC site, indicates that spectral mineral mapping has NOT detected widespread concentrations of asbestos in the debris above a few percent, mostly leaving just the black and white base image (see Iron-bearing Material Map or Dust Plume for examples of contiguous clusters of colored pixels). The AVIRIS map (A-Figure 1a, b) does show pockets (or small clusters of pixels) of serpentine (closest spectral match is chrysotile, A-Figures 2, 3). The strengths of the spectral signatures indicate levels of a few percent, up to the 10 and 20% levels (A-Figures 2, 3) observed in sample WTC01-08. Again, some or all of these pixels may be non-asbestiform serpentines in building materials.

Mineralogic characterization of field samples (discussed in the laboratory sections) suggests that only trace levels of chrysotile asbestos were present in some of the samples from the WTC area, with one exception. The exception is a coating from a steel beam (sample WTC01-08) which showed chrysotile levels that could be as high as 20%. It should be noted that the field sampling sites do not coincide with AVIRIS pixel locations that indicate possible chrysotile or amphibole presence (A-Figure 4). But many field sample locations whose samples contain trace asbestos occur near locations in the AVIRIS map that indicate higher levels of serpentine minerals.

The correlation of mineralogically characterized field samples and AVIRIS mapped serpentine and amphibole mineralogy is shown in A-Figure 4. There appears to be a bias in chrysotile detection into a

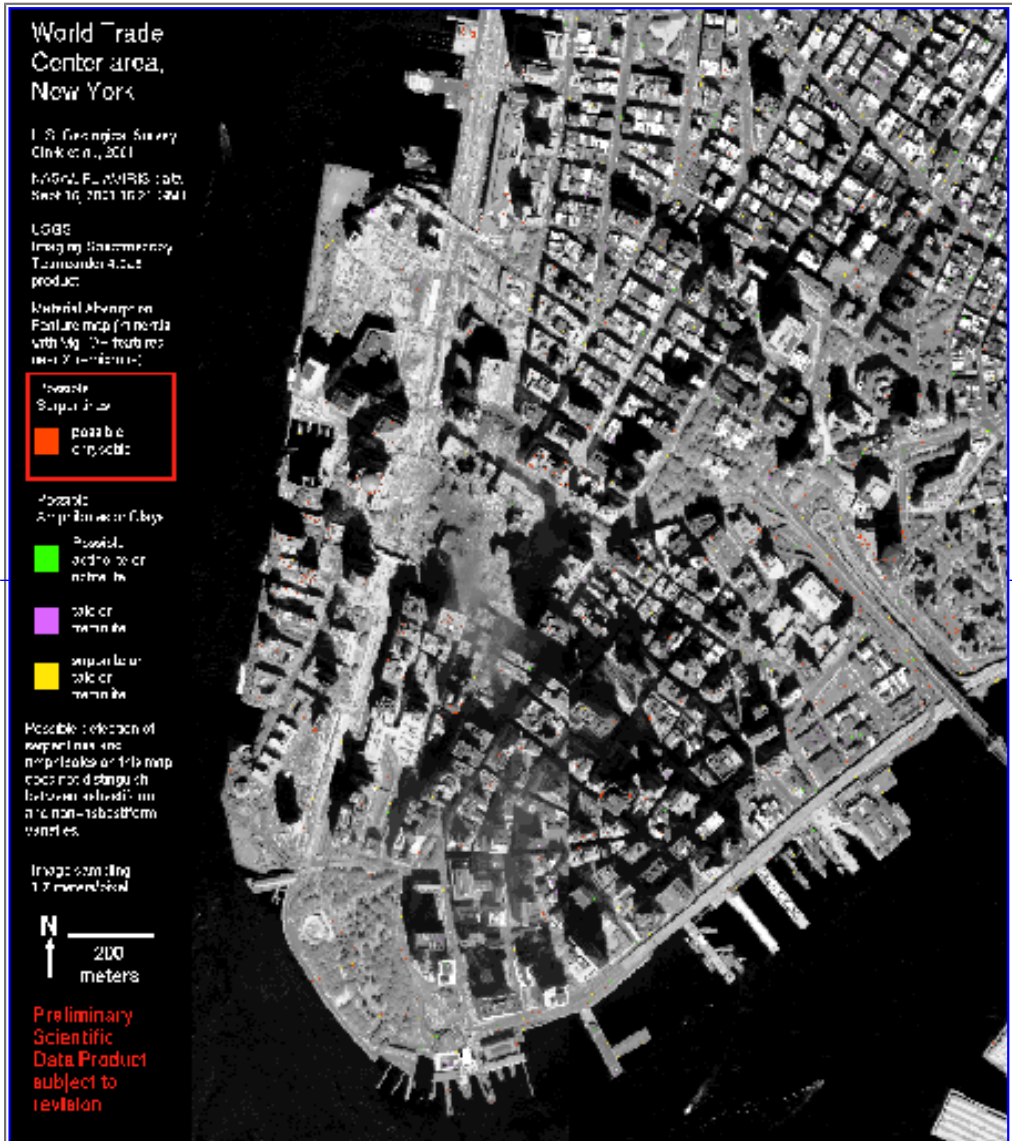
broad east-west trend, in both the AVIRIS and the laboratory results. This asymmetry in the dust/debris composition is supported by other compositional analyses, both AVIRIS and laboratory (see lab spectroscopy and integrations of results sections of this report).

The lower limit of detection of the AVIRIS instrument for asbestos minerals and, consequently, the WTC AVIRIS data set is probably in the few percent range as noted above. Asbestos levels below this detection limit and the implications of low levels of asbestos on human health are beyond the scope of this report. The fact that field sampling shows high levels of chrysotile asbestos in some of the steel beam coatings (up to 20%) indicates the need for dust control during beam removal. Workers who are removing the beams should wear proper respiratory protection. However, video from news reports of the cleanup activity show that many of the steel beams no longer have the insulation coating. Where did the coatings go? It is probably now in the dust and debris. Thus the possibility exists that there may be other pockets of high levels of chrysotile, leading to the conclusion that workers should employ protective measures when cleaning up any dust or debris.



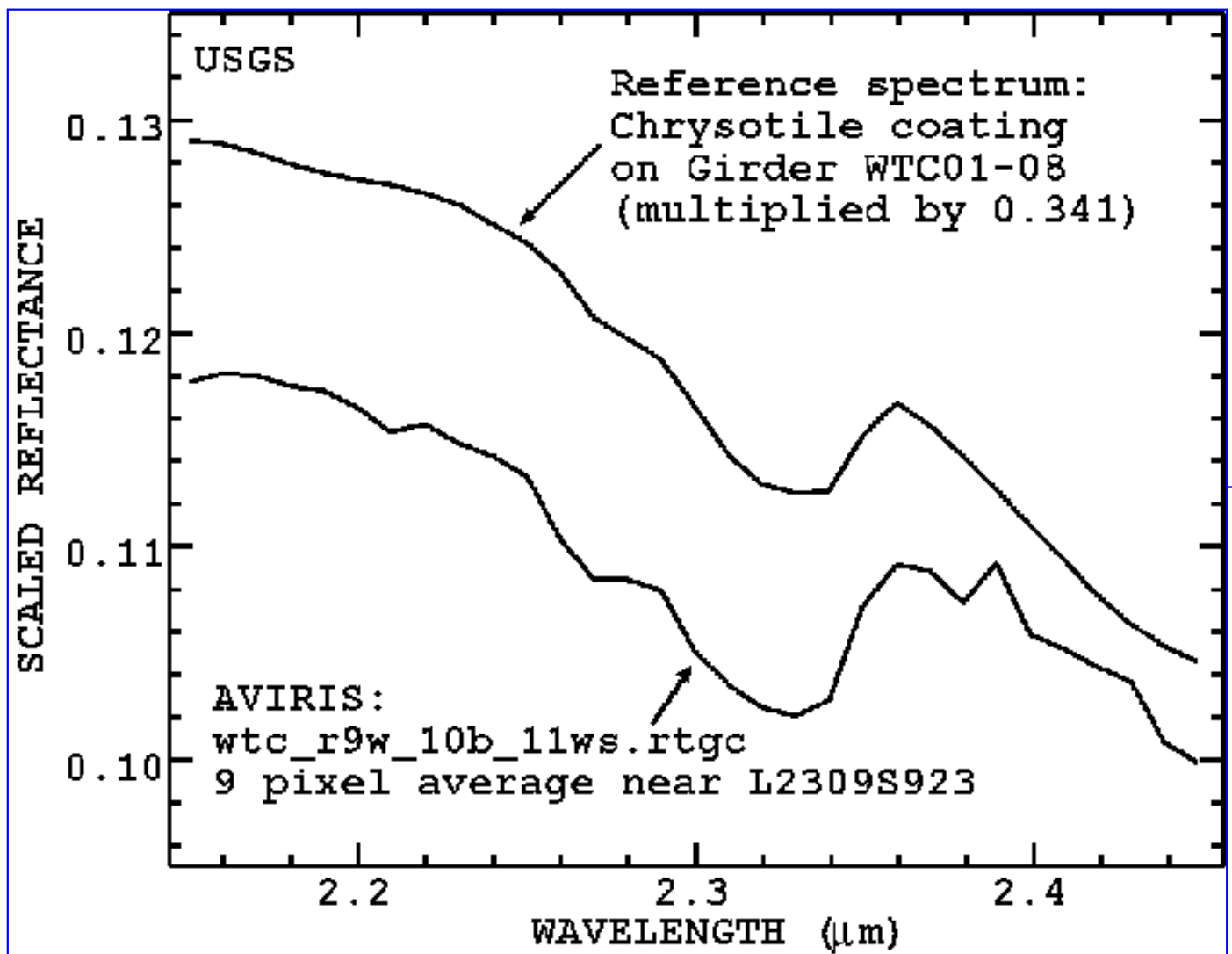
[Larger 1751 KB image](#)

A-Figure 1a. Serpentine and Amphibole minerals map.



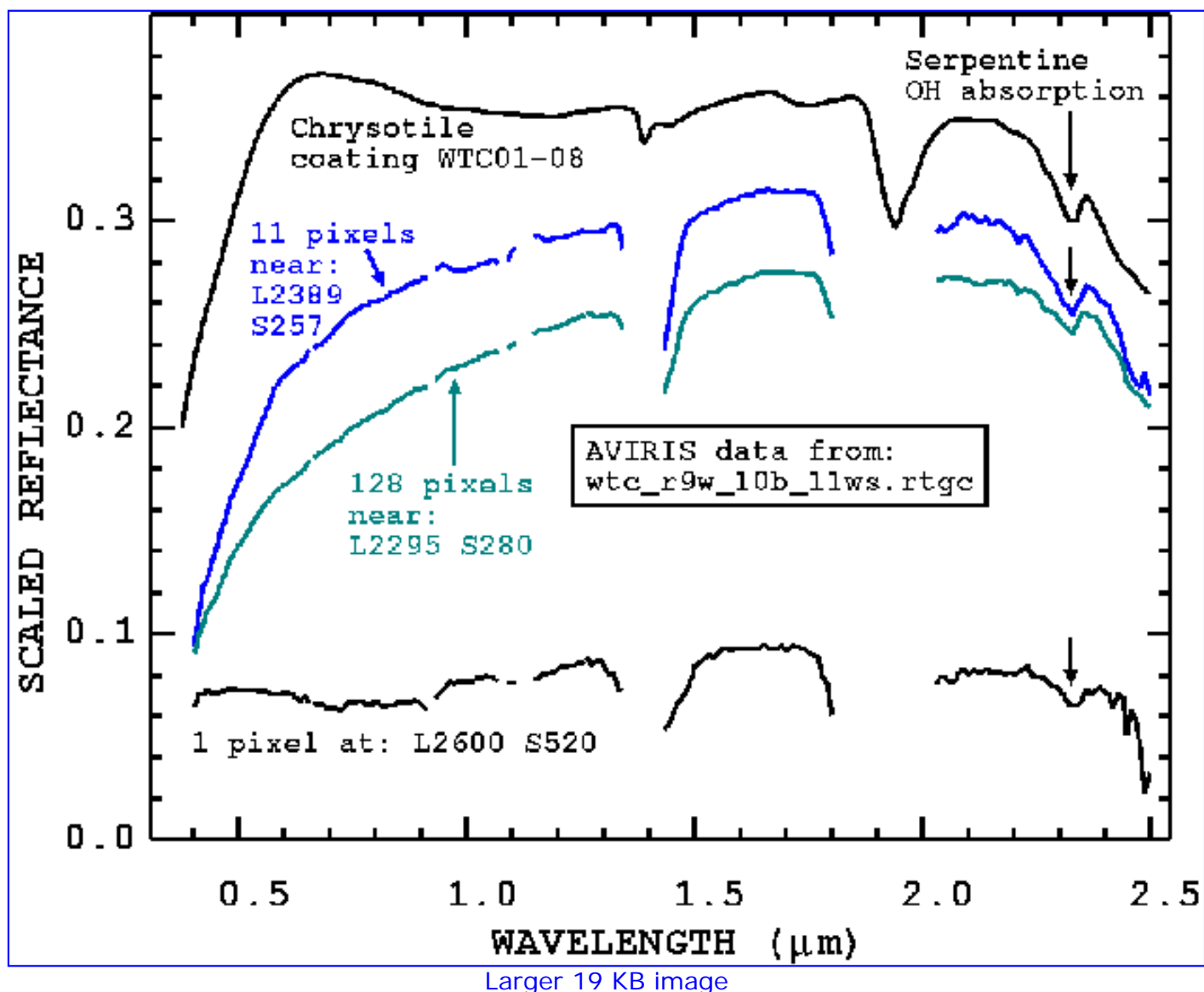
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A-Figure 1b. Serpentine and Amphibole minerals map, same as at right, but zoomed in to lower Manhattan.



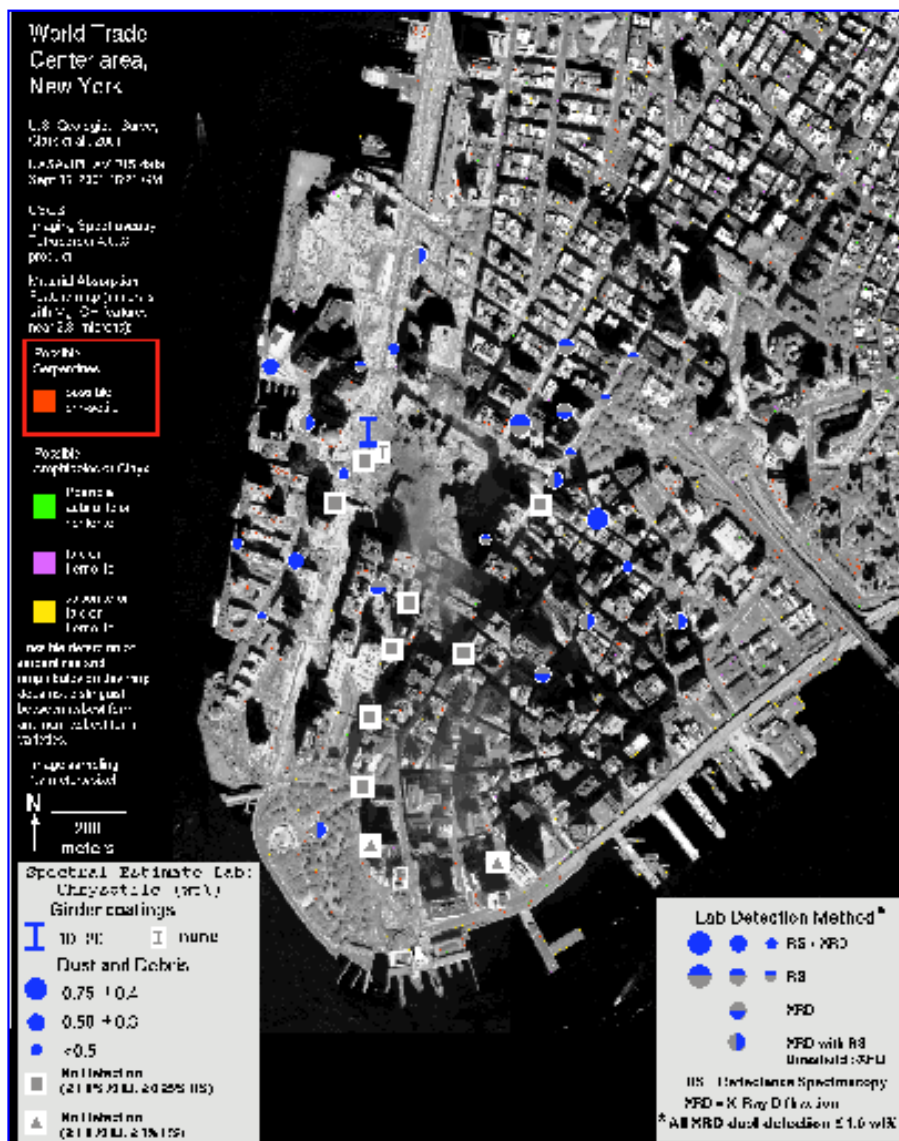
[Larger 14 KB image](#)

A-Figure 2. Spectra of some of the mapped chrysotile is a close match to the spectra of coating WTC01-08 which contains up to about 20% chrysotile.



[Larger 19 KB image](#)

A-Figure 3. Example areas in the image with serpentine-like hydroxyl absorption feature.



[Larger 633 KB image](#)

A-Figure 4. WTC Sample analyses are shown plotted on the serpentine/amphibole AVIRIS map. There is a loose correlation of chrysotile locations spread in an east-west direction in both the laboratory analyses and the AVIRIS data.

[NEXT PAGE of Report: Dust and Debris Plume Map](#)

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Maps of dust and debris show asymmetric distribution of materials.

The map images on this page (Dust Figures 1a, 1b, 2a, 2b) show locations of materials with spectral shapes similar to the spectra of field samples of dust and debris collected around the lower Manhattan area. These materials/minerals include common building materials; therefore, the maps may include materials in buildings not associated with the World Trade Center (WTC) collapse. While the minerals mapped in any one location may or may not be associated with the WTC event, a pattern is seen that appears to show the distribution of materials related to the WTC collapse. Further, the debris map qualitatively agrees with on scene observations 2 days after the imaging spectroscopy data were acquired. Production of a dust/debris map was challenging because building materials are similar all over the city (e.g. concrete occurs in many locations). However, the pulverized dust/debris does have some general spectral characteristics that can be used.

Spectra of the field samples shows a general range of spectral characteristics (Dust Figure 3). Samples WTC01-37B and WTC01-37Am are concrete that display ferrous iron absorptions (most likely due to the aggregate). The spectrum of concrete minus the aggregate is shown in sample WTC01-37A: the cement shows less ferrous absorption. Pervasive in the spectra of the debris is gypsum, and with the variations in abundance of other components, spectra of the dust and debris show the spectral variations seen in Dust Figure 3. We mapped for these general spectral shapes over the spectral range 0.5 to 2.4 microns. The ultraviolet was not included because scattering from smoke affects shorter wavelengths too much. The strategy proved effective. The maps should not be interpreted as indicating that these specific materials were mapped, only that the spectral shape is similar. However, red and yellow colors indicate areas showing more ferrous-like absorptions, and this is apparent in the WTC core zone where many steel girders dominate. Green copper roofs have a similar absorption to ferrous minerals, so they would map as red or yellow.

Two versions of the dust/debris map are shown (Dust Figure 1a, 1b, 2a and 2b). Dust Figure 2a, b is the same as Dust Figure 1a, b but without the grey-scale image background. Dust Figure 2a, b allows one to see the mapped materials without the apparent clutter of the grey-scale image.

The plume map in Dust Figures 1 and 2 indicate an asymmetry in the dust/debris distribution, with more iron bearing materials to the south by southeast. It is difficult to locate the outer boundary of the dust/debris because of the problem of matching common materials throughout the city.

The reference spectra used for matching the dust/debris was:

[wtc01-37B](#) (Note the strong Fe^{2+} absorption near 1-um.)

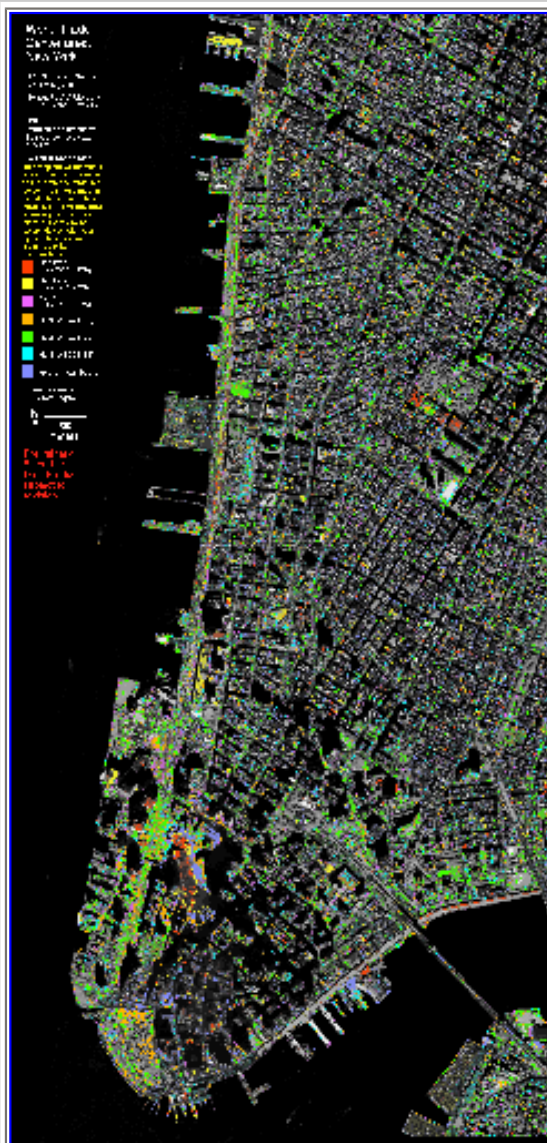
[wtc01-37Am](#)

[wtc01-37A](#)

[wtc01-15](#)

[wtc01-28](#)

[wtc01-36](#)



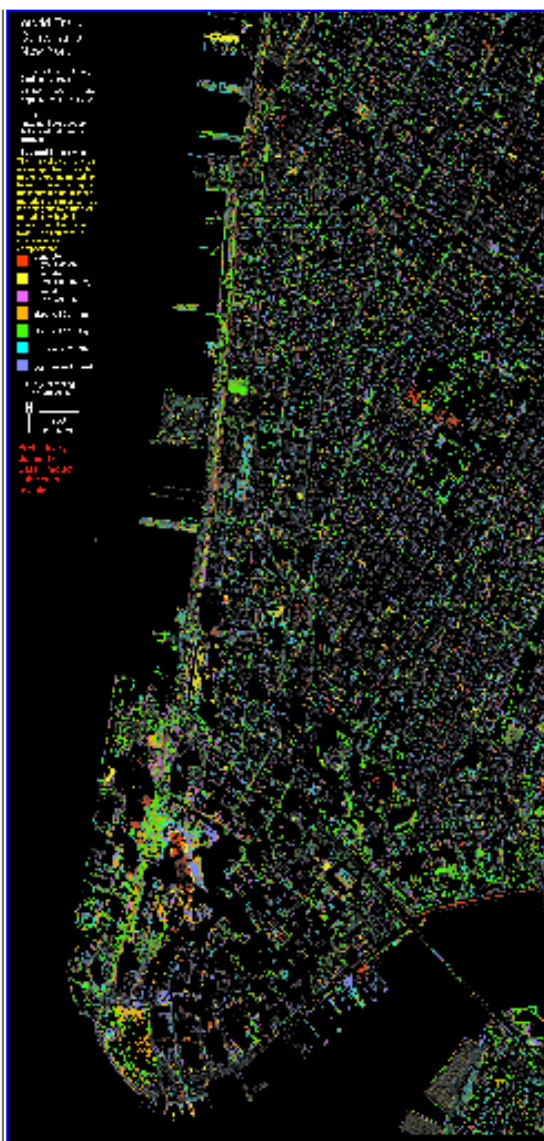
[Larger 1927 KB image](#)

Dust Figure 1a. Dust/Debris plume map.



[Larger 682 KB image](#)

Dust Figure 1b. Dust/Debris plume map, same as at right, but zoomed in to lower Manhattan.



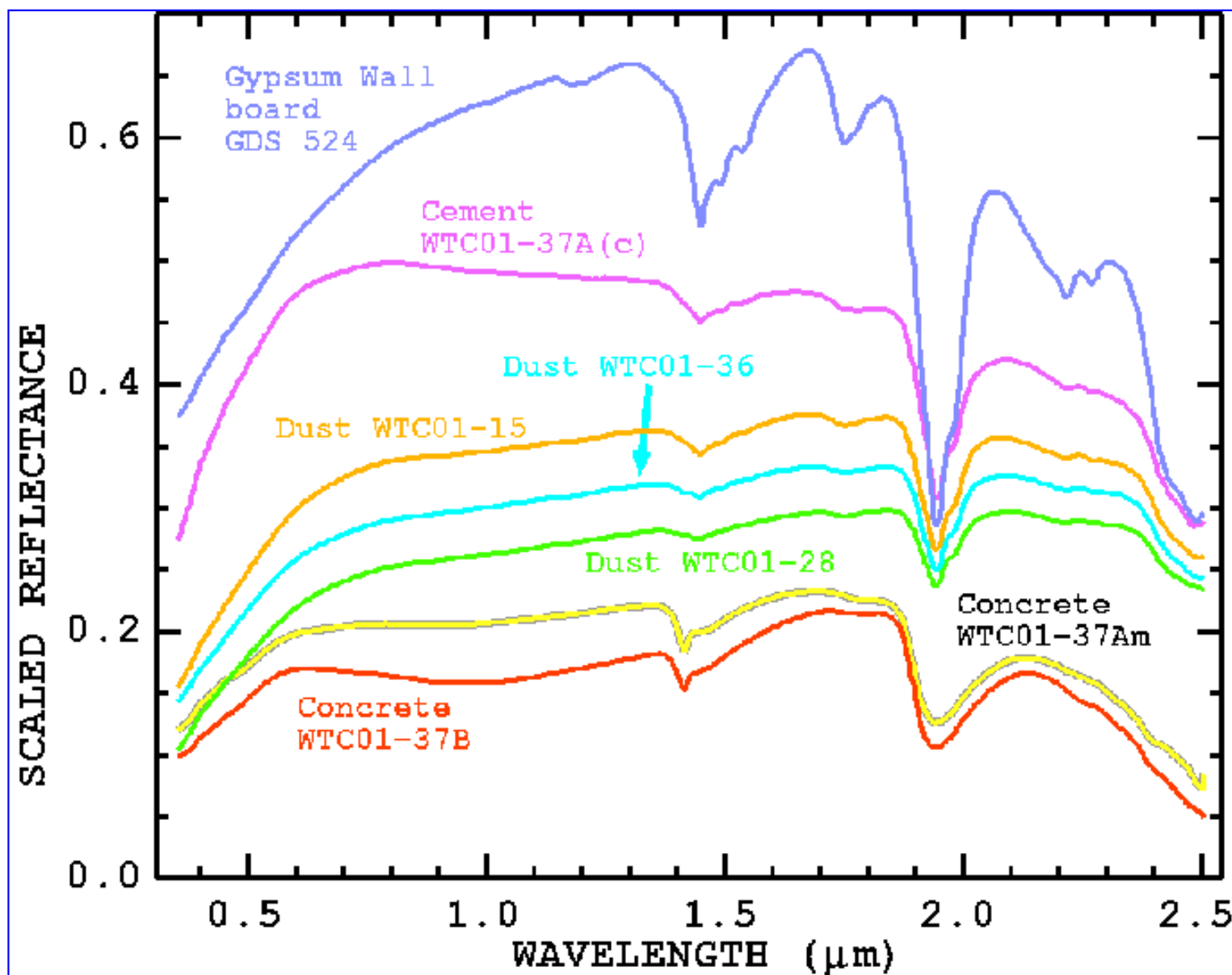
[Larger 1206 KB image](#)

Dust Figure 2a. Dust/Debris plume map without the image background so the mapped materials are easier to see.



[Larger 439 KB image](#)

Dust Figure 2b. Dust/Debris plume map, same as at right, but zoomed in to lower Manhattan.



[Larger 22 KB image](#)

Dust Figure 3. Reference spectral shapes used for making the dust/debris map. The colors match the colors on the maps in Dust Figures 2, 3.

[NEXT PAGE of Report: Ferrous and Ferric-Bearing Materials Map](#)

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Images of the World Trade Center site show significant patterns of materials with spectral absorptions near 1-micron.

The images on this page (Iron Figure 1, 2) show locations of materials with ferric and ferrous absorption features. These materials/minerals may include common building materials; therefore, the map may include materials in buildings not associated with the World Trade Center (WTC) collapse. While the minerals mapped in any one location may or may not be associated with the WTC event, a pattern is seen that shows the distribution of materials related to the WTC collapse. This is because the debris from the collapse tends to appear contiguous near the WTC or in patches unrelated to the layout of roads and buildings. Building materials that map with sharp boundaries as roads and building shapes may not be WTC debris.

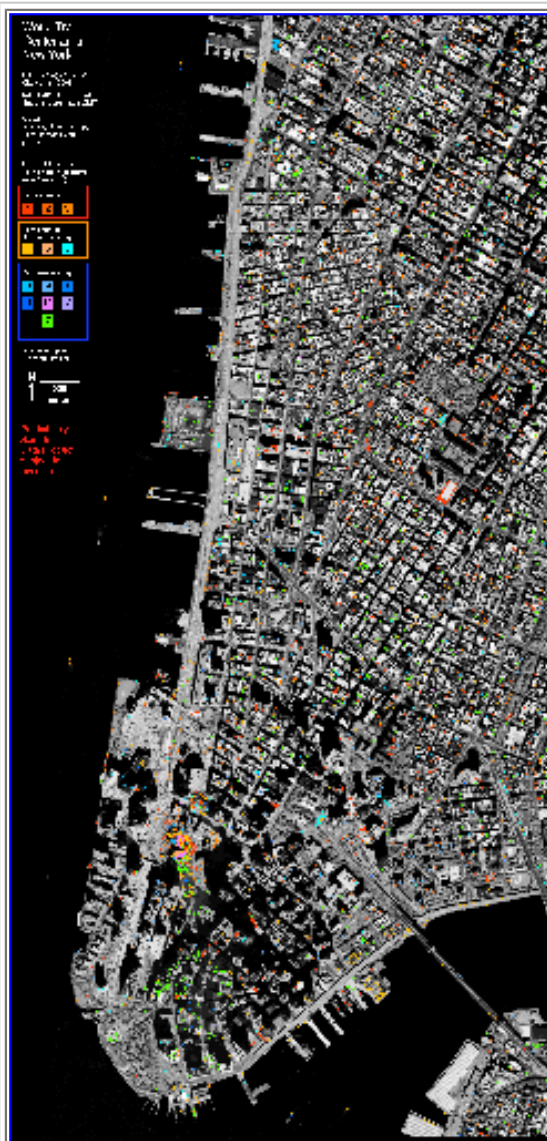
Fe-bearing materials occur in the WTC area and appear to be distributed in and around the collapse zone. Materials that were mapped show absorption features indicative of both ferric (Fe^{3+}) and ferrous iron (Fe^{2+}). Many minerals have similar ferrous absorptions, so maps show only the presence of Fe-bearing minerals and not specific mineralogy. In the maps below, the ferric and ferrous materials are identified only by numbered color. Pixels mapped as each numbered color indicate similar absorption position and shape and are likely similar in composition, but that composition is not generally a unique identifier of mineralogy.

The ferric absorptions are interpreted to be due to hematite (Fe_2O_3 - iron rust), or goethite (FeOOH). The red coatings on iron beams seen in news reports and by the field team are consistent with hematite or goethite.

Fe-bearing minerals are common in the aggregate in concrete. The Fe-absorptions appear in spectra of the debris samples and are prominent in spectra of the concrete debris. To see laboratory spectra of the dust and debris samples, [CLICK HERE.](#)

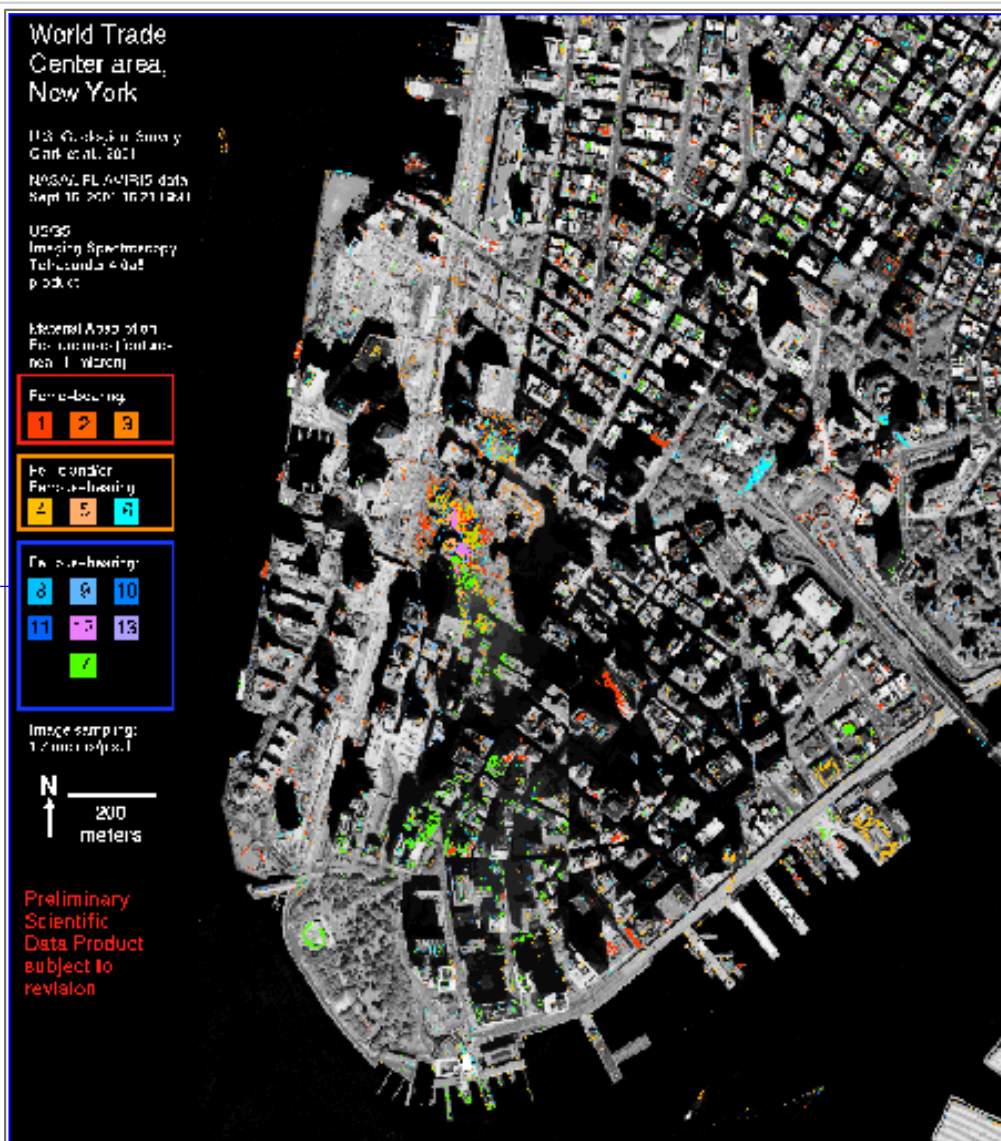
The map shows an asymmetric distribution of debris that extends to the SSE of the site. Similar distribution patterns are seen on the debris map (see previous section [Dust and Debris Plume Map.](#)) and the vibrational absorption map (next section), indicating a consistent finding of asymmetric distribution. Iron Figure 2 is the same as Iron Figure 1 but without the grey-scale image background. The debris pattern is more obvious without the background.

The asymmetry in the iron-bearing materials map may be related to the asymmetry in the asbestiform minerals map. The AVIRIS data and the laboratory analyses of the field samples indicate a lower abundance of chrysotile in the southern direction from the WTC, the same direction of the increase in iron-bearing materials. The implications of this distribution will be explored in the Integration of results and conclusions section, below.



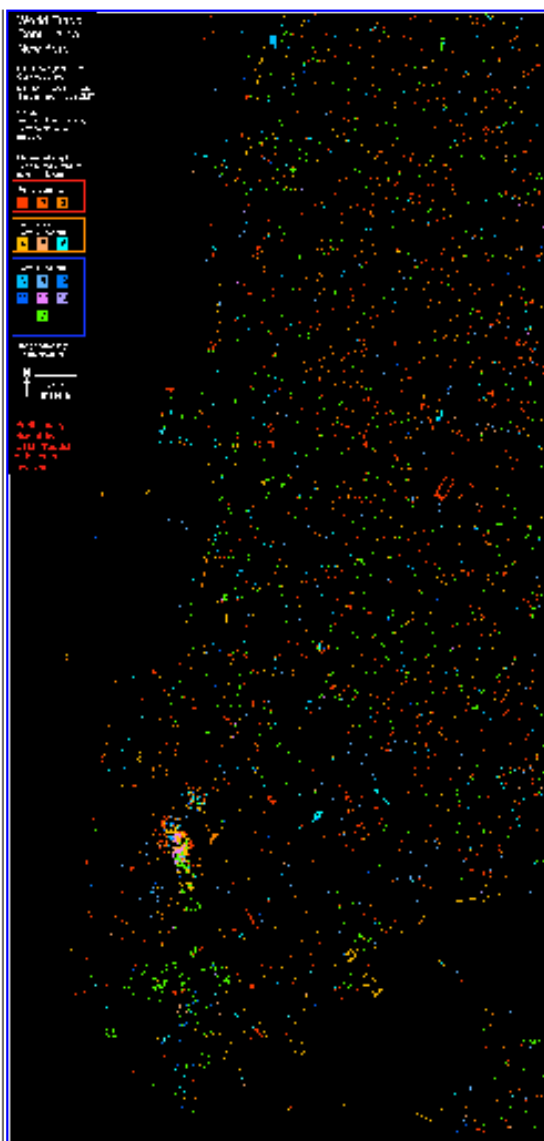
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Iron Figure 1a. Ferrous, ferric iron absorption features map.



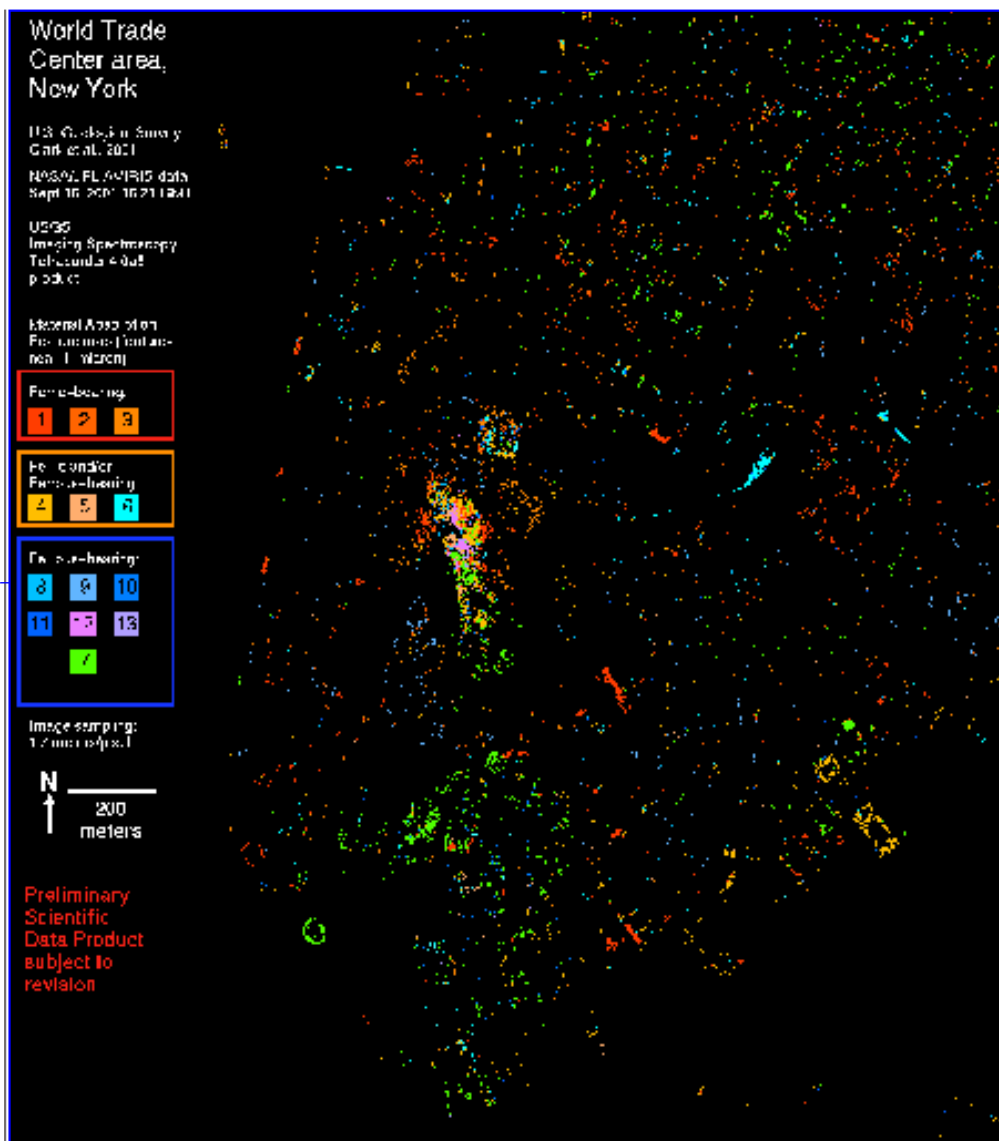
[Larger 526 KB image](#)

Iron Figure 1b. Ferrous, ferric iron absorption features map, same as at right, but zoomed in to lower Manhattan.



[Larger 153 KB image](#)

Iron Figure 2a. Ferrous, ferric iron absorption features map, without the image background so the mapped materials are easier to see.



[Larger 65 KB image](#)

Iron Figure 2b. Ferrous, ferric iron absorption features map, same as at right, but zoomed in to lower Manhattan.

NEXT PAGE of Report: Clays and other Materials Map

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OFR 01-0429: World Trade Center USGS Vibrational Processes Map

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Images of the World Trade Center site show patterns of materials with spectral absorptions due to vibrational processes

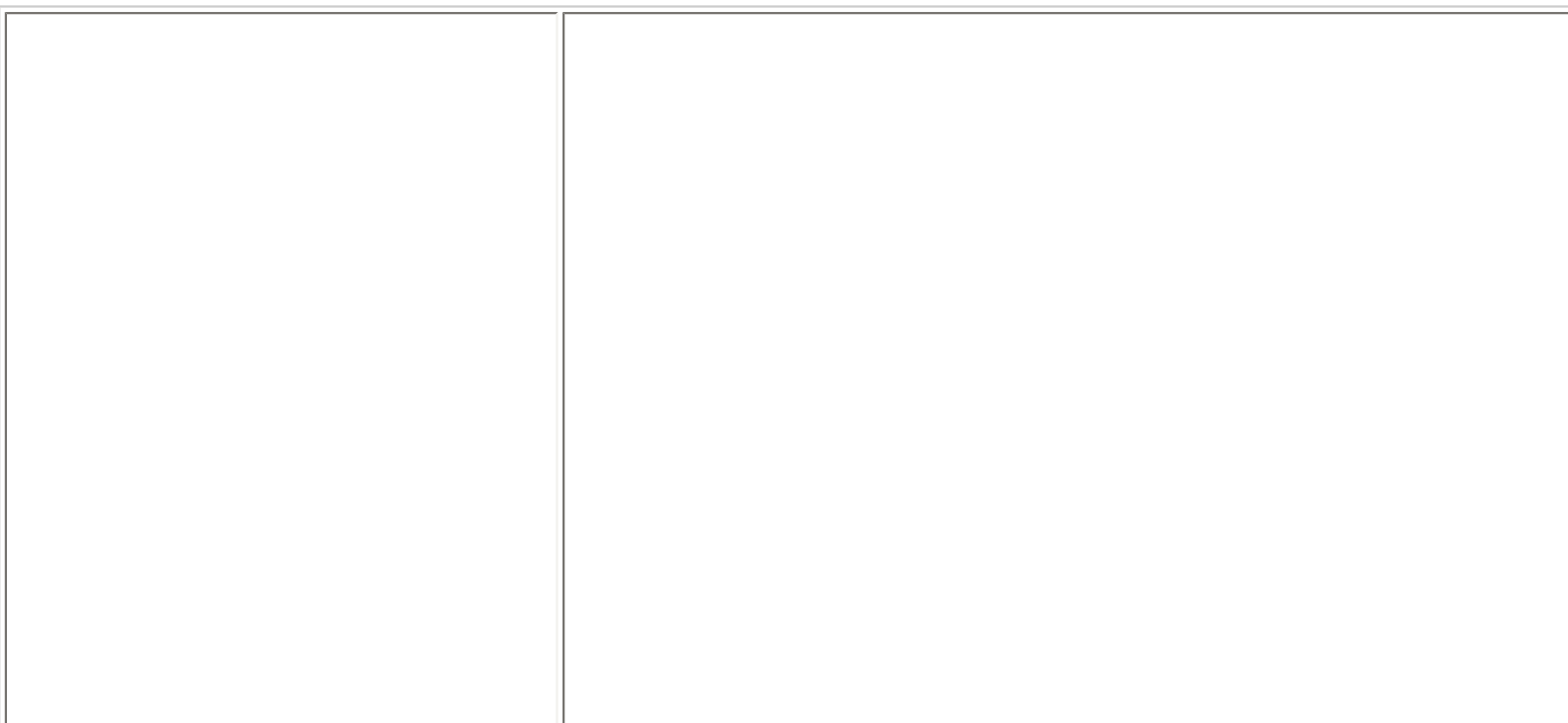
The map on this page (Vibrational Figure 1) shows locations of materials with vibrational absorption features commonly found in clays and other phyllosilicates (like muscovite), carbonates, and water-bearing sulfates. Such minerals are commonly found in building materials. For example, walls are often constructed with a board containing gypsum, a sulfate. Gypsum has been identified in samples from the WTC area (see sample analysis section). Muscovite, carbonates, and other hydroxyl-bearing minerals have also been identified in the WTC samples (see the Integration of Results section).

The debris contains common building materials, therefore, the map also shows these materials in other buildings not associated with the World Trade Center (WTC) collapse. While the minerals mapped in any one location may or may not be associated with the WTC event, a pattern is seen that shows the distribution of materials related to the WTC collapse. This pattern matches the pattern from the ferric and ferrous absorption features map.

The spectral absorptions due to vibrational processes are normally diagnostic of mineralogy or material type. The spectral signatures in the WTC debris are, however, quite weak (see laboratory spectroscopy of field samples, below). Because of their weak strength, and influences of the spectral signatures of other materials, including organics, definitive identifications could not be made in this case. Definitive identifications might be made on such samples if the sensor had a higher signal to noise.

Both the iron maps, dust/debris maps, asbestiform mineralogy maps, and vibration absorption maps show a pattern of materials suggesting asymmetric distributions to the composition of the debris/dust.

Again, at any one location in the image, the mapped materials may be unrelated to the WTC debris because they may be common building materials used in the area. However, if a certain type of debris must be cleaned up, this and the other maps indicate the locations to investigate on the ground where similar compositions occur.





[Larger 1477 KB image](#)

Vibrational Figure 1a.
Vibrational absorption features
map.



[Larger 526 KB image](#)

Vibrational Figure 1b. Vibrational absorption absorption
features map, same as at right, but zoomed in to lower
Manhattan.

[NEXT PAGE of Report: Organic Compounds Map](#)

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Images of the World Trade Center site show patterns of materials with spectral absorptions indicating the presence of C-H (organic) compounds.

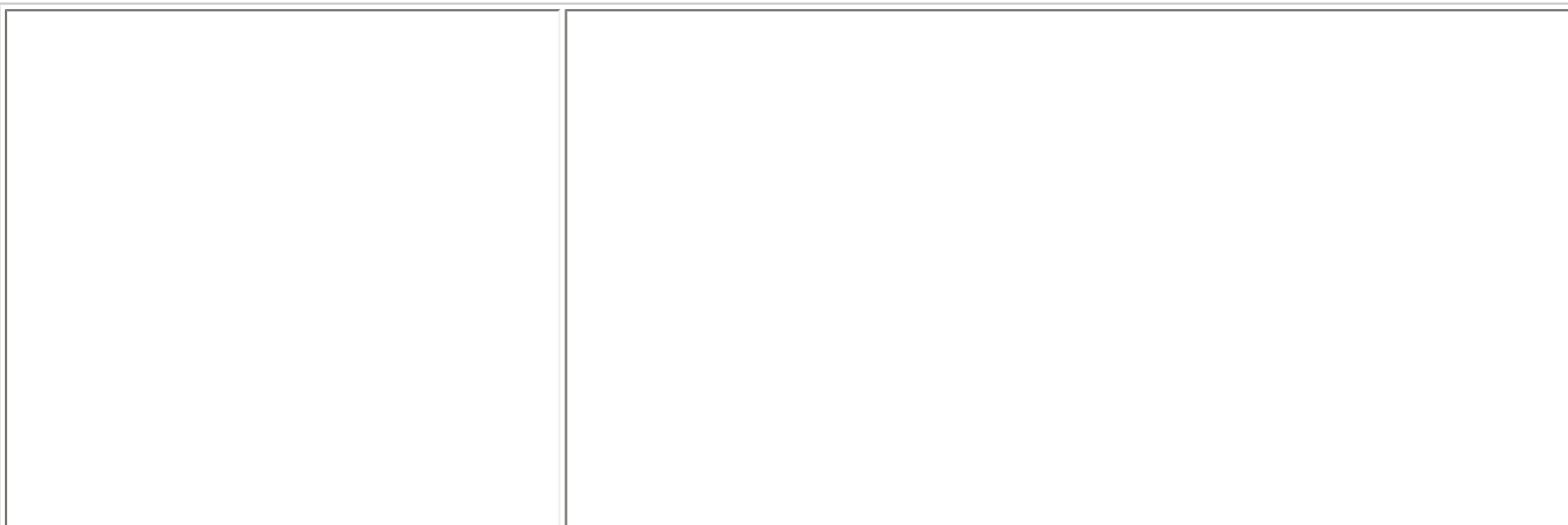
The map of materials containing organic compounds (Figure 1a, 1b) shows no pattern that is indicative of the distribution of debris from the WTC collapse at the detection limit of AVIRIS. Organic compounds include any material containing C-H chemical bonds (e.g. plastics, paints, gasoline, and many types of solvents).

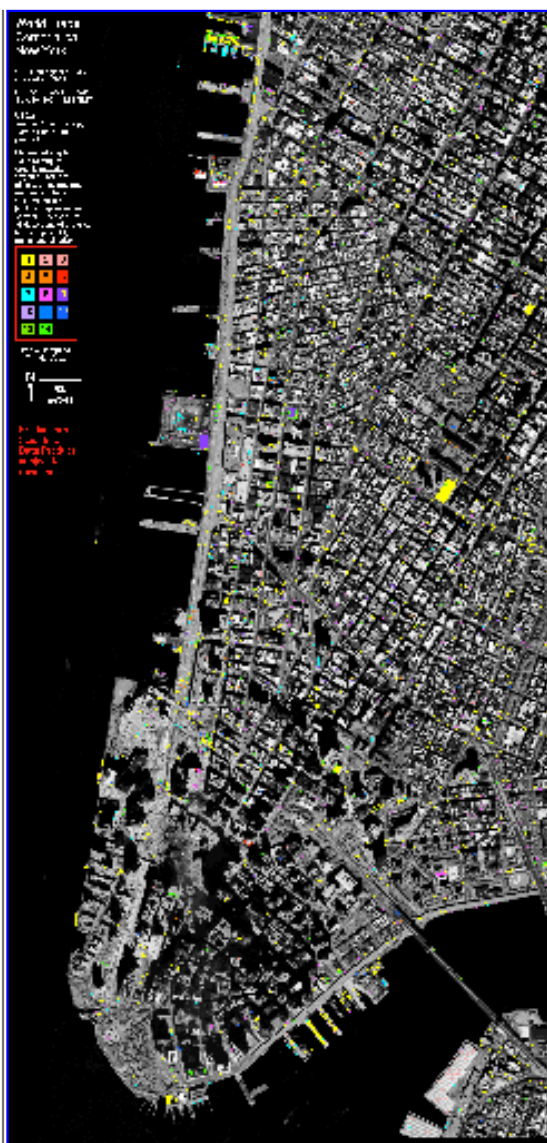
Because there are literally thousands of organic compounds and our reference materials spectral library only contains a few samples, we do not have the capability to uniquely identify the various types of organic materials. Because the reference spectra covering the AVIRIS spectral range is sparse, it is also unknown if AVIRIS has the spectral resolution to uniquely separate some types of organic compounds. Thus the organics map here does not indicate unique compounds. But the different colors indicate different spectral classes of organics and indicate broadly similar compositions.

The majority of the organics mapped in this area are probably related to plastics and paints. Paper, wood, and vegetation are also organic, but the spectral signatures of these materials occur with other known absorptions (e.g. from lignin, cellulose, and nitrogen) and are excluded from this map. Some aged wood, however, does have spectral features that can be confused with the other organics here (e.g. due to decreased signatures of lignin, cellulose, and nitrogen), and might be included in this map.

Imaging spectroscopy has not detected more than a few percent organic material in the WTC debris. It may be possible that more organic material exists but was not spectrally observable at the surface with AVIRIS.

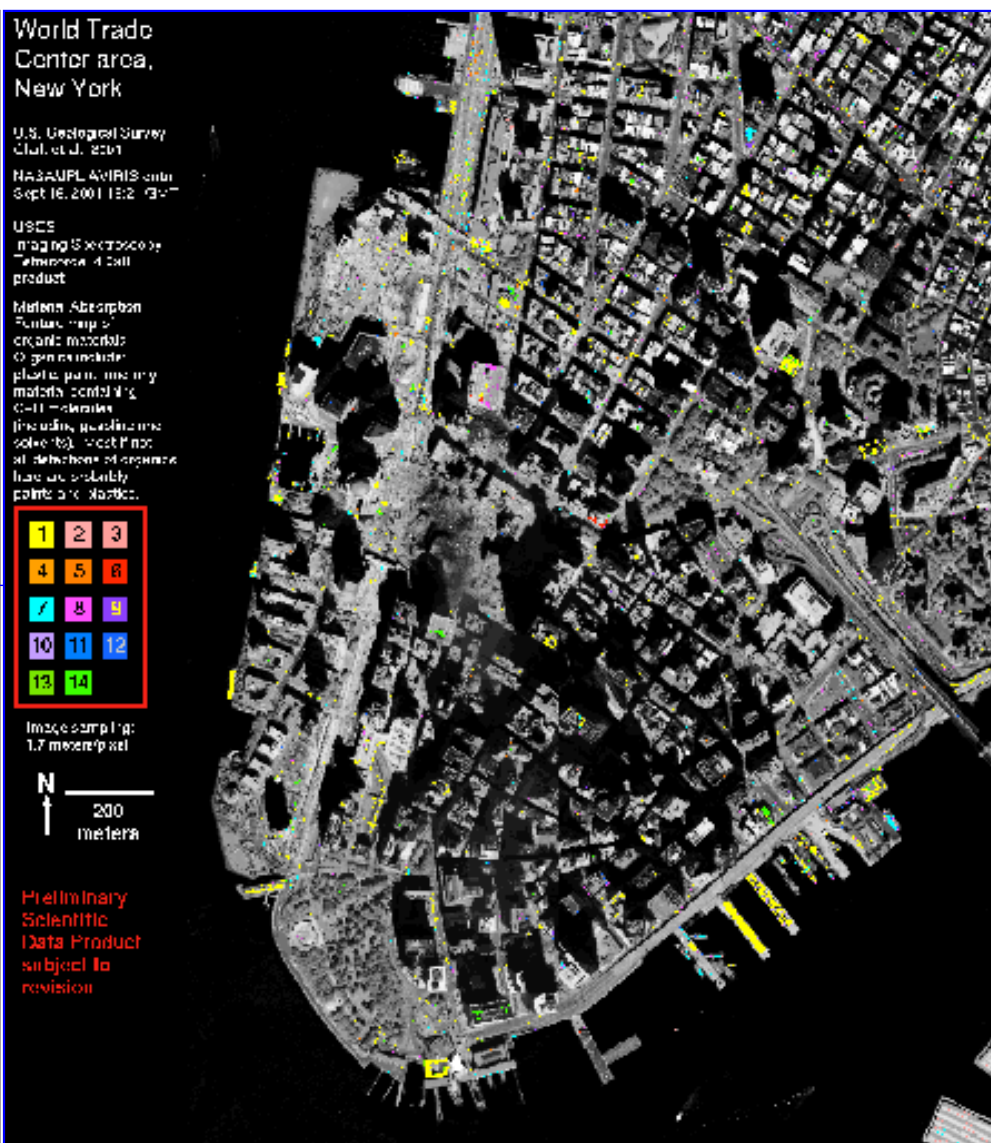
Absorptions due to CH occur near 2.3 microns: the same location as (OH) absorptions in serpentines and amphiboles (asbestiform minerals). This coincidence results in a higher threshold detection limit for asbestiform minerals when CH-absorptions are present in the spectrum. Fortunately, CH-compounds also have additional absorption features (e.g. those near 1.65 to 1.75 microns, Figures 2a, b, c) that make detecting such compounds possible and reducing false positive identifications of asbestiform minerals. Thus, locations on this map where CH-compounds are present also indicate locations where asbestiform minerals are indeterminate.





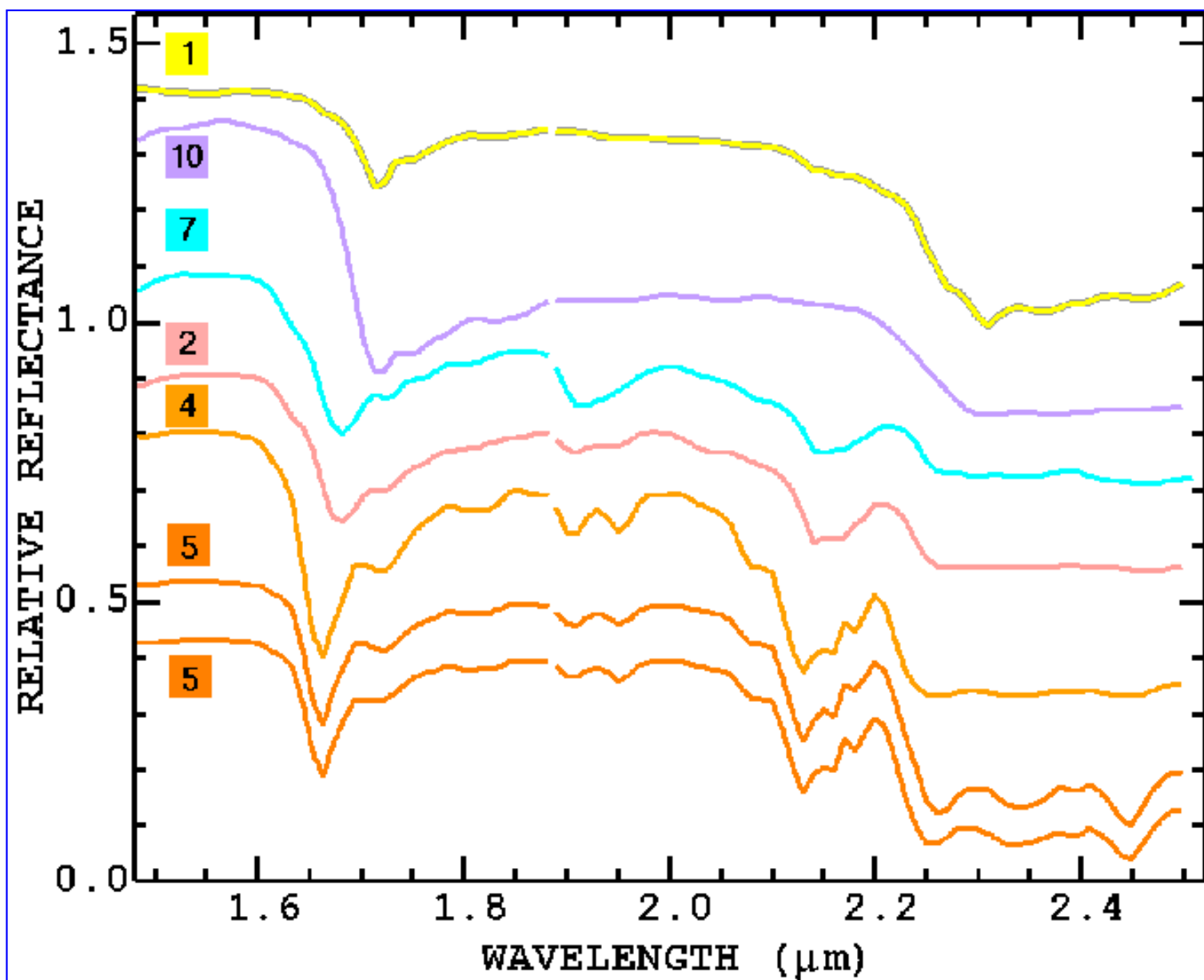
[Larger 1460 KB image](#)

CH Figure 1a. Organic materials absorption map.



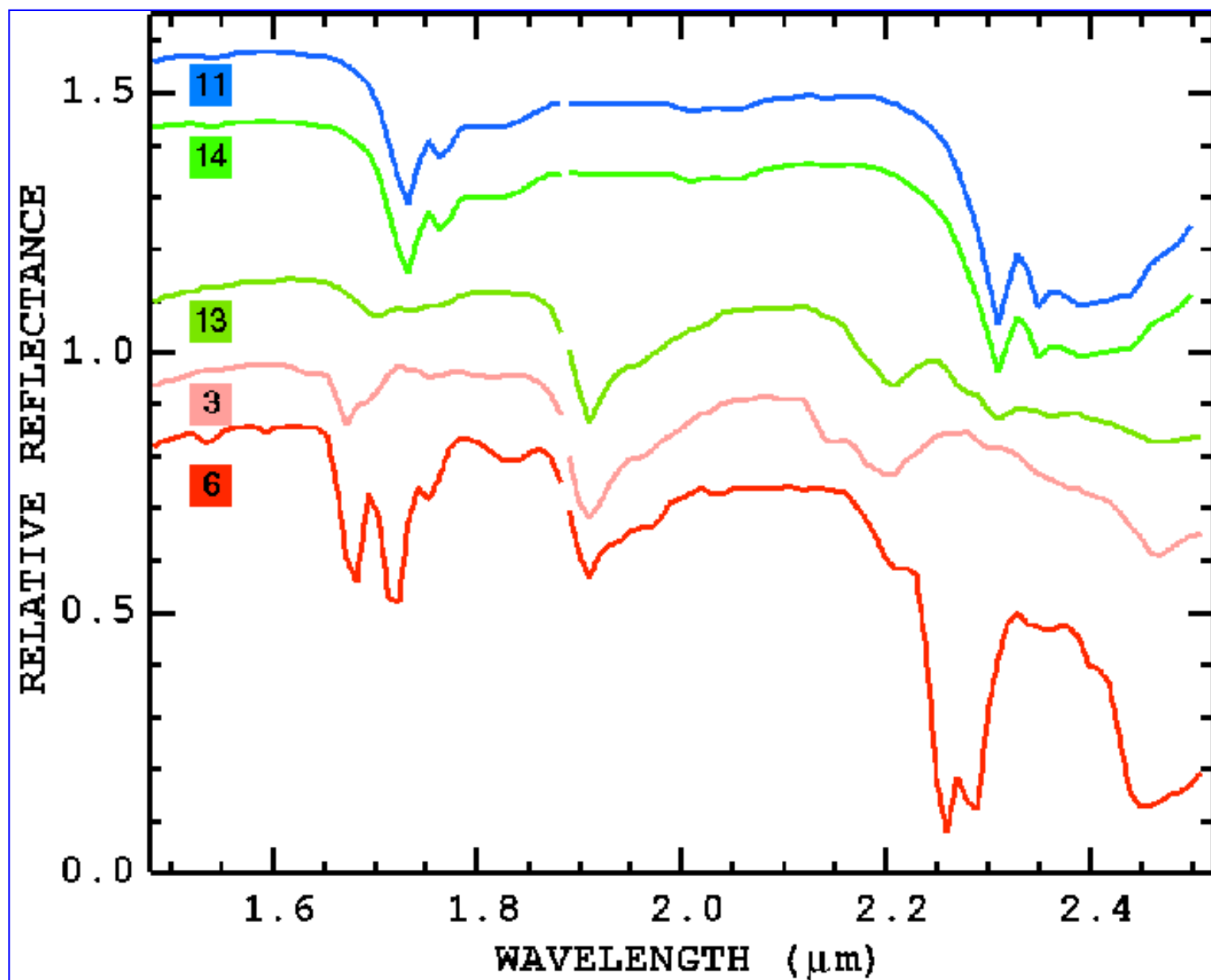
[Larger 519 KB image](#)

CH Figure 1b. Organic materials absorption map, same as at right, but zoomed in to lower Manhattan.



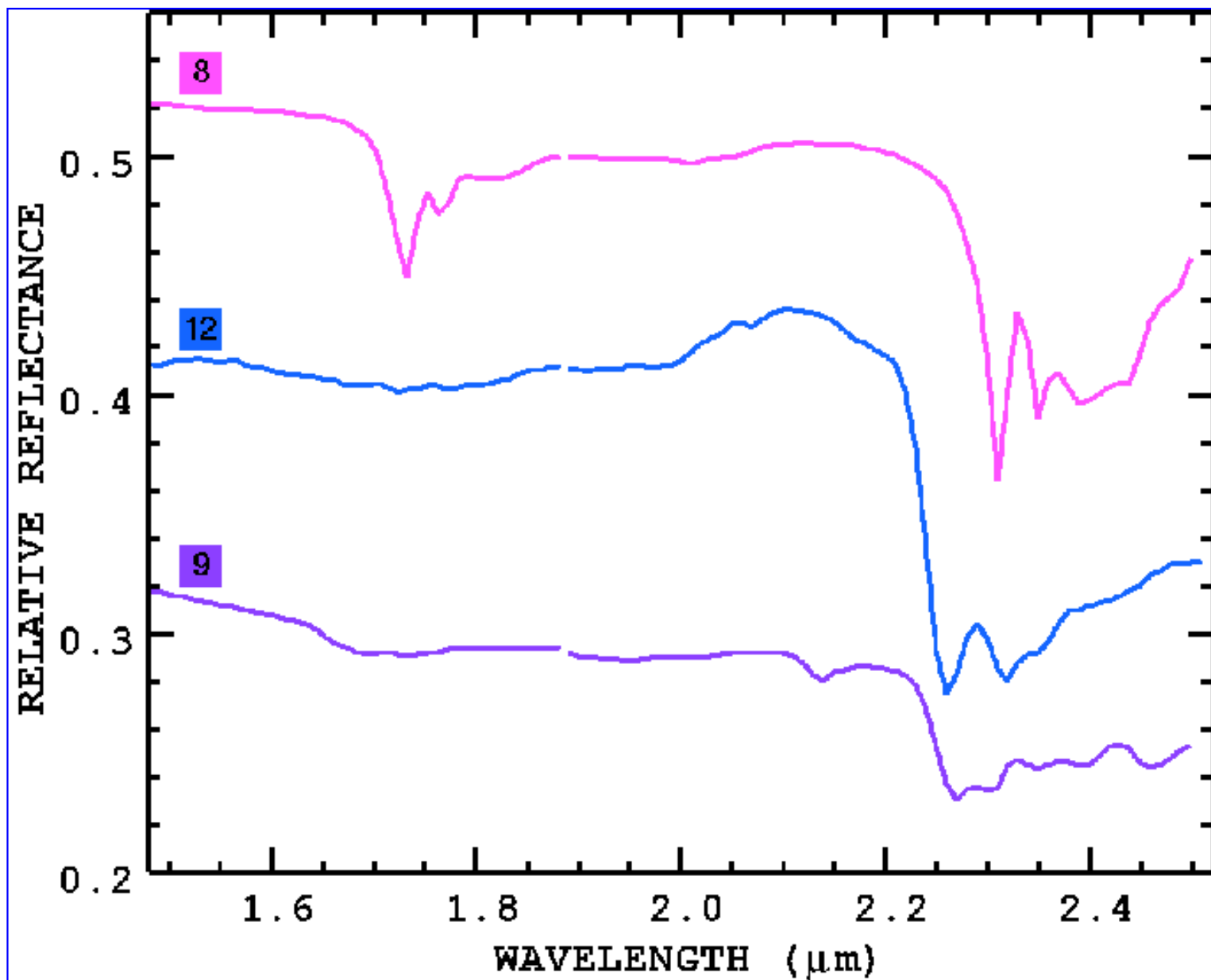
[Larger 18 KB image](#)

CH Figure 2a. Example spectra of CH compounds used to map the organics in CH Figure 1. The colors of the spectra match the colors of the materials on the map.



[Larger 16 KB image](#)

CH Figure 2b. More spectra of CH compounds used to map the organics in CH Figure 1. The colors of the spectra match the colors of the materials on the map.



[Larger 12 KB image](#)

CH Figure 2c. More spectra of CH compounds used to map the organics in CH Figure 1. The colors of the spectra match the colors of the materials on the map.

[NEXT PAGE of Report: Water Sediment Map](#)

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OFR 01-0429: World Trade Center USGS Water Sediment Map

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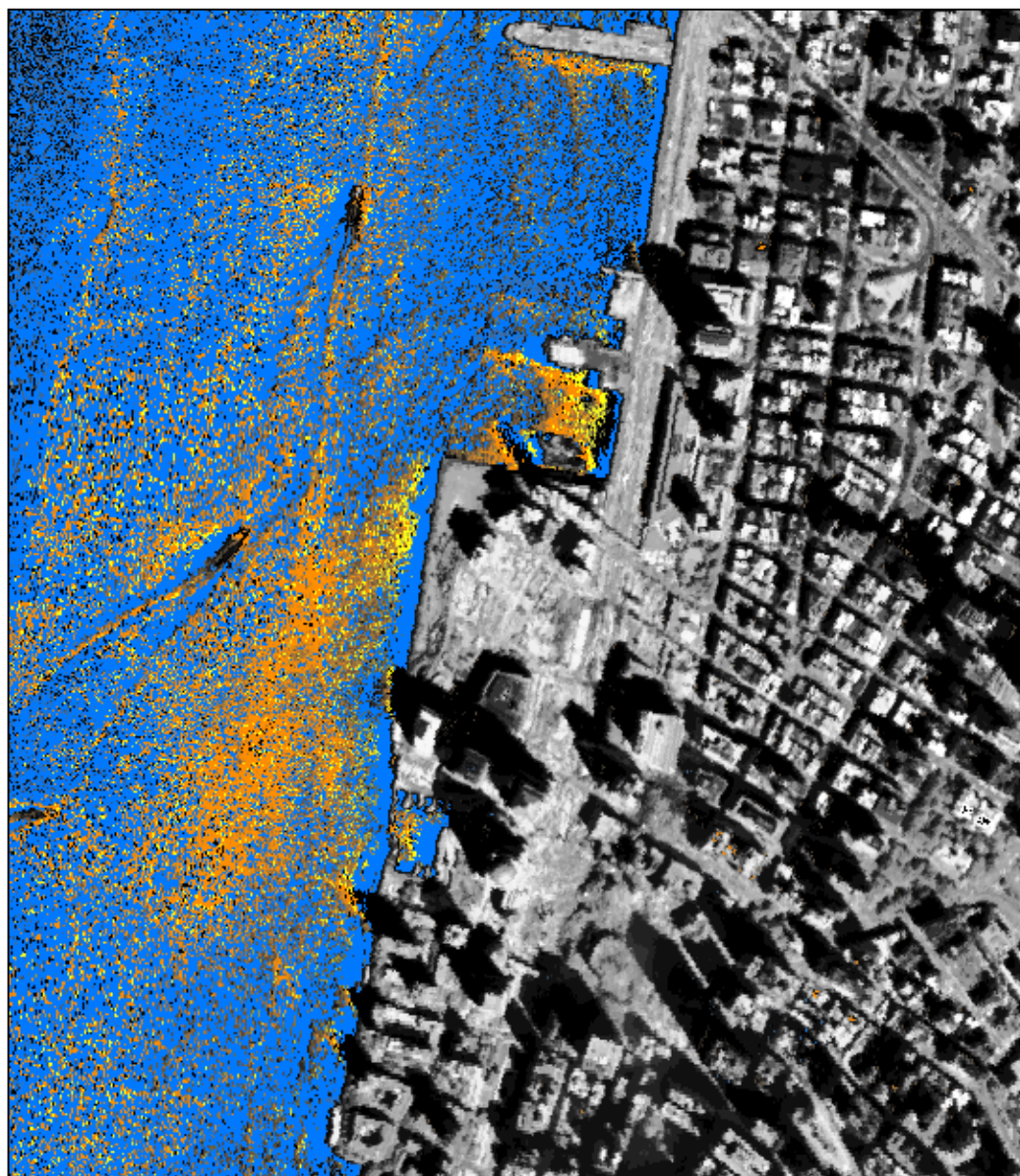
Images of the World Trade Center area show sediment in the water.

The maps in Water Figures 1, 2, produced by analysis of spectral data from the NASA/JPL Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) instrument, shows sediment in the water next to the World Trade Center. Relative abundances of solids determined for this AVIRIS data set are qualitative because the absorption strengths have not been calibrated to abundance and are shown along with presence of chlorophyll. Water absorption feature shape changes with relative abundance of sediment load. Here, the load has been differentiated as high (orange) and low (yellow) on the map. In regions of lower sediment load, chlorophyll (blue) can be detected. Water mapped as black is either clear water with low chlorophyll or areas where a surface film inhibits seeing into the water.

Waterborne sediment is shown on the map along the eastern shore of the Hudson River and in the East River. Along the Hudson River, sediment is most apparent west of the World Trade Center and alongside piers and docks. Areas with high sediment load are candidates for sampling to determine if such sediments originated from the region of the World Trade Center.

The apparent source region of the sediment occurs where debris from the WTC is being loaded onto barges. Thus, the sediments at this location may be from the WTC.

The black area on the map at the south end of Manhattan Island in the 15:15 GMT data (Water Figure 1) shows high infrared reflectance indicating the presence of a surface film. In the data from 16:21 (Water Figure 2), the surface film is mostly dissipated.






World Trade Center area, New York

U.S. Geological Survey
Clark et al., 2001

NASA/JPL AVIRIS data
Sept 16, 2001 15:15 GMT

USGS
Imaging Spectroscopy
Tetracorder 4.0a3
product

Water map:

-  low sediment load
-  high sediment load
-  water with chlorophyll

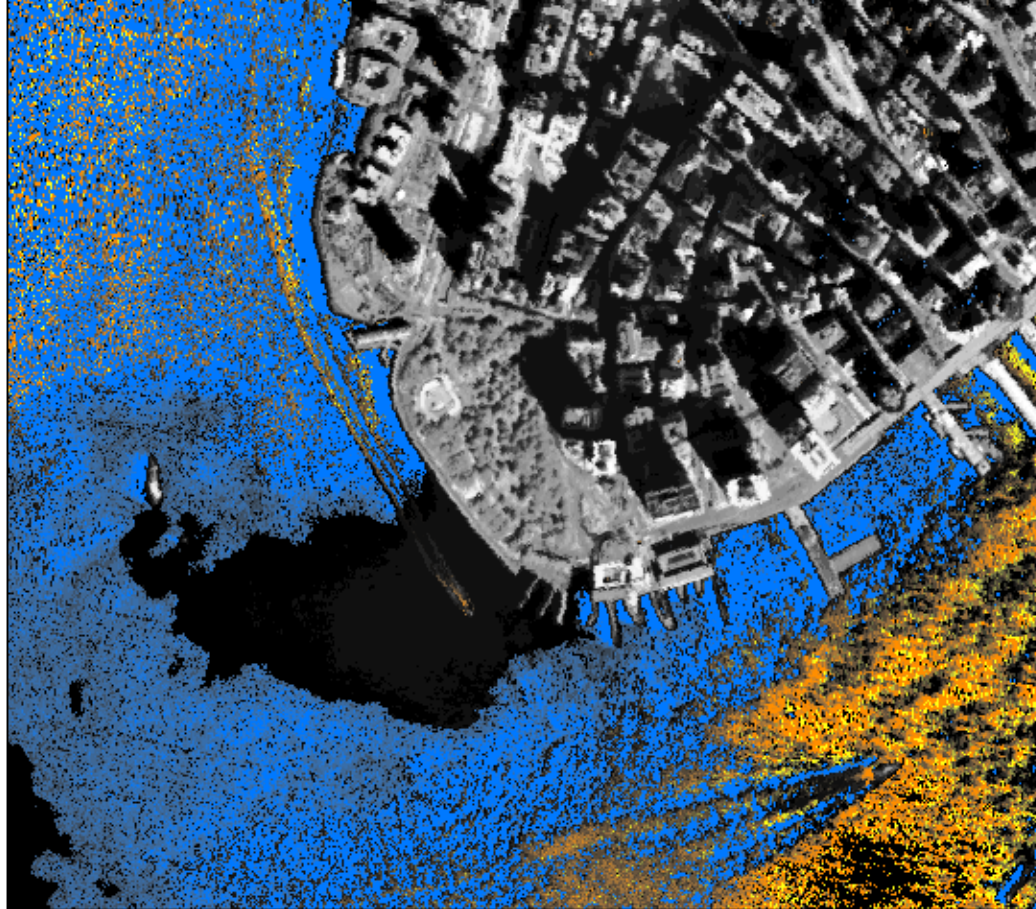
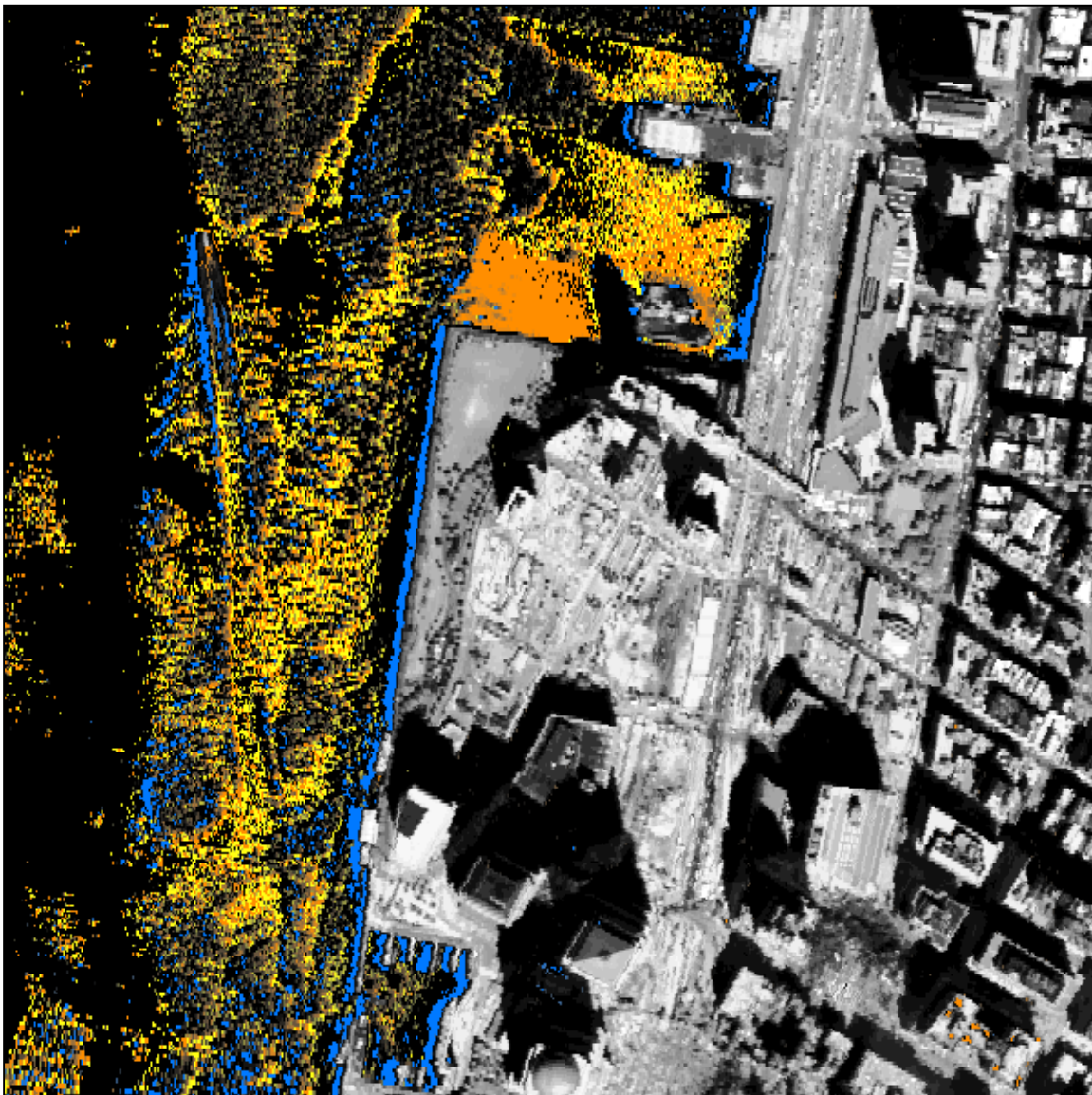


Image sampling:
3.2 meters/pixel

N
↑
200
meters

Water Figure 1. 4-meter pixel data shows sediment in the water.



World Trade Center area, New York

U.S. Geological Survey
Clark et al., 2001

NASA/JPL AVIRIS data
Sept 16, 2001 16:21 GMT

USGS
Imaging Spectroscopy
Tetracorder 4.0a3
product

Water map:

- low sediment load
- high sediment load
- water with chlorophyll

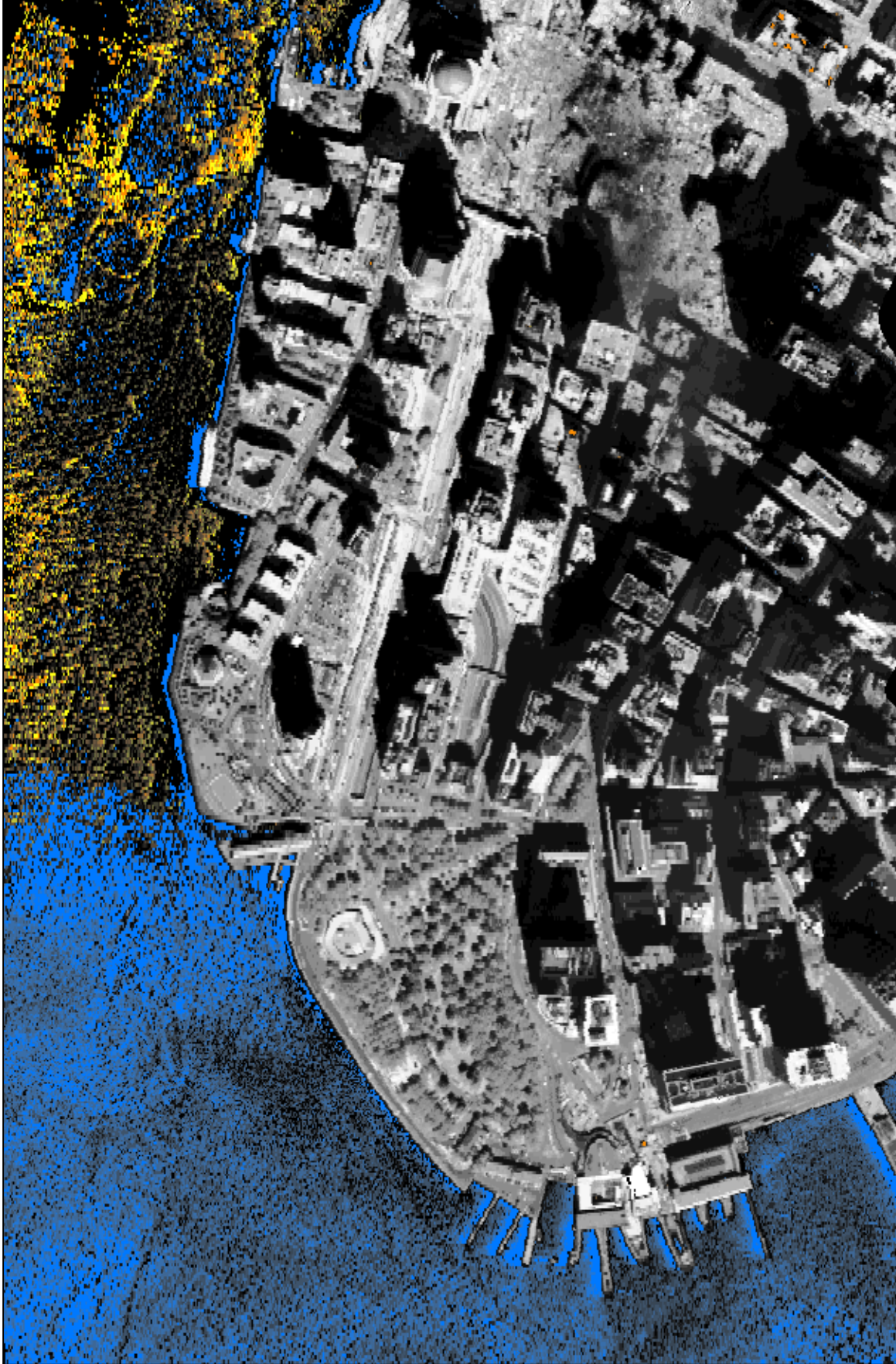
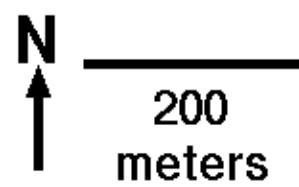


Image sampling:
1.7 meters/pixel



Water Figure 2. 2-meter pixel data shows sediment in the water.

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Sample collection in the World Trade Center area, Sept 17-18, 2001

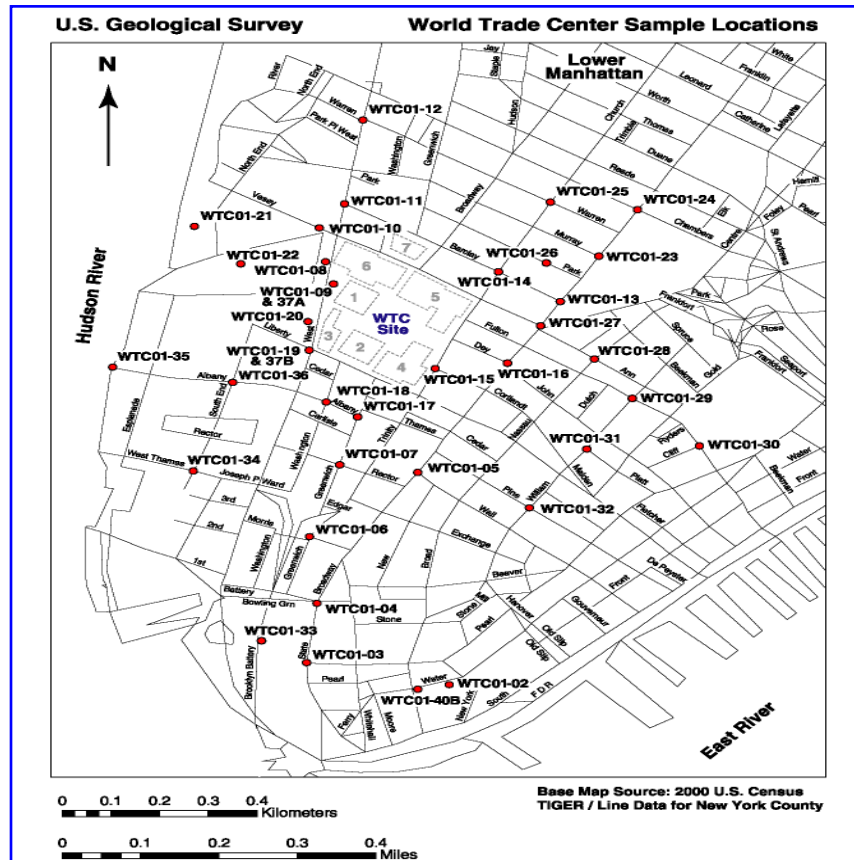
A 2-person USGS crew collected grab samples from 35 localities within a 0.5 - 1 km radius circle centered on the World trade Center site on the evenings of September 17 and 18, 2001 (see sample collection map, below). This same crew also carried out on-the-ground reflectance spectroscopy measurements during daylight hours to calibrate Airborne Visible /Infrared Imaging Spectrometer (AVIRIS) remote sensing data. Many of the streets bordering the collection locations were cleaned or were in the process of being cleaned at the time of sample collection. Given this limitation, collection of dust samples was restricted to undisturbed window ledges, car windshields, flower pots, protected areas in door entry ways, and steps. Occasionally, samples were collected from the sidewalk adjacent to walls that were afforded some degree of protection from the elements and cleanup process. In many cases the samples formed compact masses suggestive of having been dampened by rain and having dried in the intervening 3 - 4 days. Two samples of an insulation coating (WTC01-8 and WTC01-9) were collected from steel girders recently removed from the debris pile of the WTC. Samples were gathered by nitrile-gloved hand and put into doubled plastic sample bags (sample bag in another sample bag). Initially, Global Position Satellite (GPS) locations were collected for the sample collection locations, but this approach was abandoned because of difficulty in acquiring a satellite signal between tall buildings. Instead, sample locations were identified using road intersections where road signs remained intact. All but two of the samples were collected outdoors and had been subjected to wind and water during a rain storm the night of September 14. One sample (WTC01-20) was collected indoors near the gymnasium in the World Financial Center directly across West Street from the World Trade Center. Samples of concrete (WTC01-37A and WTC01-37B) were collected from the WTC debris at the same location as WTC01-9. A sample of dust (WTC01-36) blown by the collapse into an open window of an apartment located 30 floors up and 0.4 km from the center of the WTC site was also acquired a few days later.

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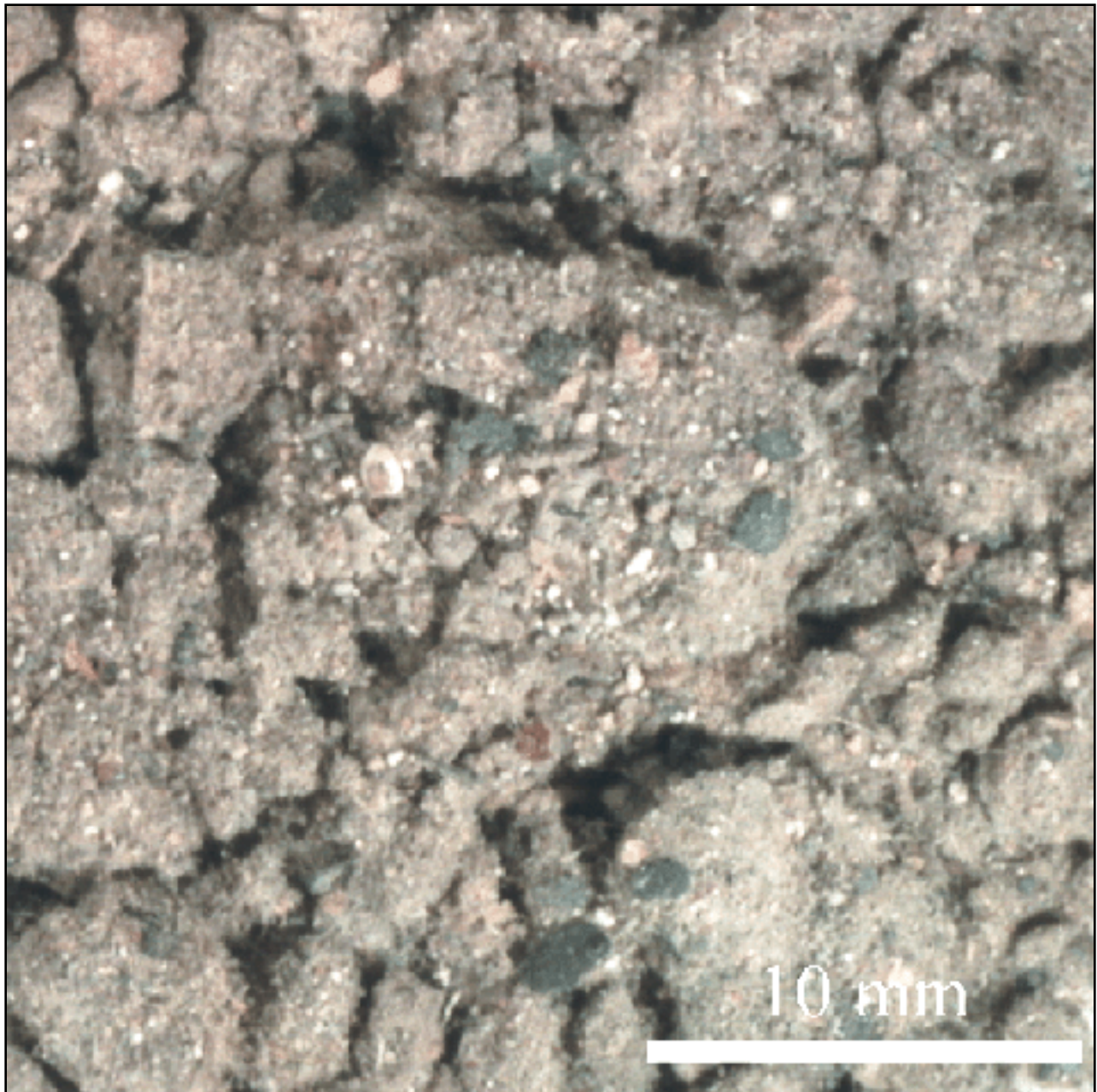
or

Todd Hoefen

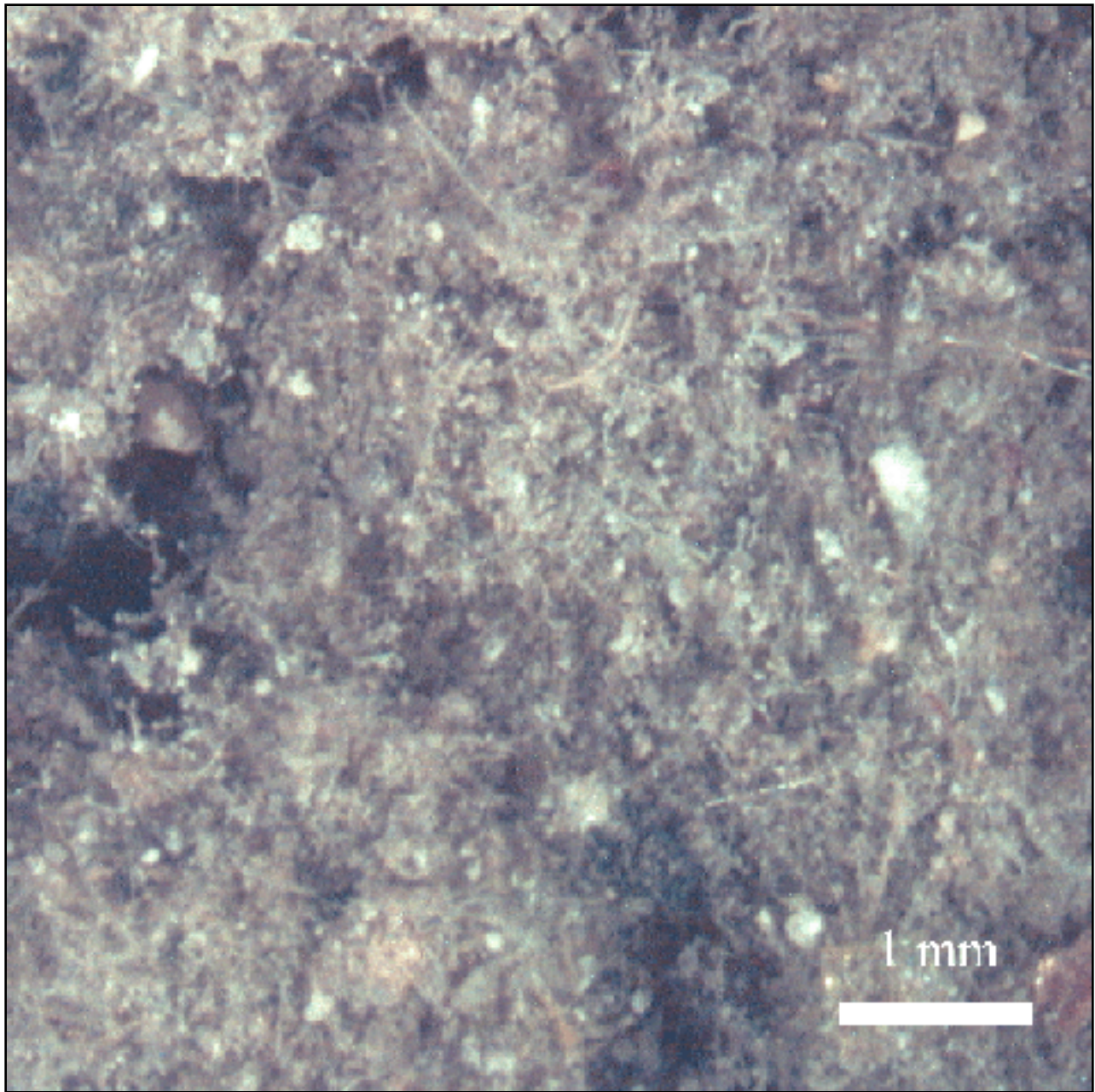


[Larger 92 KB image](#)

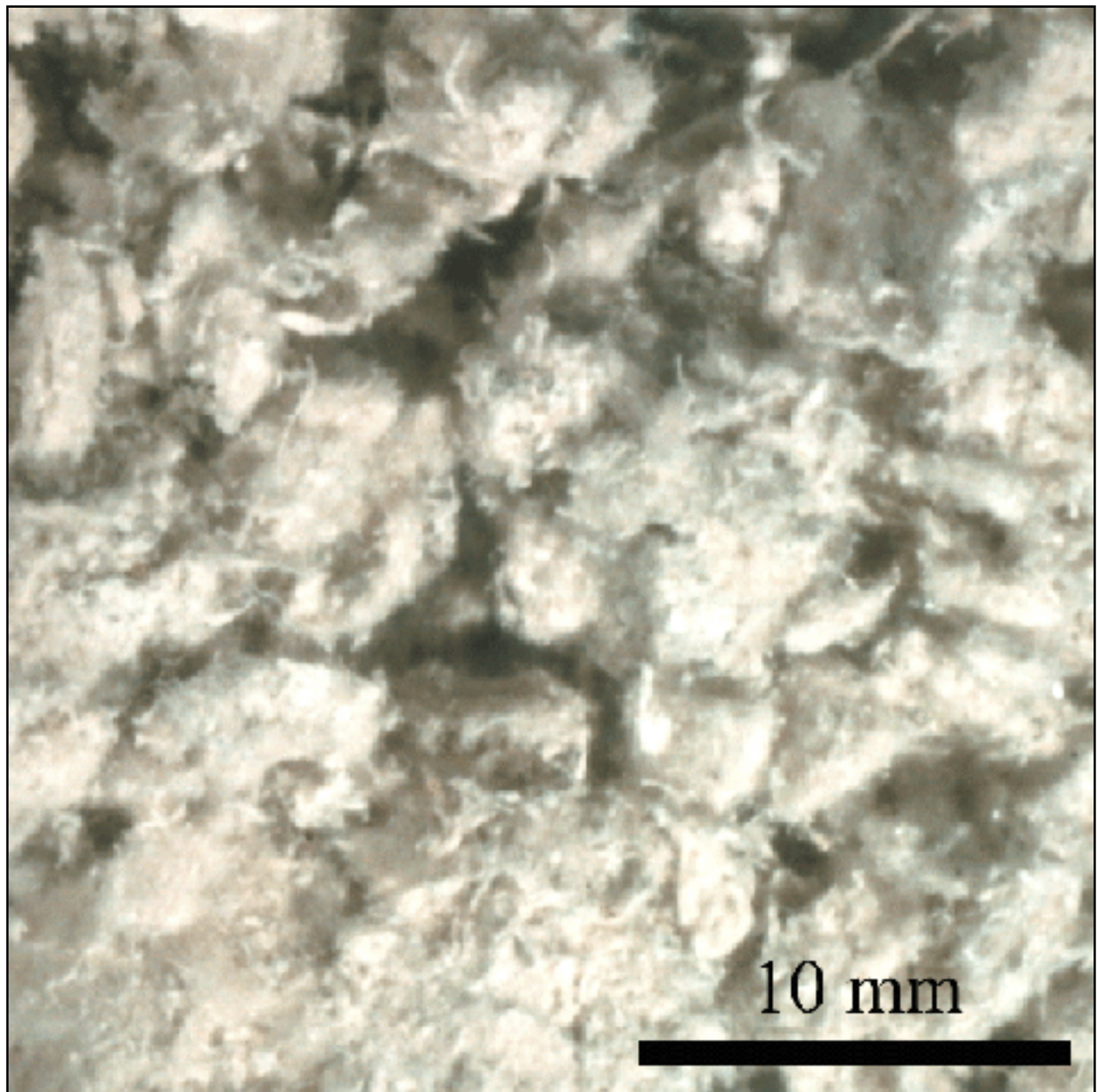
SL Figure 1. Sample location map.



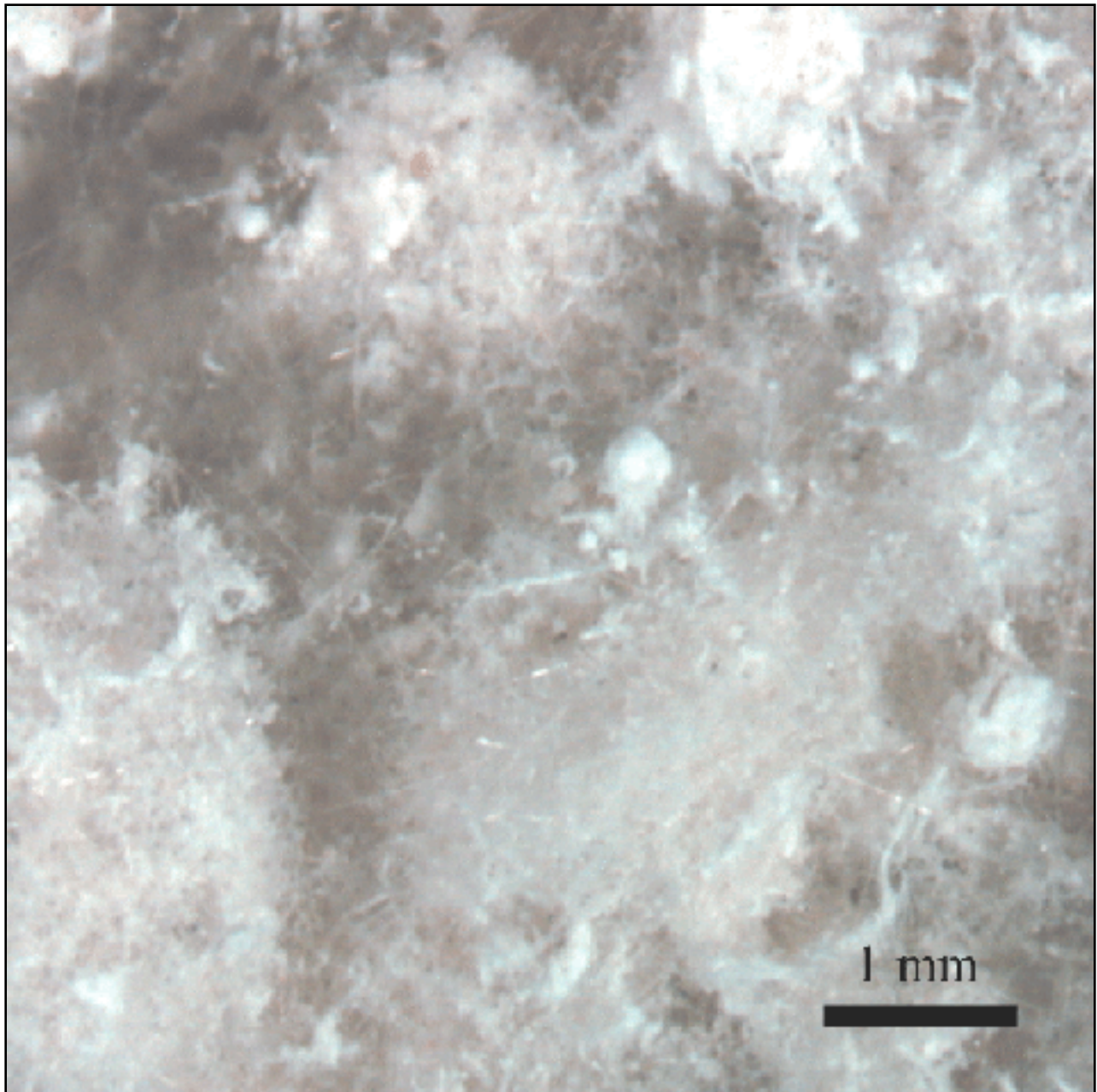
SL Figure 2. Optical image of dust and debris collected 0.3 km from ground zero (sample WTC01-27).



SL Figure 3. High magnification optical image of dust and debris collected 0.3 km from ground zero (sample WTC01-27). Most of the fibers seen in the image are probably glass fibers (e.g. from rock wool or fiberglass insulation) with a probable trace of chrysotile asbestos as detected by X-ray diffraction in this sample.



SL Figure 4. Optical image of an insulation coating collected from a steel beam removed from the WTC debris pile (sample WTC01-8).
This insulation contains up to 20 volume % chrysotile asbestos.



SL Figure 5. High magnification optical image of an insulation coating from a steel beam removed from the WTC debris pile (sample WTC01-8).
This insulation contains up to 20 volume % chrysotile asbestos.

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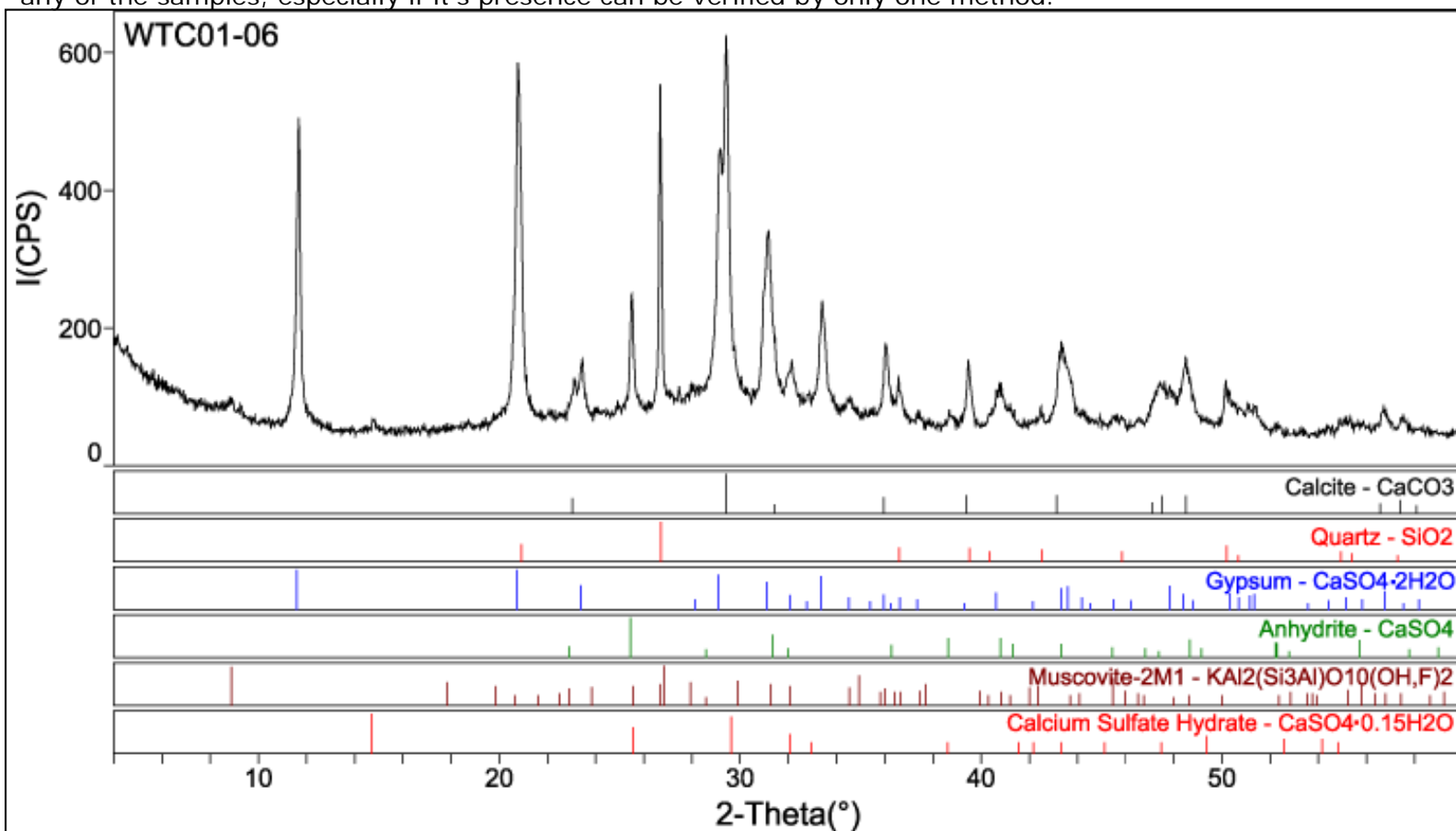


OFR 01-0429: X-Ray Diffraction (XRD) Analysis

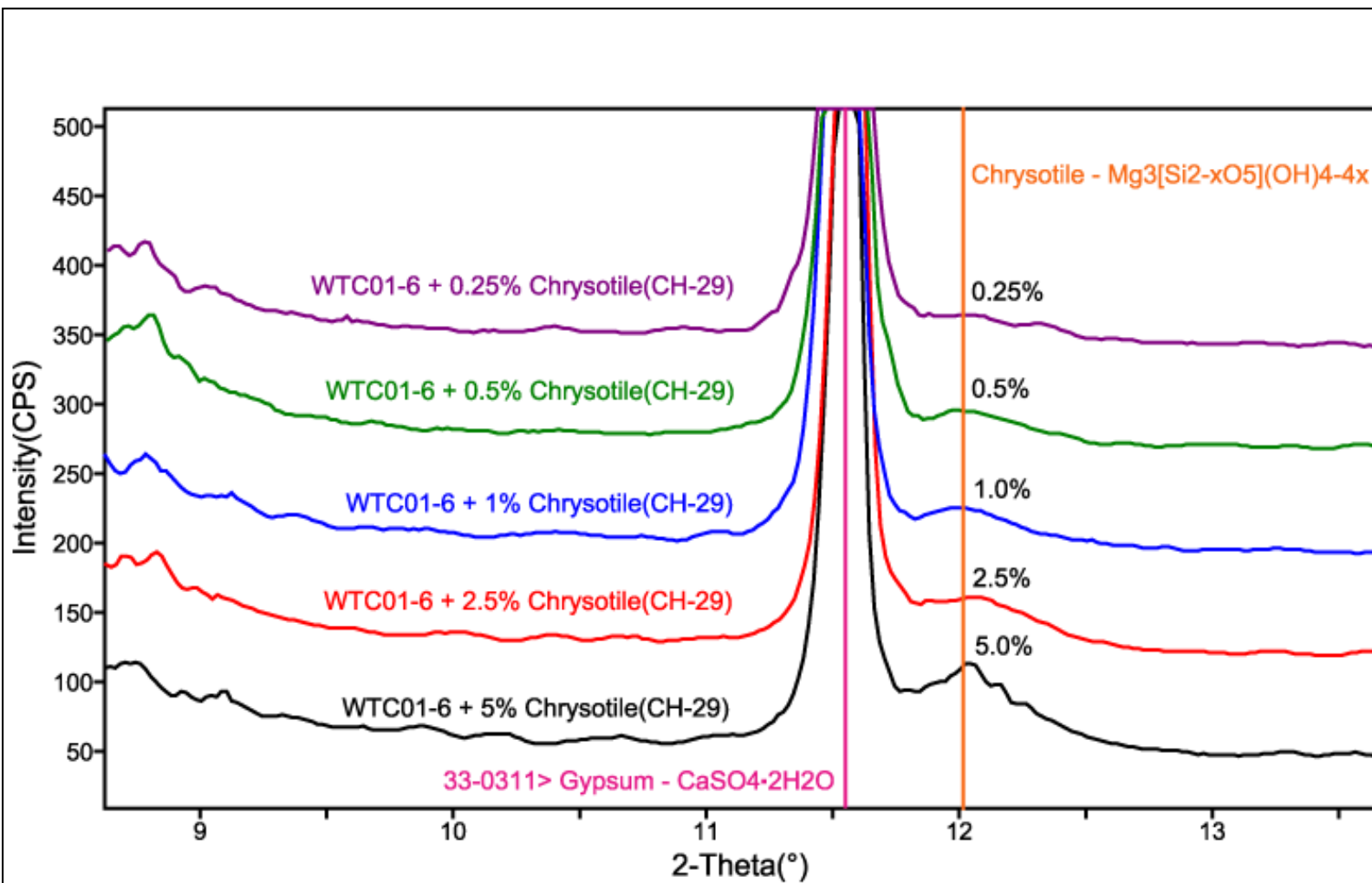
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X-Ray Diffraction (XRD) analyses of WTC samples (Table 1, on the [Integration of Results page](#)) indicate that most samples contain varying amounts of crystalline quartz, gypsum, calcite, anhydrite and amorphous material (e.g. XRD Figure 1). Other phases identified in small amounts include: muscovite, feldspar, magnesiohornblende, lizardite (non-asbestiform serpentine), dolomite, bassanite, illite, portlandite, larnite, polymorphs of calcium silicates, possible asbestiform chrysotile, and others. The results are reported as major (>20% by weight), minor (>5% but <20% by weight), and trace (<5% by weight). These ranges were determined by operator experience for the purpose of informing analysts and other interested parties of the relative concentrations of the phases present in samples.

All of the above mentioned phases can be components of the building dry wall material, concrete foundation, and/or insulation. Determining the presence of chrysotile at very low concentration levels by XRD is difficult due to the amount of other crystalline substances and the increased background due to large amounts of X-ray amorphous "slag wool," contained in all dust samples. It is possible that small amounts of chrysotile (probably <1.0%, XRD Figure 2) may be present in a few samples (see Table 1 on the [Integration of Results page](#)). The presence of chrysotile can sometimes be verified by other analytical methods; due to the heterogeneity of the samples, the splits that were made may not be representative, so results may vary. More work may be necessary to try to separate the chrysotile from the other material to determine if chrysotile is indeed present in any of the samples, especially if it's presence can be verified by only one method.



XRD Figure 1. X-ray diffractogram of World Trade Center dust sample WTC01-6. Note domination of peaks from calcite, quartz, gypsum, and anhydrite, the main minerals in most of the 33 samples collected. Also note the increased background, which indicates a major concentration of X-ray diffraction amorphous (non-crystalline) material. This sample contains no detectable chrysotile asbestos and was therefore used in preparing synthetic mixtures of dust + chrysotile.



XRD Figure 2. Details of a diagnostic X-ray diffraction peak attributed to chrysotile (NIOSH standard CH-19) in synthetic mixtures of chrysotile in sample WTC01-6 in weight percent. This set of diffractograms was used as a guide for determining relative chrysotile concentrations in the 33 dust samples collected from around the WTC site. Sample splits were not homogenous so results can vary.

[NEXT Section of Report: Laboratory Reflectance Spectroscopy \(RS\) Studies](#)

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OFR 01-0429: Laboratory Reflectance Spectroscopy (RS) Studies of WTC Samples

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Reflectance Spectroscopy

Spectroscopy is a tool that detects chemical bonds in molecules (solid, liquid or gas) through absorption (or emission) features in the spectrum of the material. While crystallinity affects the shape of spectral features, non-crystalline materials (such as glass or plastic) still display absorption features in their spectra. Results of the spectral analysis of the WTC samples is given in Results Table 1 (in the Integration of Results section, below). In general, ultraviolet to near-infrared reflectance spectroscopy used for this analysis (0.35 to 2.5 microns) has different sensitivities to materials than XRD. Reflectance spectroscopy in this spectral range is particularly sensitive to hydroxyl and water-bearing materials (OH and H₂O), organic compounds (materials containing C-H), carbonates (e.g. found in marble), water-bearing sulfates (like gypsum used in wallboard), and iron-containing compounds (like hematite: iron rust used to color bricks red).

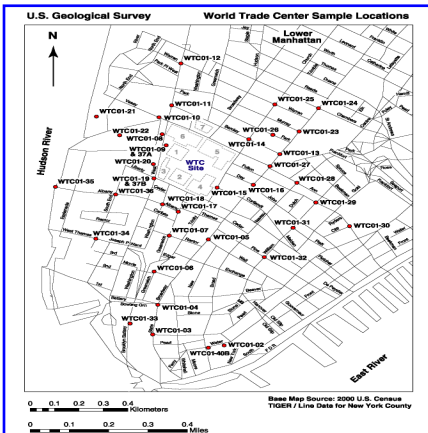
Laboratory spectroscopy differs from airborne imaging spectroscopy in 3 respects: 1) Single spots are analyzed, not images, 2) There is little interfering atmosphere to block portions of the spectrum, and 3) Signal to noise in the laboratory is much higher. Consequently, laboratory analyses have much higher sensitivity to the individual materials in a sample.

To see plots of spectra for each sample, and to get the digital spectral data for each sample (ascii list), [CLICK HERE](#).

Description of Spectroscopy Methods and Results

Reflectance spectra of 33 dust samples collected on Sept. 17, 18, and 19th from areas within a 1 km radius circle of the WTC collapse site (RS Fig. 1) were measured in a laboratory High Efficiency Particulate Air Filter (HEPA) fumehood with an Analytical Spectral Devices Full Range Spectrometer over the range from 0.35 - 2.5 microns using a halogen lamp for illumination and spectralon panel for reference. *(Use of trade names is for descriptive purposes only and does not constitute endorsement but the USGS.)* The entire unsplit sample was first poured from the plastic sample bag onto a clean sheet of paper, then the sample was mixed with a spatula leaving a relatively flat broad pile up to a few centimeters thick for spectral measurement. Mixing allowed us to avoid possible inadvertent effects of particle sorting that may have occurred during transport. Given that reflectance spectroscopy does not detect materials any deeper

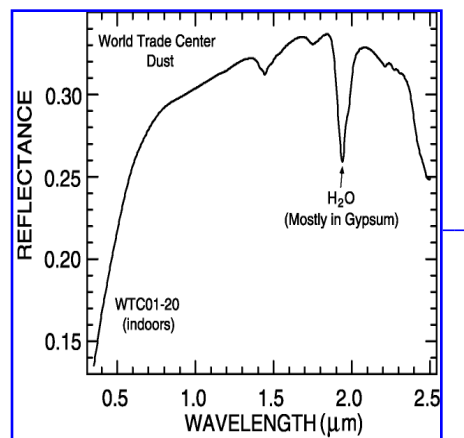
than can be seen with the eye, we tried to compensate by first measuring ten spectra of the pile and then remixing the pile before collecting an additional ten spectra. Our intent was to expose previously unmeasured material at the surface for the last set of measurements. The spectrometer optical fiber was held a few centimeters above the pile and moved constantly in an elliptical manner to spatially average the surface of all but the edges of the pile. This method allowed us to spectrally characterize about two thirds of the entire sample. Samples were then split by quartering and portions sent out for various other analyses. We used one quarter of the sample as a research split supplementing evenly from the other three quarters as needed to build the bulk of the split. After separating the research split any remaining sample was then recombined and set aside as a chain of custody archive sample.



[Larger 92 KB image](#)

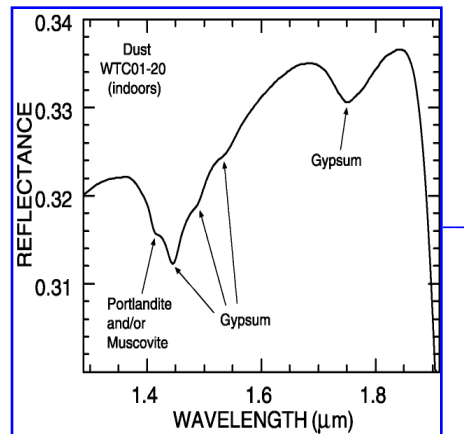
RS Figure 1. Surface sample collection locations in lower Manhattan Sept 17 - 19th, 2001.

Spectra of each dust sample were averaged and corrected to absolute reflectance using a National Institute for Standards and Technology traceable spectral correction. Overall spectra of the dust samples look nearly identical with reflectance levels that vary between 20 - 45 % with a strong absorption edge between 0.35 - 0.8 microns (sharp downturn in RS Fig. 2). There are only weak spectral absorptions, apart from the absorption edge, in the electronic region of the spectra (0.35 - 1.35 microns) indicating that the dust contains only low abundances of materials with Fe absorptions or absorptions from other transition elements. However, there are numerous spectral absorptions in the vibrational spectral region from 1.35 - 2.5 microns principally at 1.45, 1.75, 1.94, 1.97, and from 2.2 - 2.4 microns. The strongest spectral feature is at 1.94 microns and is due to structural and adsorbed water, with the next weaker feature at 1.45 microns (due to water and/or OH) which varies in depth from 2 - 6 % and up to 13 % in WTC01-17. Spectral features at 1.75 microns are next weakest with depths of only a few %. Spectral features in the 2 micron region are weakest varying from a fraction of a percent up to 1 % depth.



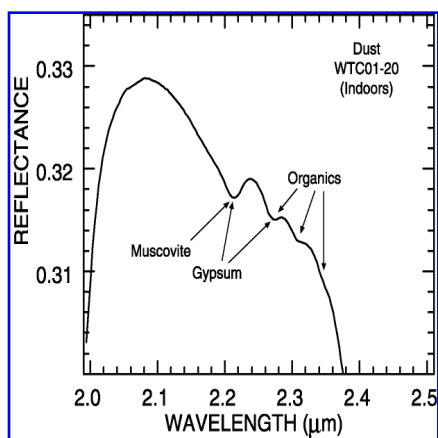
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RS Figure 2a. Reflectance spectrum of a sample of World Trade Center dust collected indoors near the "gym" immediately adjacent to the WTC site. The 0.35 - 2.5 micron spectral region is dominated by vibrational absorptions caused by gypsum from pulverized wallboard.



[Larger 21 KB image](#)

RS Figure 2b



[Larger 20 KB image](#)

RS Figure 2c

Absorption features can be diagnostic of the materials contained in the dust. Gypsum, probably from crushed wallboard, has the strongest spectral features accounting for most of the bands observed in the vibrational portion of the spectra. This mineral has three diagnostic bands that form a stair-step like triplet between 1.42 - 1.54 microns recognizable in nearly all dust samples. It also has bands at 1.75, 1.95, 1.975, 2.17, 2.217, and 2.268 microns closely matching the positions and geometry of the bands observed in the dust. In addition to those absorptions attributable to gypsum, an absorption at 1.413 microns may be due to portlandite or muscovite, both mineral components of the WTC concrete (see XRD results in Table 1 for samples WTC01-37A&B). Spectral evidence for muscovite is seen in the 2 micron region where the overall shape of the absorptions match gypsum but the expected band position of gypsum at 2.217 microns is shifted to 2.209 microns as would be expected in a sample containing both gypsum and muscovite. Additional absorptions located at 2.307 and 2.343 microns are due to C-H stretches from organic materials.

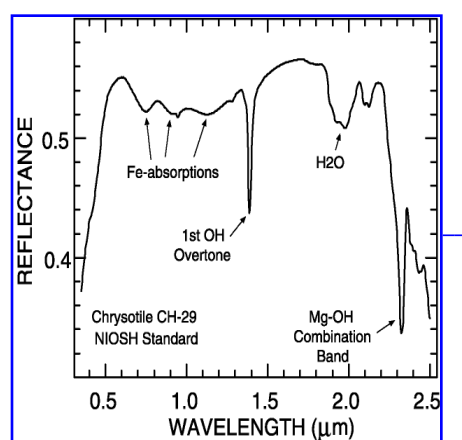
SEM energy dispersive analysis indicates fibrous glass with elemental composition closely matched by slag wool in all dust samples analyzed by this method. Slag wool has only weak spectral absorptions and is virtually spectrally transparent over the 0.35- 2.5 micron spectral range. However, other materials associated with slag wool may contribute to some of the spectral features observed in the dust. An asbestos-free coating (WTC01-9) taken from a steel girder from the debris pile west of WTC tower 1 has relatively strong 2.307 and 2.343 micron absorptions that match the positions of similar but weaker bands in all of the dust samples. Although the positions of these bands are compatible with C-H absorptions in most organic materials (e.g. plastics, paper, fabric) washing of sample WTC01-9 with methanol was sufficient to significantly reduce the strength of these absorptions indicating they are caused by a soluble organic material, possibly an oil used as a dust suppressant in insulation containing slag wool. Spectra of both girder coating samples (WTC01-8 and WTC01-9) have an absorption at 1.725 microns, perhaps too weak to be seen in the dust samples, that closely matches the position of a C-H absorption found in oil. Use of slag wool, a type of mineral wool insulation, was widespread in the WTC towers (Hyman Brown, personal communication) as part of fireproof coatings on steel girders and the undersides of

floors, thermal insulation around glass windows, and possibly in ceiling tiles. The apparent widespread use of slag wool and its brittle nature may explain its presence in all of the dust samples as a volumetrically significant component.

Notably absent from the reflectance spectra of the dust samples is evidence for paper in the form of a cellulose absorption expected at 2.1 micron. Visual examination of the dust samples reveals numerous strips of paper. A possible explanation is that microscopic gypsum particles form an optically opaque coating on the paper and other coarser fragments thereby concealing them from spectral detection. When pieces of dust coated paper are cleaned and then re-measured their spectra have distinct 2.1 micron absorptions. Gypsum from pulverized wallboard, in the dust samples, has a strong wide absorption at 1.95 microns that may obscure the 2.1 micron cellulose absorption from paper.

Possible Sources of Asbestos in the WTC Dust

There are several possible sources of asbestos in the collapsed buildings at the WTC. One source is the fireproof coatings sprayed onto steel girders and the undersides of floors. Asbestos was reportedly used in a fireproof coating in Tower 1 up to the 20th floor (Hyman Brown, personal communication). Sample WTC01-8 was taken from a coating on a steel girder removed from the debris pile west of WTC tower 1. Most notable in its spectrum are absorptions at 1.385 and 2.323 microns which match in position and overall shape those of chrysotile (RS Figure 3). Chrysotile is one of three serpentine minerals and the only one to form with an asbestiform crystal habit. XRD analysis and the depth of these spectral absorptions is consistent with chrysotile forming up to 20 wt% of this coating material. The position of the 2.323 micron absorption in WTC01-8 is consistent with that of chrysotile but the band width is somewhat wider possibly indicating the presence of overlapping 2.307 and 2.343 micron absorptions from dust suppressant oil.



[Larger 24 KB image](#)

RS Figure 3. Reflectance spectrum of chrysotile asbestos. The 0.35 - 2.5 micron region is dominated by strong 1.385 and 2.323 micron vibrational absorptions.

Other potential asbestos sources are ceiling tiles and to a more limited extent, vinyl flooring (Hyman Brown, personal communication). Apparently the cement used to construct the WTC towers probably did not contain asbestos (Leslie Robertson, written communication). Spectroscopy and XRD analysis of our two concrete samples did not reveal any chrysotile asbestos. Vermiculite has the potential to contain amphibole asbestos, but its possible use in fireproof coatings at the WTC is unclear at this time. Vermiculite was not present in the one sample of an asbestos-free coating (WTC01-9) we collected at the site. Vermiculite was not detected in the dust samples during SEM, XRD, and spectral analysis. No amphibole asbestos was identified by these analytical methods either. However, a few flakes of a vermiculite-like mica were noted during visual examinations of the dust.

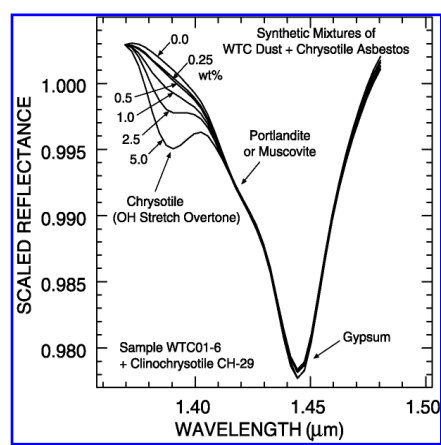
Constructed Mixtures

To better constrain the abundance of chrysotile asbestos in the dust, we constructed mixtures of dust and chrysotile. We chose WTC01-6 as representative of an asbestos-free dust sample based on XRD and spectral evaluations. We added known amounts of a well characterized, very finely ground, National Institute of Occupational Safety and Health (NIOSH) Chrysotile standard (CH-29) to splits of WTC01-6 dust to create mixtures with 0.25, 0.5, 1.0, 2.5 and 5.0 weight % chrysotile. These samples were then measured spectrally and characterized by XRD, to provide a set of spectra and diffractograms that could be directly compared to those of the dust samples. Chrysotile (RS Fig. 3) has, as mentioned earlier, two strong absorptions at 1.385 and 2.323 microns due to the 1st OH stretch overtone and an Mg-OH combination band respectively. Even though the 2.323 micron chrysotile absorption is the stronger of the two bands, its wavelength position is wedged between stronger C-H absorptions at 2.307 and 2.343 microns, and overlaps with a 2.317 micron absorption from concrete (e.g. muscovite?), all of which tend to mask the presence of chrysotile in the dust samples at levels below 1 wt% in laboratory spectra. The weaker 1.385 micron chrysotile absorption occurs in a relatively less cluttered spectral region on the short wavelength side of the 1st OH stretch overtone gypsum absorption at 1.446 microns, thus providing a means of estimating chrysotile contents at even lower concentrations.

Spectral Detectability of Chrysotile

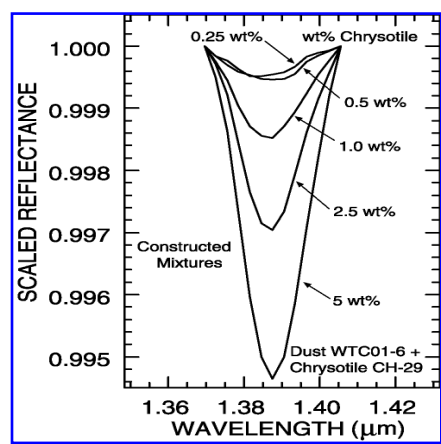
RS Figure 4A shows spectra of dust + chrysotile mixtures with continua removed from the 1.4 micron region (Clark and Roush, 1984). The presence of chrysotile is indicated by a distinct absorption in the 5, 2.5, and 1 wt% mixtures and as an inflection in the 0.5, and 0.25 wt% mixtures. RS Figure 4B shows these same samples with a curved continuum removed from the region centered on the 1.385-micron chrysotile absorption. Non-chrysotile bearing dust samples have convex upward curves in the 1.385 micron region. Band depths of the 1.385 absorption do not increase linearly with increasing chrysotile abundance due to the effects of multiple scattering (e.g. Clark and Roush, 1984). Sensitivity to changes in concentration is lowest for mixtures with trace amounts of chrysotile, however, the lack of convexity at the wavelength

corresponding to the 1.385 micron chrysotile band, is a reliable indicator of the presence of chrysotile for the WTC dust samples. Because the chrysotile absorptions are relatively weak, even for the 5 wt% mixture (about 0.25 % depth), diagnostic spectral measurements must be done with high signal-to-noise ratio.



[Larger 31 KB image](#)

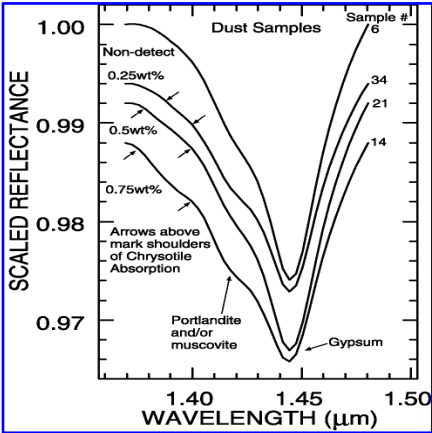
RS Figure 4A. Details of the 1.3 - 1.5 micron spectral region of dust + chrysotile synthetic mixtures constructed from an asbestos-free World Trade Center dust sample and a NIOSH chrysotile asbestos standard. Note the progressive growth of a chrysotile absorption from a mere inflection (0.25 wt%) to full fledged band (5 wt%) with increasing chrysotile content. Chrysotile-free dust samples have convex upward spectral curves in the 1.385 micron region.



[Larger 41 KB image](#)

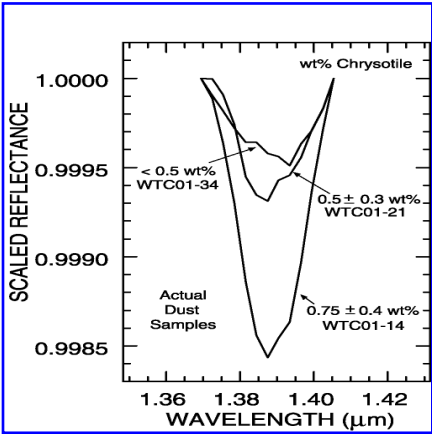
RS Figure 4B. Same mixture spectra as in RS Figure 4A with the spectral region centered on the chrysotile 1.385 micron absorption divided by the asbestos-free WTC01-6 spectrum. Removal of this curved continuum from the mixture spectra produces distinct absorption bands even in at the 0.25 and 0.5 wt% mixtures.

RS Figure 5A shows examples of the detection of chrysotile in three of the WTC dust samples at the 0.25, 0.5, and 0.75 wt% level. Arrows mark the inflection points (or shoulders) of the 1.385 micron chrysotile absorption. Note how the inflection points move outward as chrysotile content increases. Sequentially overlaying all of the dust spectra on top of the asbestos-free WTC01-6 spectrum provided a means of detecting these inflection points and thereby estimating the amount of chrysotile present in each sample. Figure 5B shows the same spectra as in RS Figure 5A with a convex continuum (provided by WTC01-6) removed from the 1.385 micron region. This process reveals absorptions due to chrysotile even in the 0.25 and 0.5 wt% samples.



[Larger 46 KB image](#)

RS Figure 5A. Actual examples of World Trade Center dust with variable chrysotile asbestos contents. Arrows mark outer edges of an absorption band caused by trace levels of chrysotile. These inflection points move progressively outward as the chrysotile content increases.

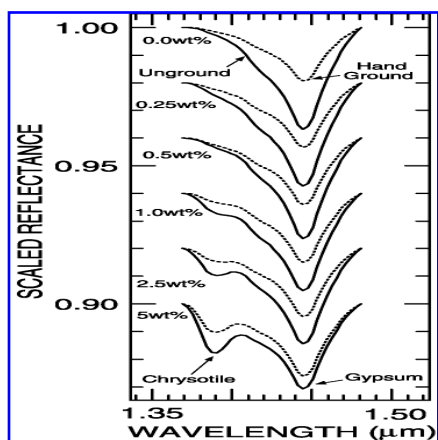


[Larger 37 KB image](#)

RS Figure 5B. Same spectra as in RS Figure 5A with the spectral region centered on the chrysotile 1.385 micron absorption divided by the asbestos-free WTC01-6

spectrum. This continuum removal process reveals distinct absorptions due to chrysotile.

The lower limit of detection for chrysotile in the WTC dusts depends to a degree on the grain size and albedo (brightness) of the dust. RS Figure 6 shows a series of dust + chrysotile mixtures constructed using dust sample WTC01-15, a coarser grained sample than WTC01-6. The dotted curves are spectra of the mixtures after hand grinding to fine powders. Because diffuse reflectance is a non-linear process, decreasing the grain size of the dust results in more scattering causing a decrease in the strength of all the absorptions including those of chrysotile. The size of individual grains in the 33 WTC dust samples is quite variable ranging from centimeter-sized fragments to submicron diameter fibers. It is likely that the grain size of the hand ground mixtures is smaller than the average grain size of even the finest of the dust samples, therefore the hand ground samples may represent the worst case detection scenarios. Even though grinding does significantly decrease the depths of the chrysotile absorption, the lack of convexity over the 1.385 micron chrysotile band is still evident in spectra of the hand ground mixtures down to the 0.5 wt% level. As an empirical rule of thumb, a given estimate of chrysotile content decreases by about half the wt% value over this extreme grain size range.



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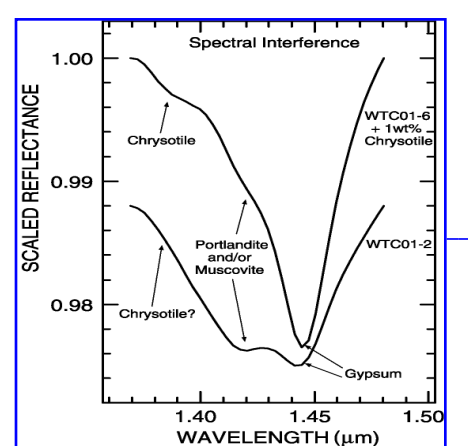
RS Figure 6. Unground versus finely ground synthetic mixtures of World Trade Center dust WTC01-15 + NIOSH chrysotile. Note decrease in strength of spectral absorptions in the hand ground samples. Spectral sensitivity to the presence of chrysotile decreases as grain size of the dust decreases.

Lowering the albedo of a mixture results in less scattering thereby decreasing the likelihood that a given photon will encounter a chrysotile fiber and be scattered to the sensor, resulting in a lower sensitivity to chrysotile content. The albedo of the dust samples varies from 0.2 to 0.4 in the 1.4 micron spectral region, with about 80 % of the samples varying between 0.29 and 0.35. The dust samples used for the mixtures have albedos around 0.32 in the 1.4 micron region. The effects of albedo on spectrally

measuring chrysotile contents have not been quantitatively evaluated. However, because most of the dust samples have an albedo similar to that of the samples used to create the mixtures, errors in estimating chrysotile content will probably be smaller than those due to grain size variations. In samples brighter than the mixture samples, chrysotile contents may be systematically overestimated. The reverse is true for samples darker than the mixture samples.

Spectral Interference

Spectroscopy could not be used to estimate chrysotile content of the dust below the 1wt% level for 9 out of 33 samples because of interference from nearby spectral absorptions. RS Figure 7 shows a 1wt% chrysotile + dust mixture compared with dust sample WTC01-2 which contains a relatively high concentration of portlandite and/or muscovite. These minerals have strong OH overtone absorptions located at 1.41 - 1.42 microns, with shoulders that overlap and conceal the nearby chrysotile 1.385 micron band. None of the 9 samples contained more than 1wt% chrysotile as determined by spectroscopy. XRD did detect trace levels of chrysotile in 7 of these samples. The other known constituent of the dust samples that has a weak spectral absorption near the 1.385 micron chrysotile absorption is that of bassanite ($\text{CaSO}_4 \cdot 1/2\text{H}_2\text{O}$) at 1.391 microns. Potential interference from this bassanite absorption is negligible because in at least one of those samples where it was detected with XRD (WTC01-19), the spectral curve was convex upward in the 1.385 micron region showing neither the presence of chrysotile or bassanite.



[Larger 36 KB image](#)

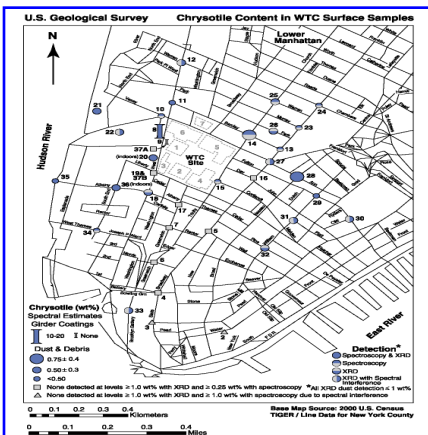
RS Figure 7. Spectra of dust samples that contain significant concentrations of portlandite and muscovite (probably from pulverized concrete) have wide 1.42 micron absorptions that overlap and conceal chrysotile absorptions that may be present at 1.385 microns.

Chrysotile Asbestos Contents of WTC Dust Samples

Spectral and XRD estimates of chrysotile content were made for all 33 dust samples (RS Fig. 8). Circles represent dust samples from the surface that contain trace levels of chrysotile asbestos. Solid circles represent detection of chrysotile by both spectroscopy and XRD analysis. Circles with their upper halves filled represent detection of chrysotile by spectroscopy; circles with their lower halves filled represent detection of chrysotile by XRD analysis. The size of the circle represents the amount of chrysotile detected by spectroscopy. Circles with their right halves filled represent samples where spectral interference prevented an estimate of chrysotile below 1% but where XRD analysis did detect chrysotile. Triangles represent samples where spectral interference prevented an estimate of chrysotile content but where XRD analysis revealed no chrysotile at or above the 1 wt% level. Squares represent samples where neither spectroscopy or XRD analysis were able to detect chrysotile at or above the 0.25 wt% (spectroscopy) and 1.0 wt% (XRD) levels. Samples 20 and 36 were collected indoors and were not subjected to rain and wind during the September 14th thunderstorm. The large filled "I" represents the location of the chrysotile bearing coating collected from the steel girder; the smaller "I" represents the the asbestos-free coating collected from a different steel girder. If plotted in its true proportion, the "I" representing the chrysotile bearing coating (WTC01-8) would be so large that it would conceal information from the other samples on this diagram, therefore its size is not proportional to its estimated 10 - 20 wt% chrysotile content.

Chrysotile was detected in a little over two thirds of the dust samples. Neither spectroscopy or XRD analysis revealed a chrysotile concentration higher than about 0.75 wt% in any of the 33 dust samples. Chrysotile was detected in 24 of the dust samples (exclusive of the girder coatings and concrete samples) with spectroscopy detecting it in 15 of the samples and XRD analysis detecting it in 16 of the samples. Chrysotile was detected by both methods in 7 dust samples. One explanation for the apparent disagreement between methods is the heterogeneous nature of the dust samples. While XRD measurements were made on 1.5 gram splits of each dust sample, spectroscopic measurements were made on approximately two thirds of the entire sample (or between 50 - 300 grams of material). Initial XRD measurements on samples WTC01-14 and 28 showed no trace of chrysotile, while replicate XRD measurements on different splits of these samples revealed chrysotile in 28. The problems of detecting unevenly distributed chrysotile in the dust are likely to plague any analytical method.

From RS Figure 8 it is apparent that trace levels of chrysotile were distributed with the dust radially in west, north, and easterly directions perhaps at distances greater than 3/4 kilometer from ground zero. The lack of chrysotile at levels above the detection limits of both spectroscopy and XRD analysis in samples collected south of ground zero (except in WTC01-33) may indicate that chrysotile was not distributed uniformly during the collapse.



[Larger 110 KB image](#)

RS Figure 8. Chrysotile concentrations in surface dust samples in Lower Manhattan. Two thirds of the dust samples have chrysotile asbestos concentrations above 0.25 wt%. See text for a more detailed explanation of the map symbols.

[NEXT Section of Report: Scanning Electron Microscopy \(SEM\) and Energy Dispersive X-Ray Analysis \(EDS\)](#)

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OFR 01-0429: Laboratory Spectra of WTC Samples

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[All spectral plots on one page \(78 plots, approx 450 kbytes download\)](#)

Spectra and ascii data for each sample:

wtc01-01	wtc01-11	wtc01-21	
wtc01-02	wtc01-12	wtc01-22	
wtc01-03	wtc01-13	wtc01-23	wtc01-31
wtc01-04	wtc01-14	wtc01-24	wtc01-32
wtc01-05	wtc01-15	wtc01-25	wtc01-33
wtc01-06	wtc01-16	wtc01-26	wtc01-34
wtc01-07	wtc01-17	wtc01-27	wtc01-35
wtc01-08	wtc01-18	wtc01-28	wtc01-36
wtc01-09	wtc01-19	wtc01-29	wtc01-37Aa
wtc01-10	wtc01-20	wtc01-30	wtc01-37Ac
			wtc01-37Am
			wtc01-37B



[Larger 81 KB image](#)

Sample Location Map

[Back to NEXT Section of:](#)

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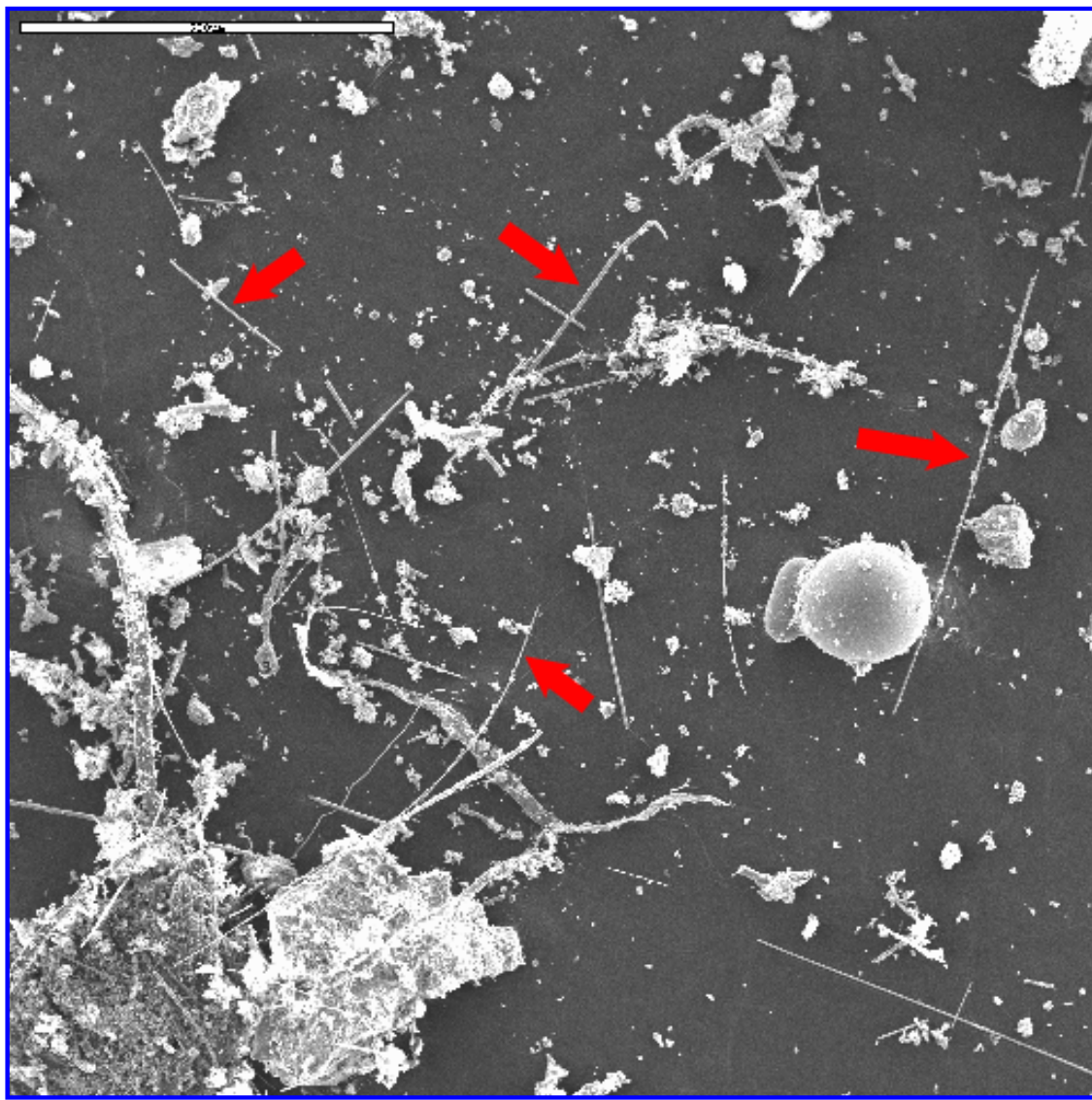
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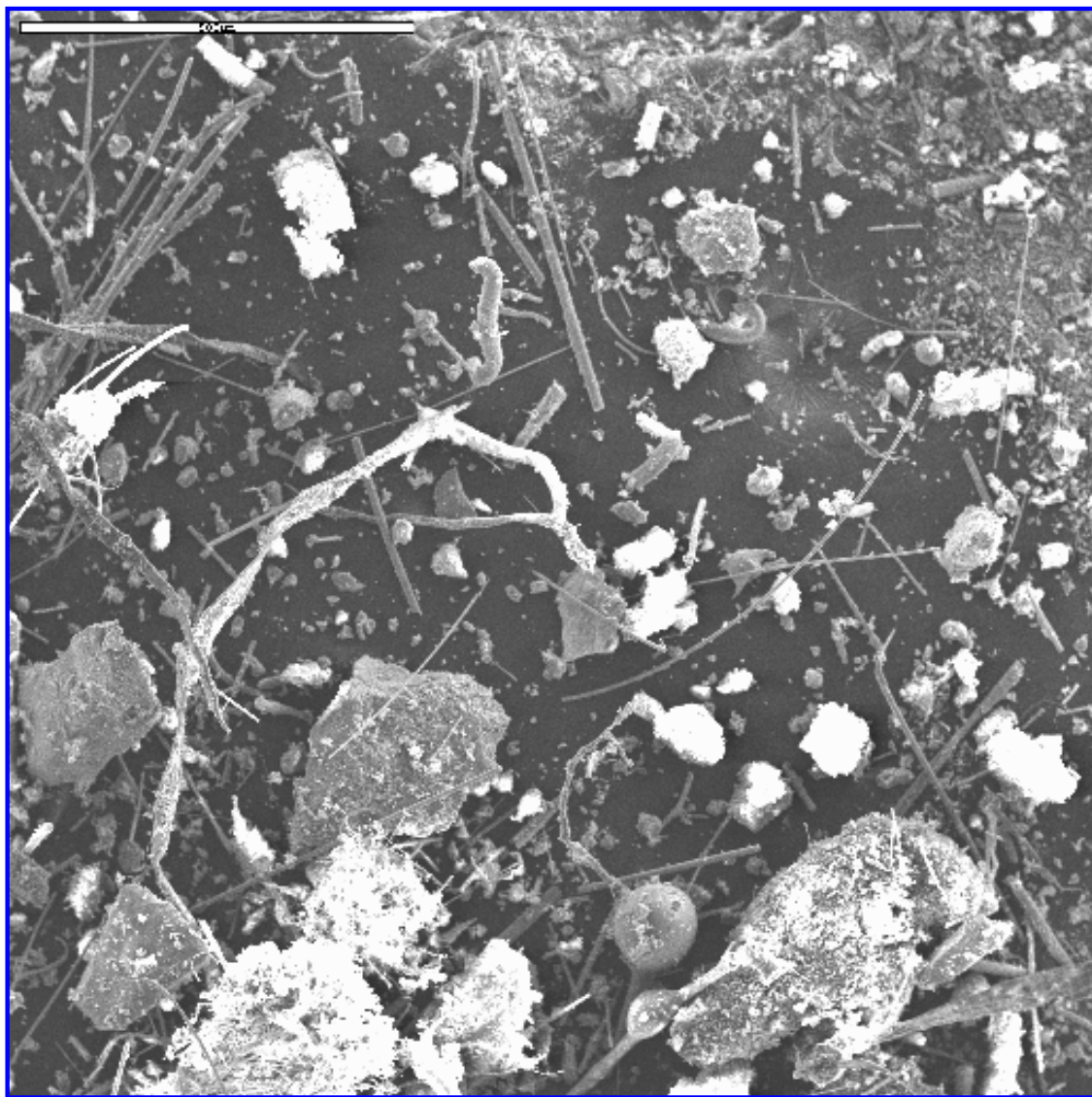
Analysis I.D.	Na2O	MgO	Al2O3	SiO2	SO3	K2O	CaO	TiO2	MnO	FeO	Material
---------------	------	-----	-------	------	-----	-----	-----	------	-----	-----	----------

wtc 22 sp 5	2	11	12	44	trace	1	24	1	BDL	4	glass fiber
wtc 22 sp 1	trace	11	9	47	trace	1	32	trace	BDL	BDL	glass fiber
wtc 22 sp 2	12	2	3	71	trace	trace	11	trace	BDL	trace	glass fiber
wtc 3 sp 3	trace	11	11	43	trace	trace	32	1	BDL	BDL	glass fiber
wtc 3 sp 6	trace	11	10	44	trace	trace	32	trace	BDL	1	glass fiber
wtc 8 sp 1	BDL	8	9	43	trace	trace	36	1	BDL	1	glass fiber
wtc 15 sp 1	BDL	10	10	42	trace	trace	36	trace	trace	BDL	glass sphere
wtc 22 sp 4	BDL	12	8	47	trace	trace	31	BDL	BDL	BDL	glass sphere
wtc 8 sp 8	BDL	47	BDL	50	trace	BDL	trace	BDL	trace	2	chrysotile
wtc 14 sp 5	BDL	BDL	1	2	53	BDL	43	BDL	BDL	BDL	Gypsum/ anhydrite

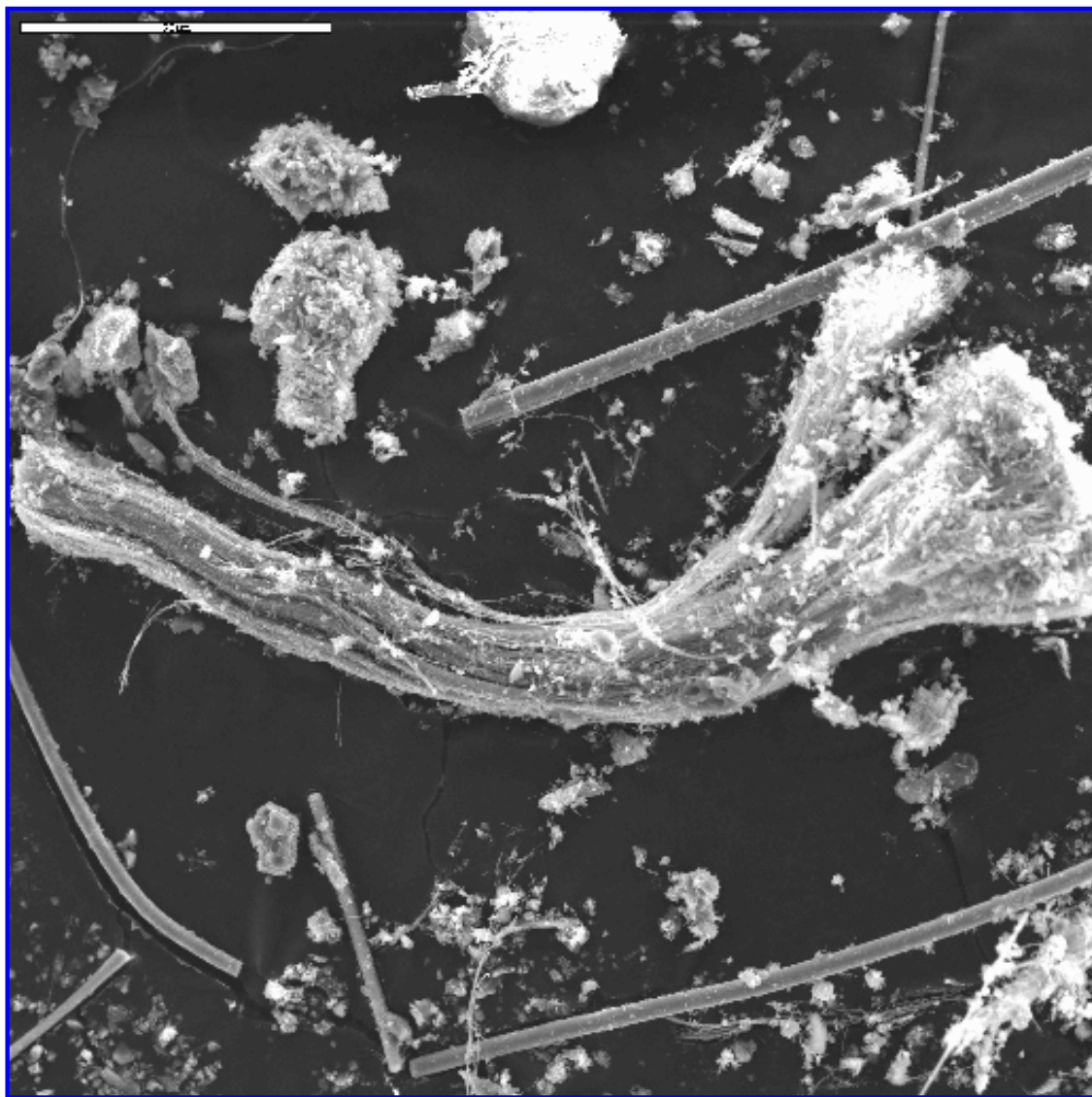
Data normalized to 100%. BDL=below detection limit. Analytical error is approximately +/- 5% relative concentration



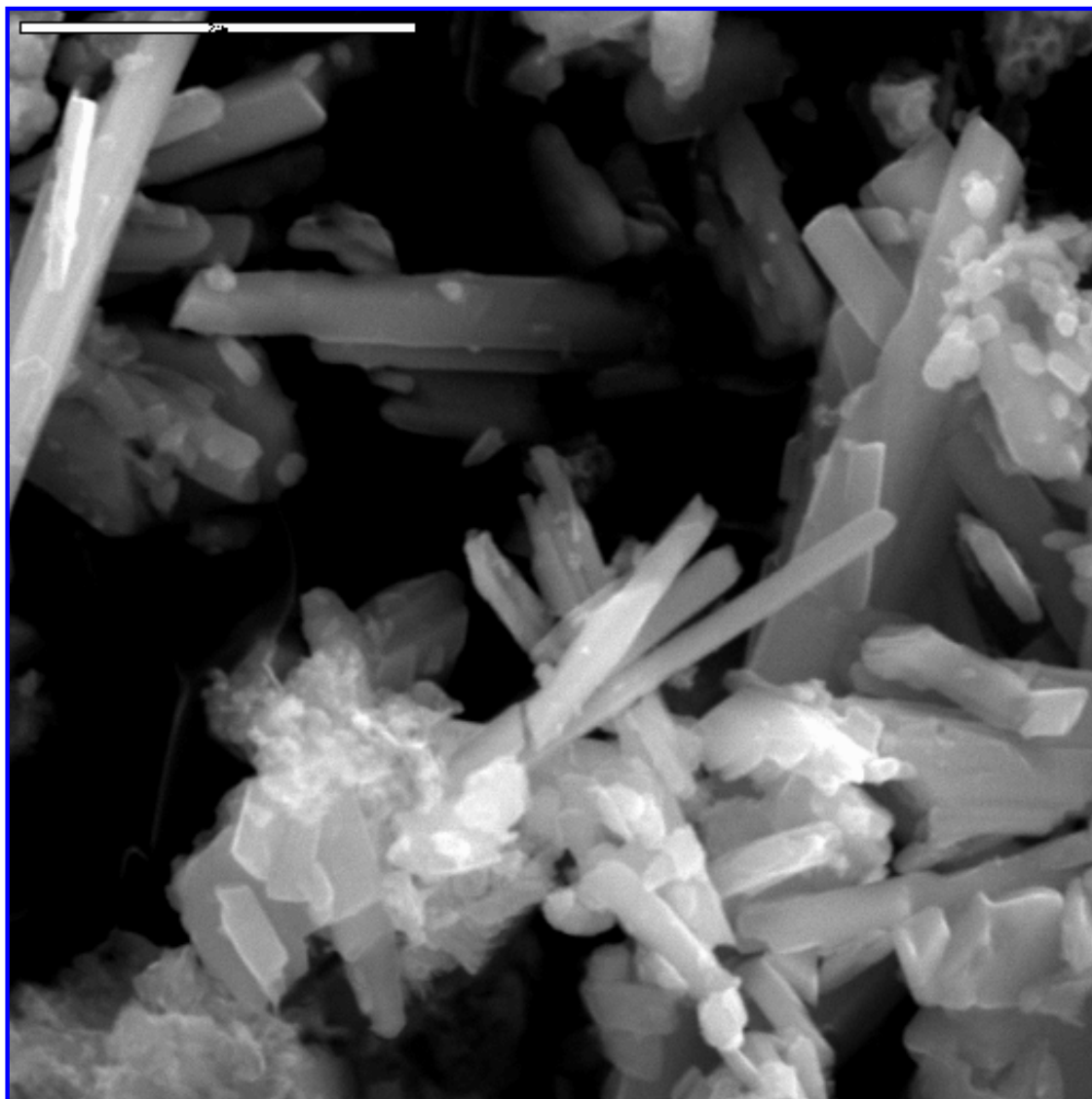
SEM Figure 1. Secondary electron SEM image of a representative portion of sample 22. The image shows abundant glass fibers (red arrows) and other materials as described above. The round object at the right side of the image is a glass sphere with a composition similar to the fibers (see Table SEM-1). Spheres like these are typical components of slag wool.



SEM Figure 2. Secondary electron SEM image of a representative portion of sample 3 collected from Battery Park. The image shows abundant glass fibers and other materials as described above.



SEM Figure 3. SEM image of a chrysotile bundle (center) and glass fibers from sample 8. Similar bundles have been identified at trace levels in several of the dust samples.



SEM Figure 4. Secondary electron SEM image of gypsum and/or anhydrite crystals from sample 20.

[NEXT Section of Report: Chemical Compositions](#)

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World Trade Center area, New York

U.S. Geological Survey
Clark et al., 2001

NASA/JPL AVIRIS data
Sept 16, 2001 16:21 GMT

USGS
Imaging Spectroscopy
Tetracorder 4.0a8
product

Material Absorption
Feature map (minerals
with Mg-OH features
near 2.3-microns):

Possible
Serpentines

possible
chrysotile

Possible
Amphiboles or Clays

Possible
actinolite or
richterite

talc or
tremolite

saponite or
talc or
tremolite

Possible detection of
serpentines and
amphiboles on this map
does not distinguish
between asbestiform
and non-asbestiform
varieties.

Image sampling:
1.7 meters/pixel

N



N
↑
200
meters





World Trade Center area, New York

U.S. Geological Survey
Clark et al., 2001

NASA/JPL AVIRIS data
Sept 16, 2001 16:21 GMT

USGS
Imaging Spectroscopy
Tetracorder 4.0a8
product

Material Absorption
Feature map (minerals
with Mg-OH features
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Possible
Serpentines

possible
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Possible
Amphiboles or Clays

Possible
actinolite or
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talc or
tremolite

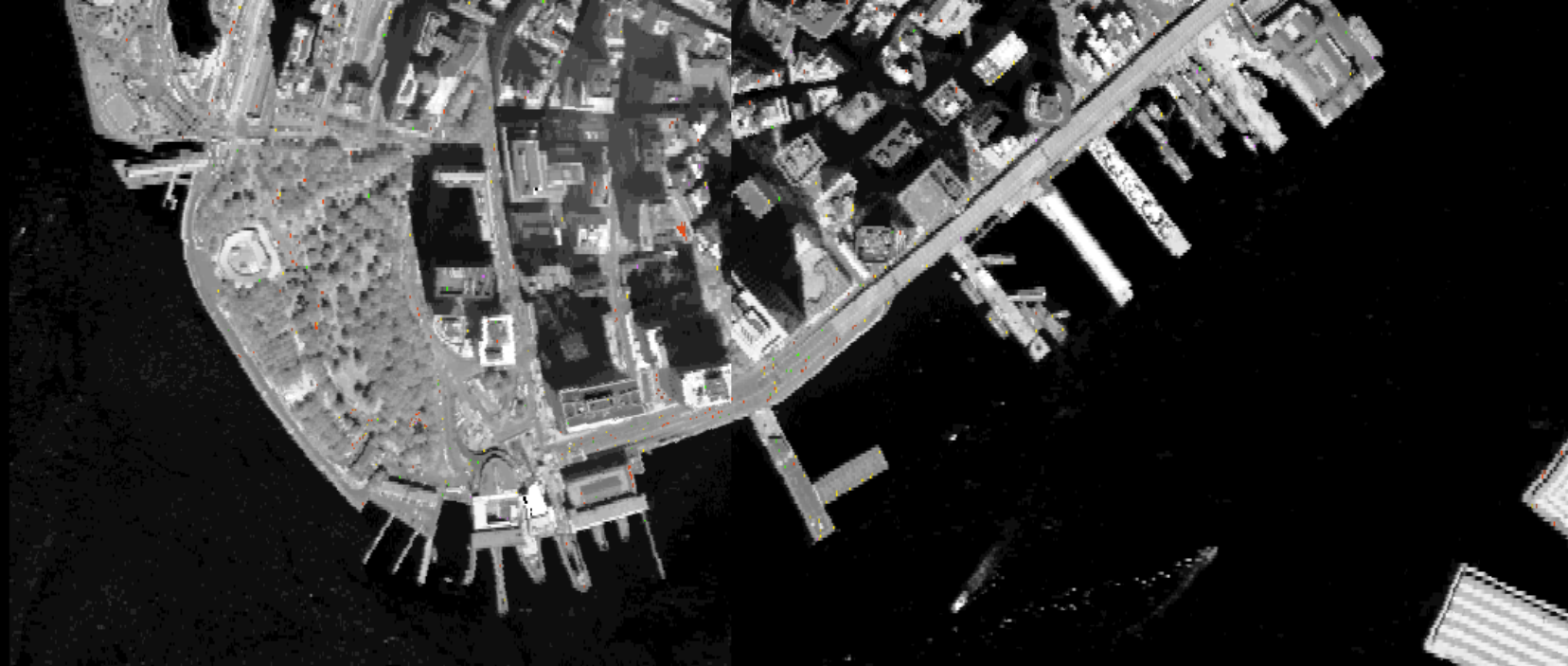
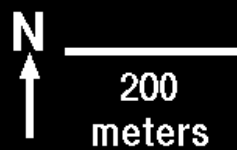
saponite or
talc or
tremolite

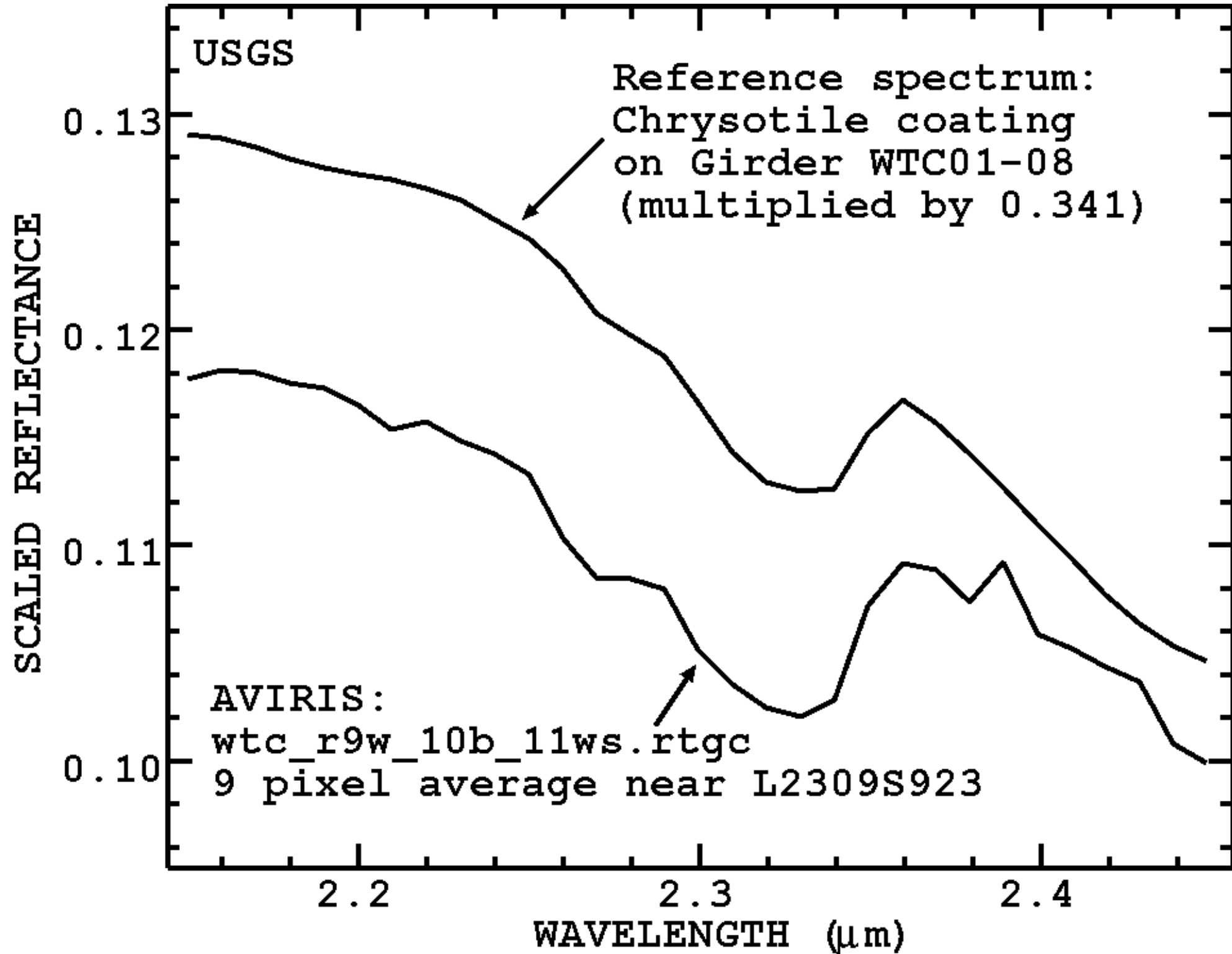
Possible detection of
serpentines and
amphiboles on this map
does not distinguish
between asbestiform

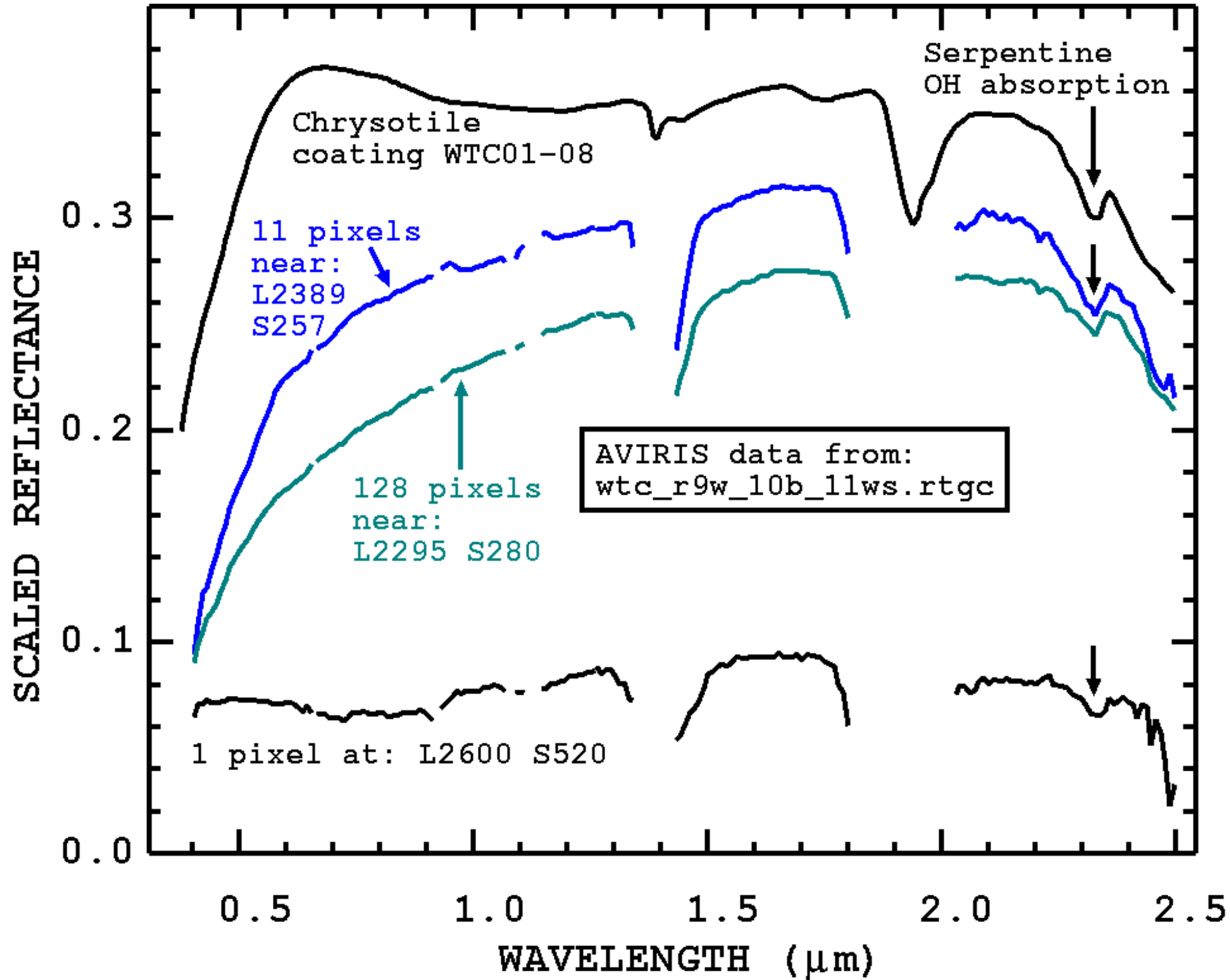


between asbestiform
and non-asbestiform
varieties.

Image sampling:
1.7 meters/pixel







World Trade Center area, New York

U.S. Geological Survey
Clark et al., 2001

NASA/JPL AVIRIS data
Sept 16, 2001 16:21 GMT

USGS
Imaging Spectroscopy
Tetracorder 4.0a8
product

Material Absorption
Feature map (minerals
with Mg-OH features
near 2.3-microns):

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possible
chrysotile

Possible
Amphiboles or Clays

Possible
actinolite or
richterite

talc or
tremolite

saponite or
talc or
tremolite

Possible detection of
serpentines and
amphiboles on this map
does not distinguish
between asbestiform
and non-asbestiform



and non-asbestiform varieties.

Image sampling:
1.7 meters/pixel

N
↑
200
meters

Spectral Estimate Lab:
Chrysotile (wt%)
Girder coatings

I 10-20 I none

Dust and Debris

● 0.75 ± 0.4

● 0.50 ± 0.3

● <0.5

■ No Detection
(≥ 1.0% XRD, ≥ 0.25% RS)

▲ No Detection
(≥ 1.0 XRD, ≥ 1% RS)

Lab Detection Method*

● ● ● RS + XRD

● ● ● RS

● XRD

● XRD with RS
threshold >XRD

RS = Reflectance Spectroscopy

XRD = X-Ray Diffraction

* All XRD dust detection ≤ 1.0 wt%

Open-File Report 01-0429: World Trade Center USGS Bulk Chemistry Results

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Chemical compositions of the WTC dusts and girder coating materia

Representative splits of samples of dusts from the WTC area and of steel girder coatings from the WTC debris were analyzed for total major element composition by Wavelength-Dispersive X-Ray Fluorescence (WD-XRF), for total major and trace element composition by Inductively Coupled-Plasma Mass Spectrometry (ICP-MS), for total carbon and sulfur by combustion, and for carbonate carbon by coulometric titration.

Sampling and analytical methods

Representative sub-samples of the dust and beam-coating samples were obtained using a standard cone and quartering approach. The sub-samples were then ground and homogenized prior to chemical analysis.

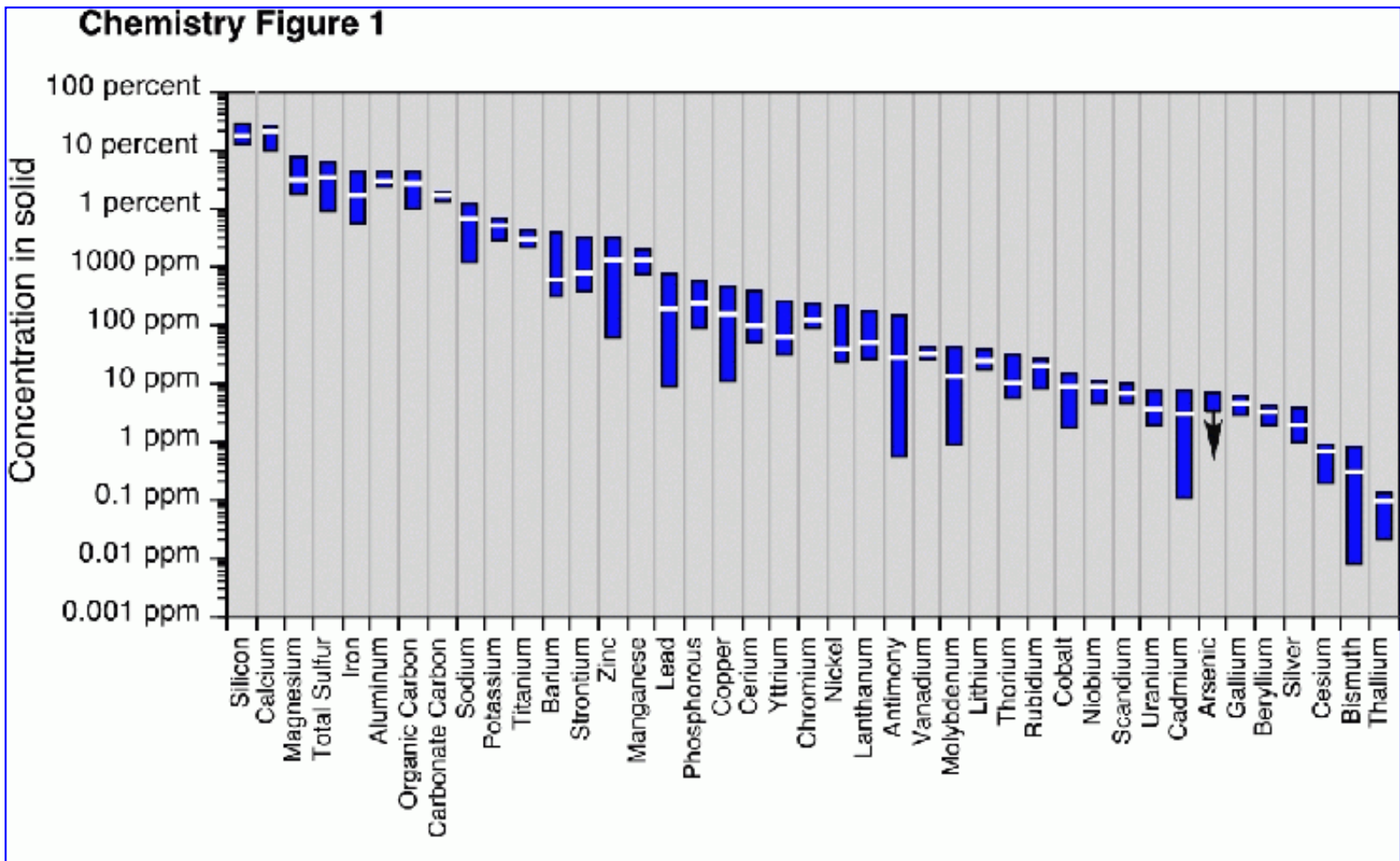
X-ray fluorescence analytical methods, which are summarized in Arbogast (1996), involve heating the sample at 925°C for 40 minutes to determine the weight of volatiles lost from the sample. The sample is then mixed with lithium tetraborate and fused for 56 minutes at 1120°C. The molten sample is poured into a mold and cooled, producing a homogeneous glass disc of the sample material. This disc is then analyzed in a WD-XRF spectrometer, and results are given in total weight percent. The amounts of volatile components in a sample, such as organic material (wood, paper, plastic, other organic compounds), water, sulfur, inorganic carbon, and nitrogen compounds, can be determined by the weight lost by the sample during its initial heating.

ICP-MS analysis was carried out on splits of the samples that were first dissolved using a multi-acid digestion combining hydrochloric, hydrofluoric, nitric, and perchloric acids (Crock et al., 1999, and references therein). ICP-MS methods are given in Briggs and Meier (1999), and Crock et al. (1999).

Total carbon and total sulfur were analyzed by combustion (Crock et al., 1999). Carbonate carbon was determined by coulometric titration, and organic carbon determined by the difference between total carbon and carbonate carbon (Crock et al., 1999).

Analytical results are tabulated in [Chemistry Table 1](#), and summarized graphically in Chemistry Figures 1-4. The elements measured by the chemical analyses are those routinely measured by the USGS for studies of rocks, sediments, soils, and environmental samples. Total mercury concentrations have not been measured in the WTC solid samples, but have been measured in leach solutions derived from the samples (see the next section of this report). Quality-assurance, quality control data and information for the analyses are available upon request.

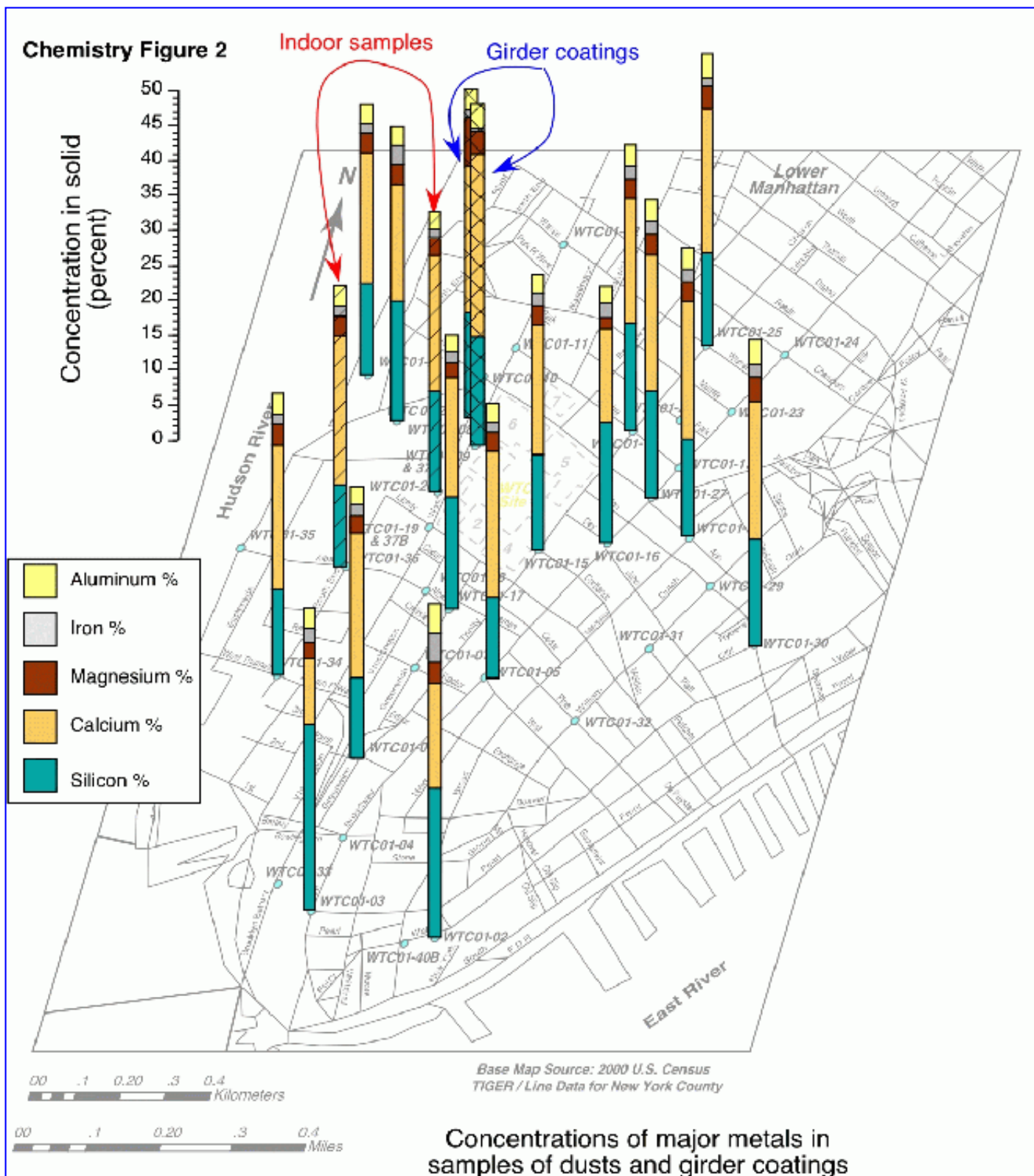
These analytical methods determine the total concentration (in weight percent or parts per million) of each element in any given sample. The samples are likely to contain a mixture of different components, such as particles of gypsum, concrete, steel, etc., that together make up the total concentration of elements.



[Larger 141 KB image](#)

Chemistry Figure 1.

Plot showing the concentration ranges (colored boxes) and means (horizontal white bars) for major and trace elements in samples of WTC dusts and girder coatings. Several samples had arsenic concentrations below the analytical detection limits, indicated on the graph by the arrow extending downward from the detection limit concentration. Concentrations of some elements (such as tin) were not determined in these samples. For comparison, 1 percent equals 10,000 parts per million.



[Larger](#)

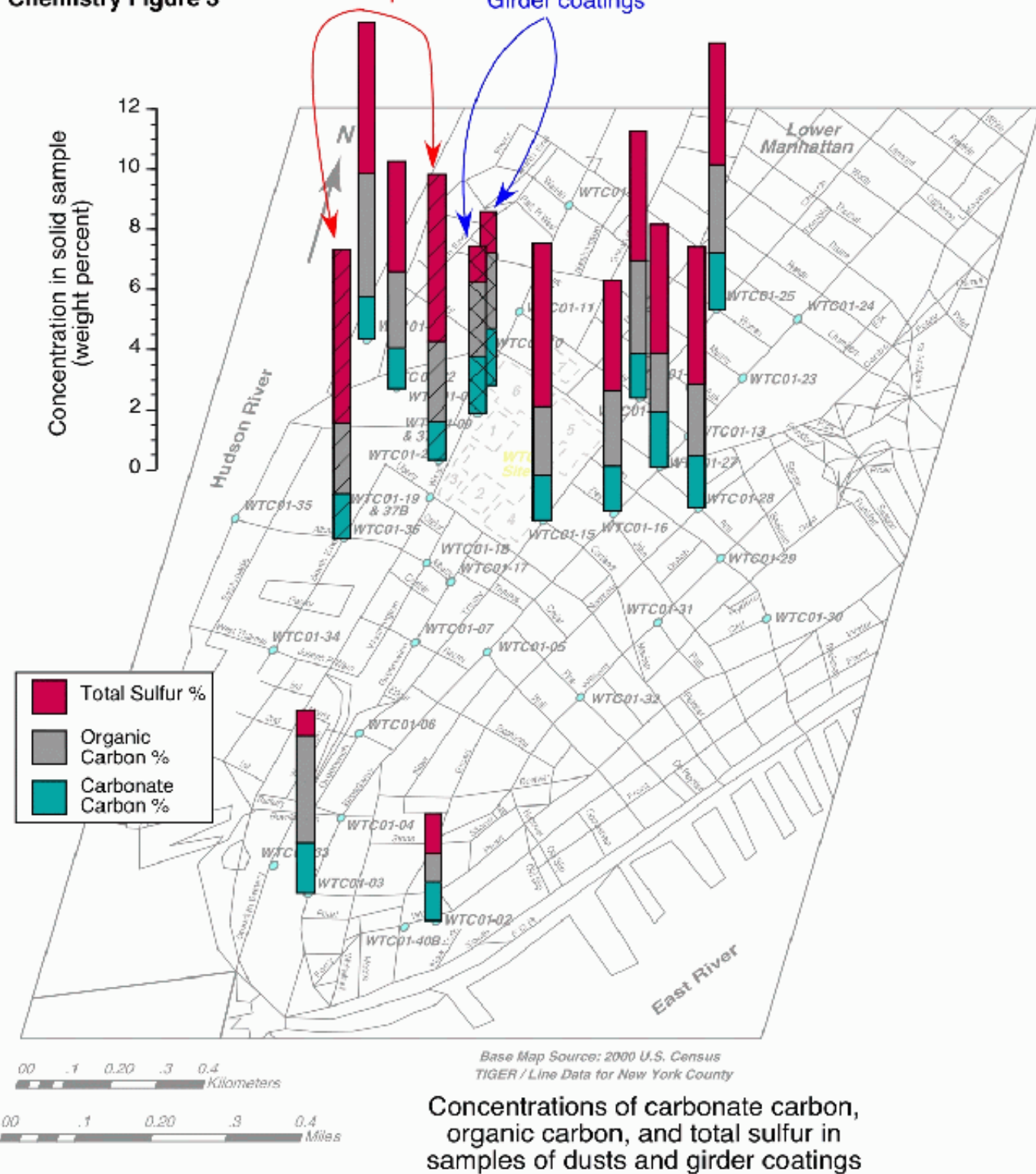
Chemistry Figure 2.

Map of lower Manhattan showing (as stacked bar charts) variations in concentration (in percent) of major elemental components of WTC dust and girder coating samples. Dust samples collected indoors are indicated by the single hatch pattern and girder coating samples by the cross-hatch pattern; all others are dust samples collected outdoors. For comparison with Chemistry Figure 4, 1 percent equals 10,000 parts per million.

Chemistry Figure 3

Indoor samples

Girder coatings



[Larger](#)

[207 KB image](#)

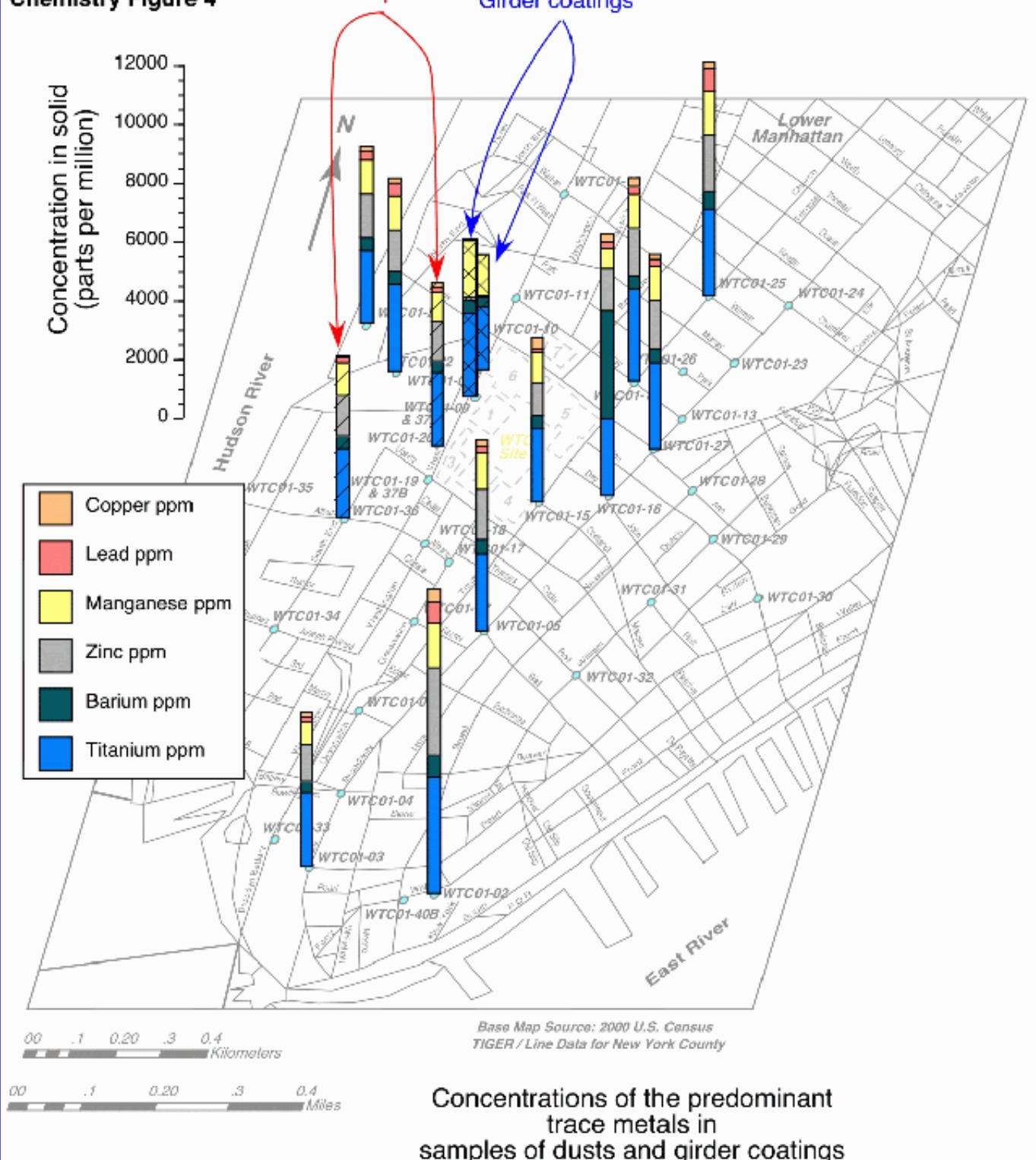
Chemistry Figure 3.

Map of lower Manhattan showing (as stacked bar charts) variations in concentration (in percent) of inorganic carbon, carbonate carbon, and total sulfur of WTC dust and girder coating samples. Dust samples collected indoors are indicated by the single hatch pattern and girder coating samples by the cross-hatch pattern; all others are dust samples collected outdoors. For comparison with Chemistry Figure 4, 1 percent equals 10,000 parts per million.

Chemistry Figure 4

Indoor samples

Girder coatings



Larger 220

[KB image](#)

Chemistry Figure 4.

Map of lower Manhattan showing (as stacked bar charts) variations in concentration (in parts per million) of some predominant trace elements of WTC dust and girder coating samples. Dust samples collected indoors are indicated by the single hatch pattern and girder coating samples by the cross-hatch pattern; all others are dust samples collected outdoors. For comparison with Chemistry Figures 2 and 3, 1 percent equals 10,000 parts per million.

Results

WD-XRF results show that silicon, calcium, sulfur, magnesium, aluminum, iron, and carbon are the predominant elemental components of the dusts. The contents of volatile compounds in the dusts approach nearly 20% by weight. The identities and amounts of volatile components (such as water bonded in minerals and adsorbed onto materials; organic materials such as papers, plastics, etc.) in the samples have not been determined. The WD-XRF analyst noted a smell of burning wood or paper in all of the dust samples during sample combustion, another indication that organic material is present in the dusts.

There are no systematic differences in total element composition between the dust samples collected indoors and outdoors, nor are there systematic spatial variations in dust composition between sample sites. The two samples of girder coating material have generally similar major-element concentrations to those in the dust samples. One notable exception is magnesium, which is somewhat elevated in the girder coating sample (WTC01-08) that has higher chrysotile asbestos content (as determined by SEM analysis). The dust and girder coating samples are substantially more variable in their trace element compositions than in their major element compositions. In most dust samples, zinc is the predominant trace metal, with concentrations as high as 3000 parts per million. With the exception of one sample that is high in barium (WTC01-16), the trace metals barium, lead, copper, and chromium are present in concentrations of hundreds of parts per million. Concentrations of other trace metals and metalloids such as molybdenum, antimony, and titanium, are tens of parts per million or less. As with the major elements, there are no discernible differences in trace metal content between the dust samples collected outdoors and those collected indoors. There are also no apparent spatial variations in trace-element composition between sample sites. The girder coating materials (samples WTC01-08, and -09) contain quite low concentrations of trace metals relative to the dust samples.

Interpretation

The total element compositions of the dust samples reflect the chemical makeup of materials such as: glass fibers (containing silicon, aluminum, calcium, magnesium, sodium, and other elements); gypsum (containing calcium and sulfate); concrete and aggregate (containing calcium and aluminum hydroxides, and a variety of silicate minerals containing silicon, calcium, potassium, sodium, and magnesium); particles rich in iron, aluminum, titanium, and other metals that might be used in building construction; and particles of other components, such as computers, etc. Organic carbon in the dusts is most likely from paper, wallboard binder, and other organic materials.

The trace metal compositions of the dust and girder coatings likely reflect contributions of material from a wide variety of sources. Possibilities include metals that might be found as pigments in paints (such as titanium, molybdenum, lead, and iron), or metals that occur as traces in, or as major components of, wallboard, concrete, aggregate, copper piping, electrical wiring, and computer equipment. Further detailed SEM studies of dust and beam coating samples are needed to develop a better understanding of the residences of metals in the samples. A detailed review of the materials used in construction, and the elemental composition of materials commonly found in office buildings would also be useful to understand more completely the potential sources and compositions of the materials in the dusts.

It is important to note that the total chemical analyses presented in this section do not provide an indication of the metals in the dusts and girder coating materials that may potentially be bioavailable (readily assimilated by organisms). For example, heavy metals, such as lead, may occur in forms that range from highly soluble to highly insoluble in water or body fluids. Consequently, high concentrations of total lead in dust samples may or may not translate into elevated concentrations of readily bioavailable lead. Chemical leach tests such as those presented in the next section of this study aid in understanding potential release and bioavailability of heavy metals and other constituents from the girder coatings and dust samples.

[*NEXT Section of Report: Leachate Studies*](#)

[*Back to document Table of Contents*](#)

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For further information on ICP-MS analytical methods, contact:
Paul Lamothe,
plamothe@usgs.gov

For further information on results and interpretation, contact:
Geoff Plumlee,
gplumlee@usgs.gov

[Accessibility](#)[FOIA](#)[Privacy](#)[Policies and Notices](#)

[U.S. Department of the Interior](#) | [U.S. Geological Survey](#)

URL: <<http://pubs.usgs.gov/of/2001/ofr-01-0429/chem1/>>

Questions or Assistance: [Contact USGS](#)

Page Last Modified: Fri Dec 16 17:18 EDT 2005



World Trade Center area, New York

U.S. Geological Survey
Clark et al., 2001

NASA/JPL AVIRIS data
Sept 16, 2001 16:21 GMT

USGS
Imaging Spectroscopy
Tetracorder 4.0awtc2
product

Spectral Shape Map

This map shows materials whose spectra are similar to the reference materials below. It is not a map of the identification of these materials. A similarity map is analogous to a map of materials with similar colors viewed with your eyes. The colors may indicate similar compositions.








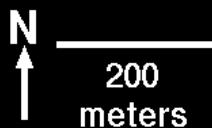
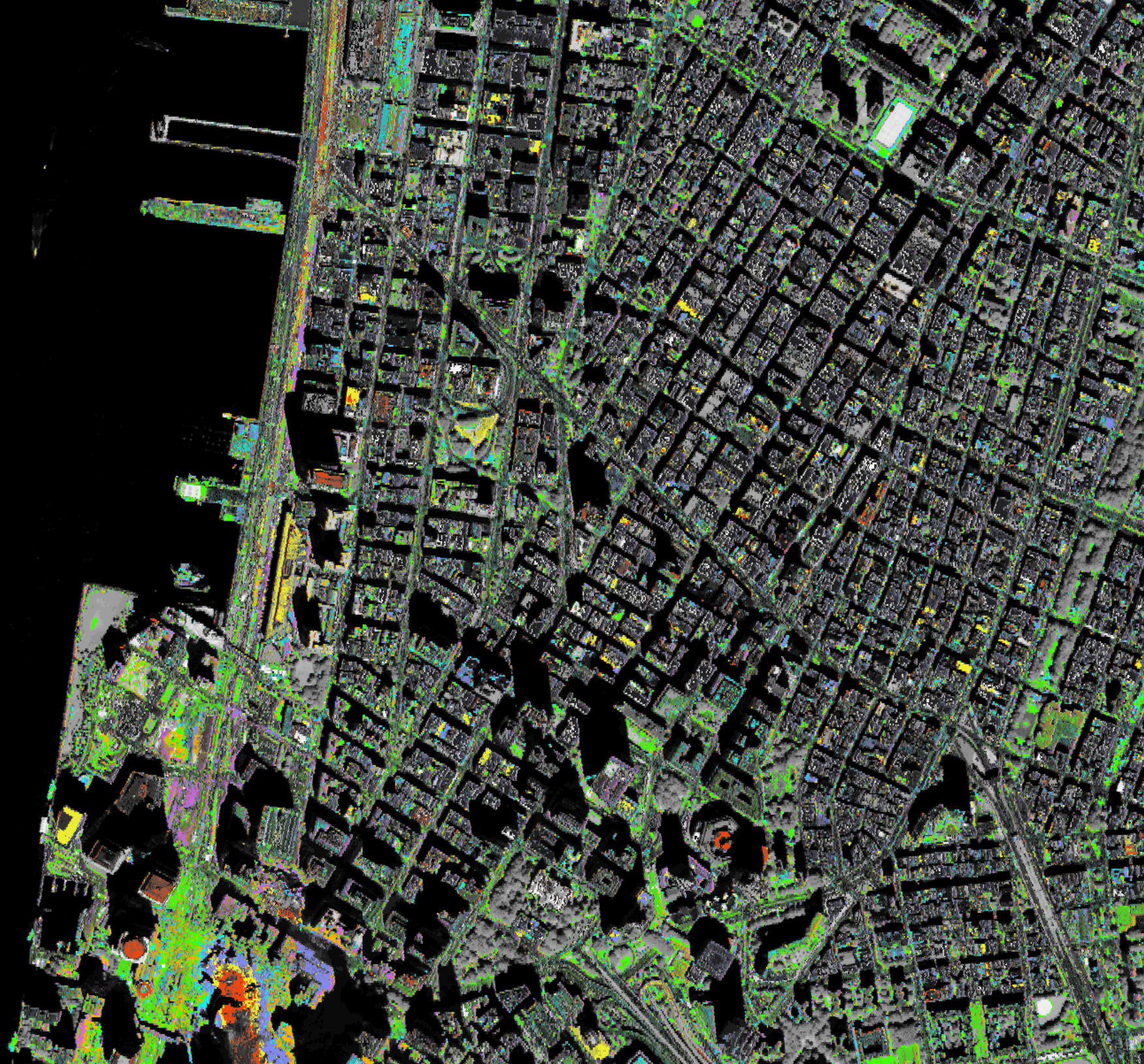
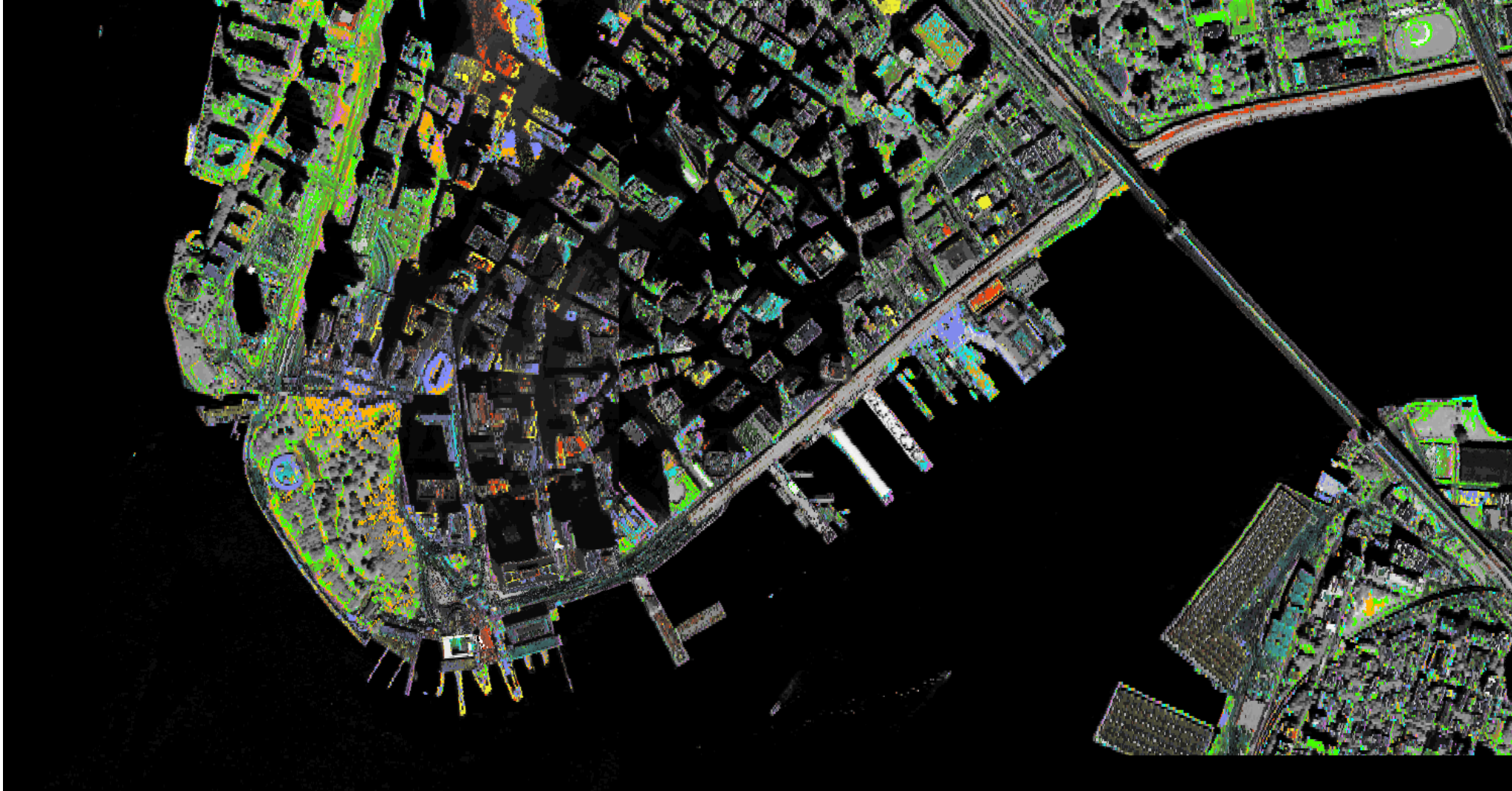
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-  concrete (WTC01-37Am)
-  cement (WTC01-37A)
-  dust (WTC01-15)
-  dust (WTC01-28)
-  dust (WTC01_36)
-  gypsum wall board

Image sampling:
1.7 meters/pixel







World Trade Center area, New York








U.S. Geological Survey
Clark et al., 2001

NASA/JPL AVIRIS data
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-  dust (WTC01-15)
-  dust (WTC01-28)
-  dust (WTC01_36)
-  gypsum wall board

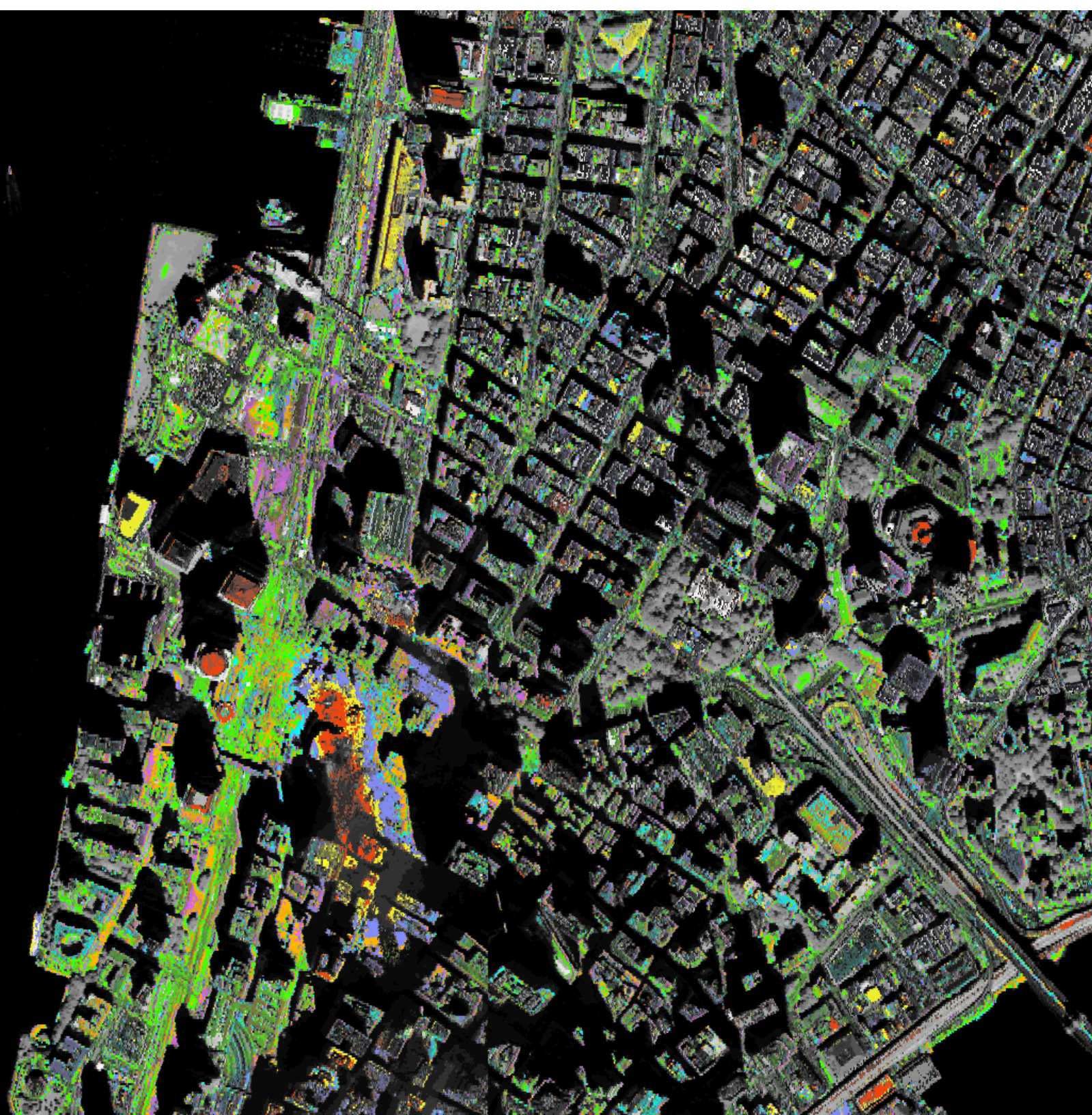
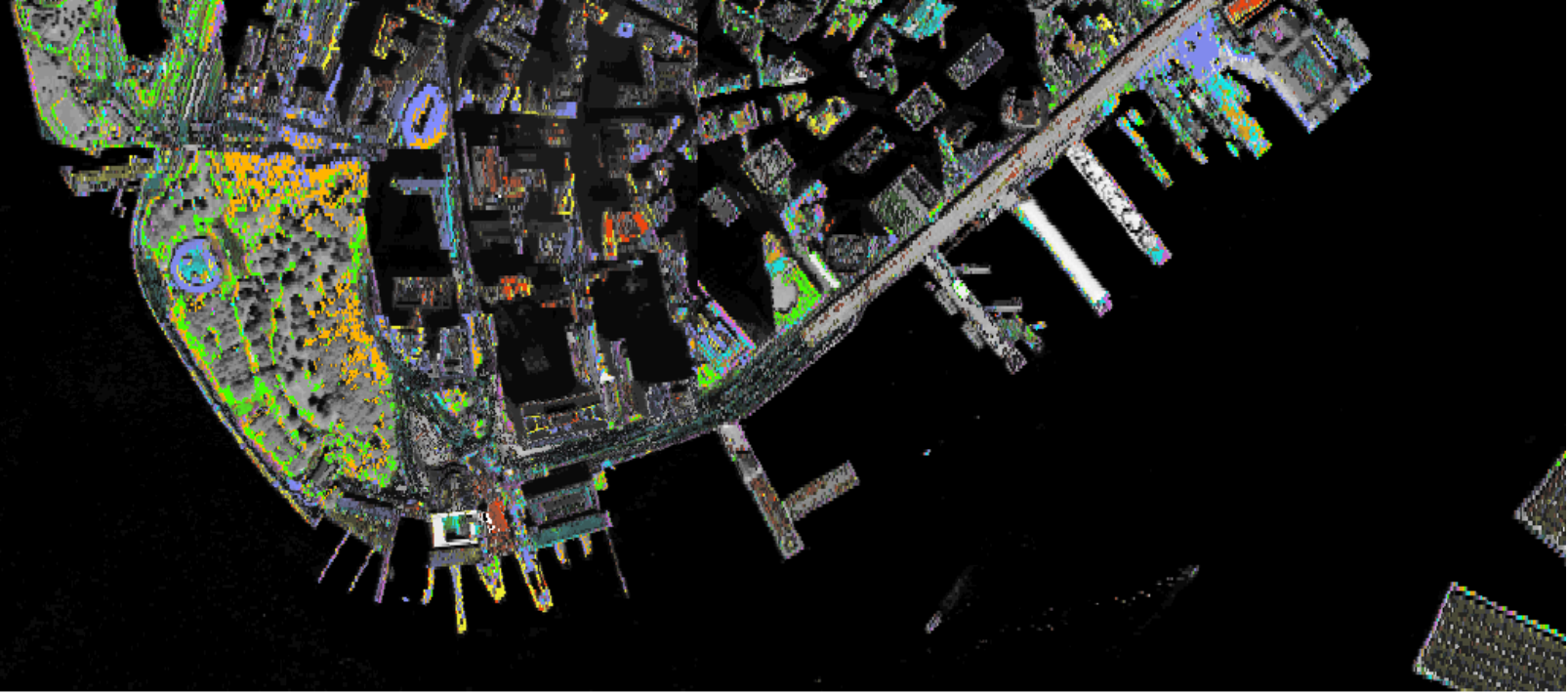
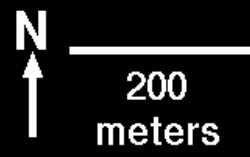


Image sampling:
1.7 meters/pixel



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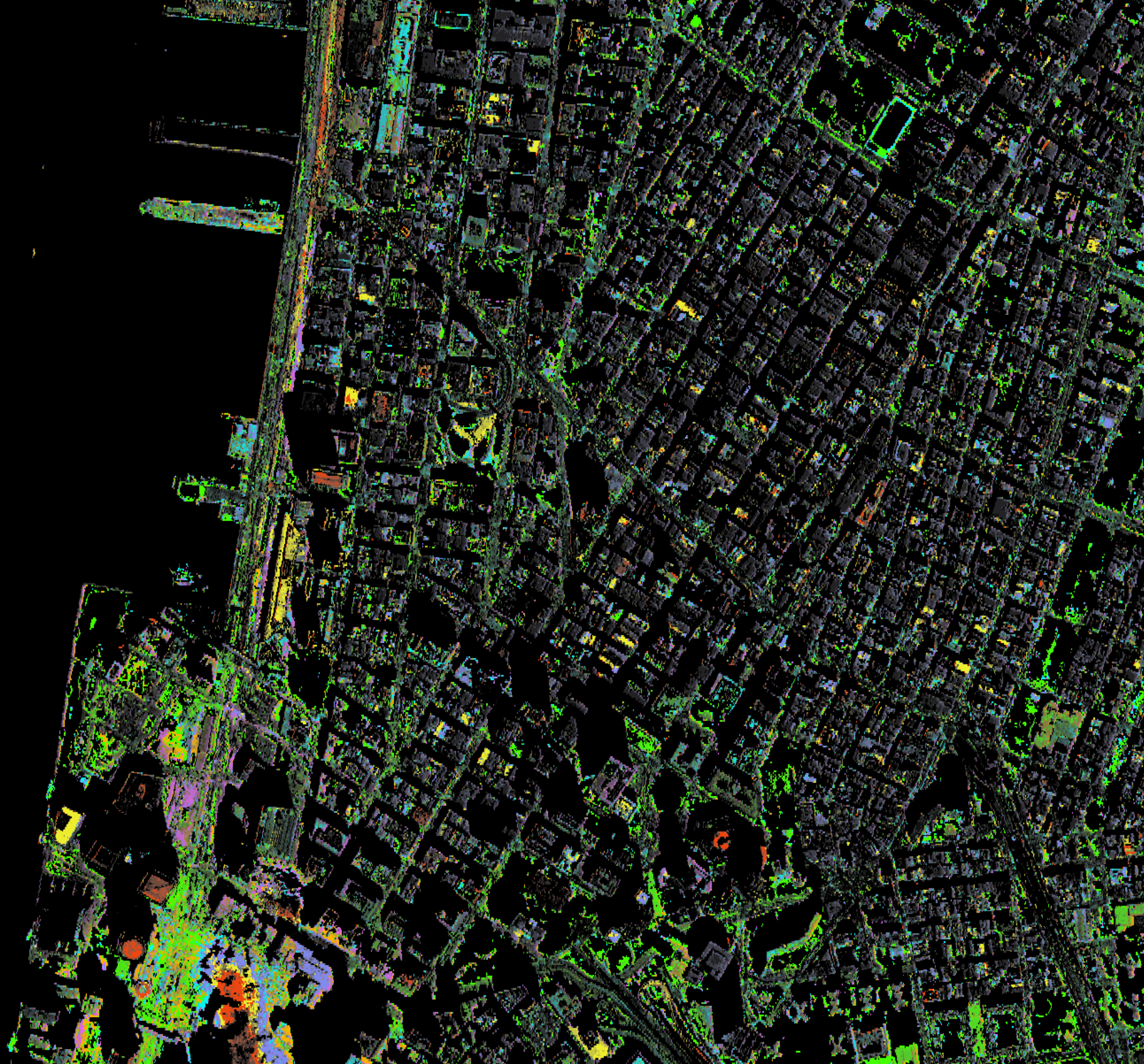
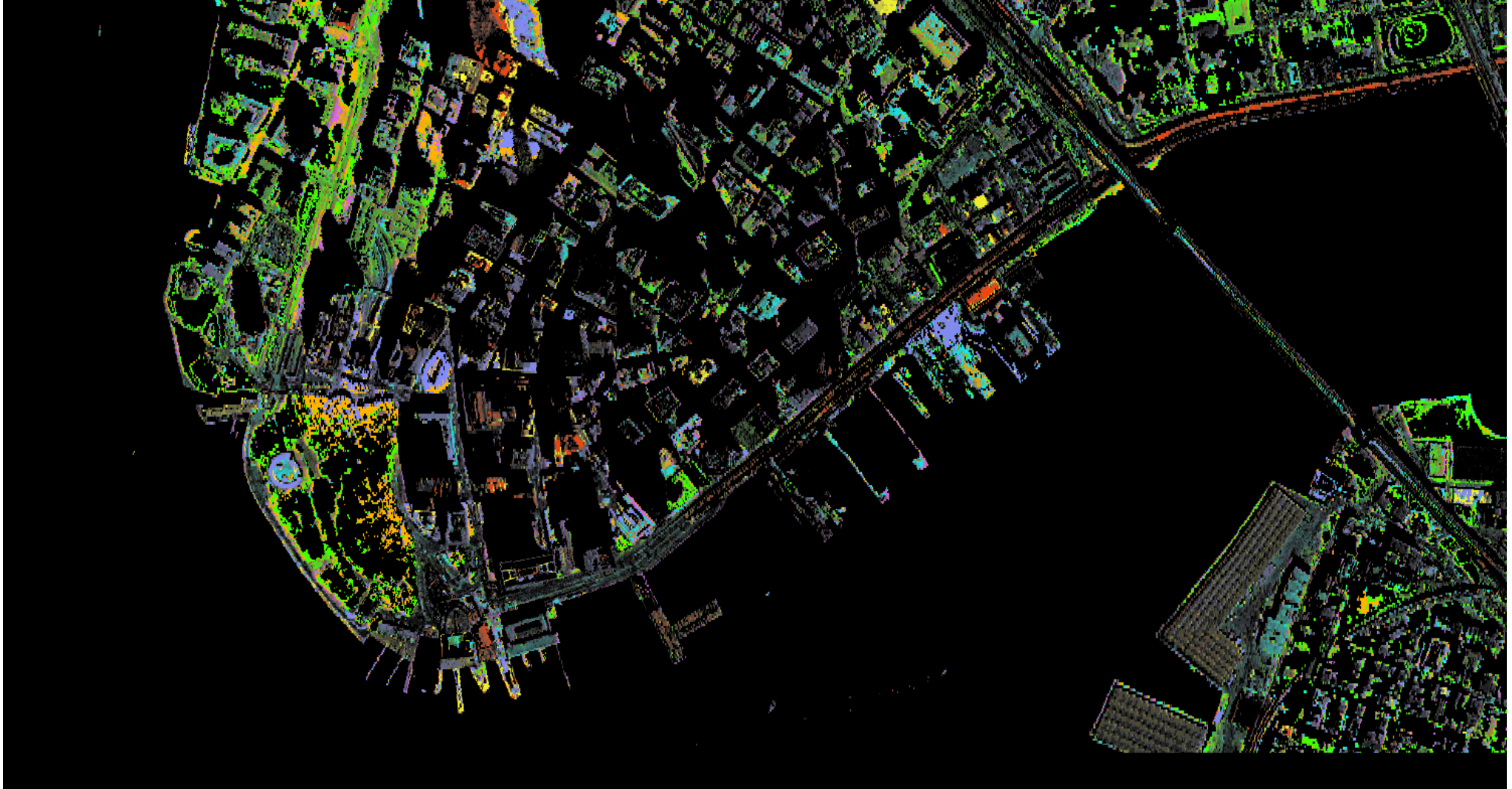
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-  cement (WTC01-37A)
-  dust (WTC01-15)
-  dust (WTC01-28)
-  dust (WTC01_36)
-  gypsum wall board

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-  concrete (WTC01-37B)
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-  dust (WTC01-15)
-  dust (WTC01-28)
-  dust (WTC01_36)
-  gypsum wall board

Image sampling:

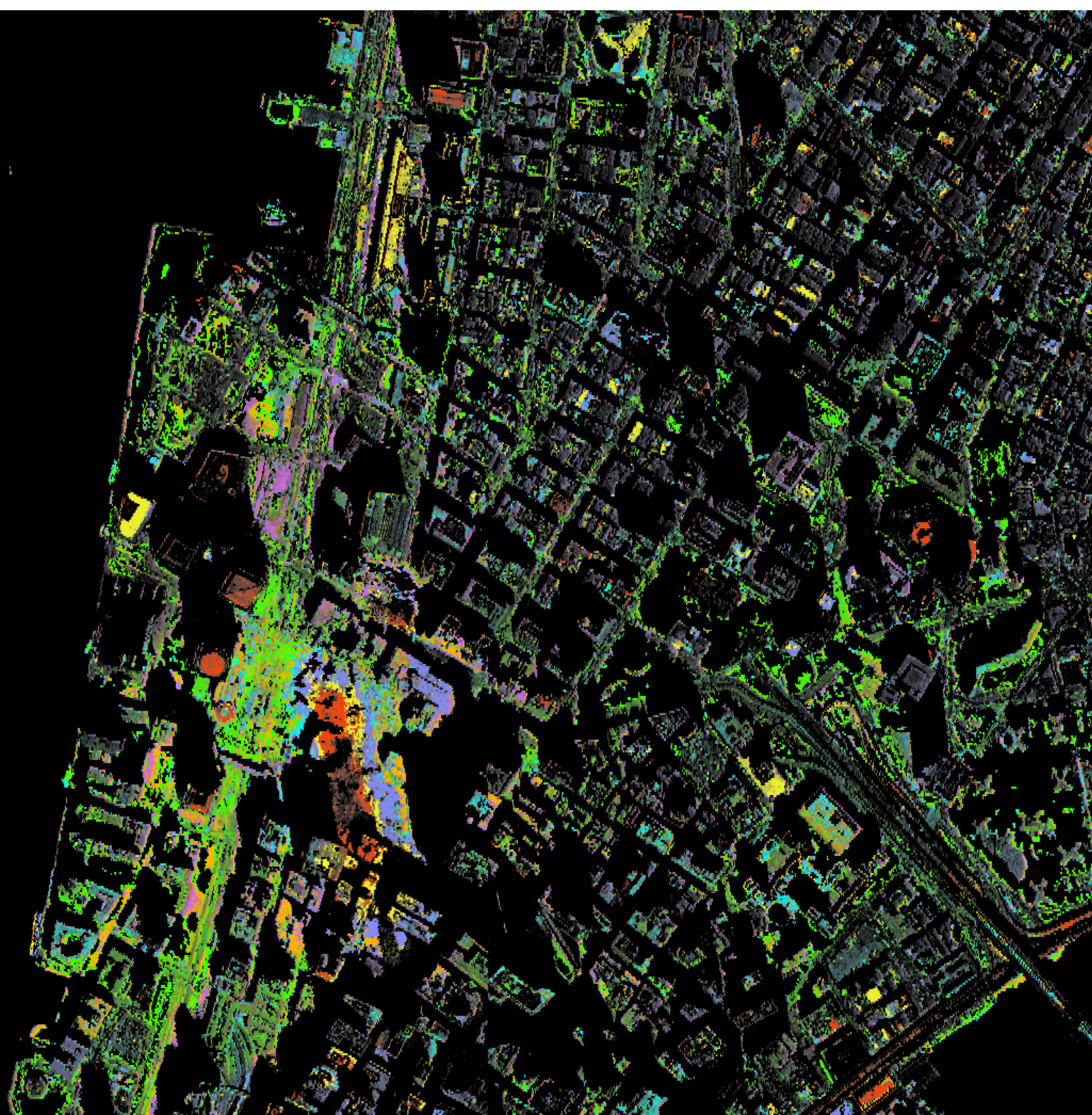
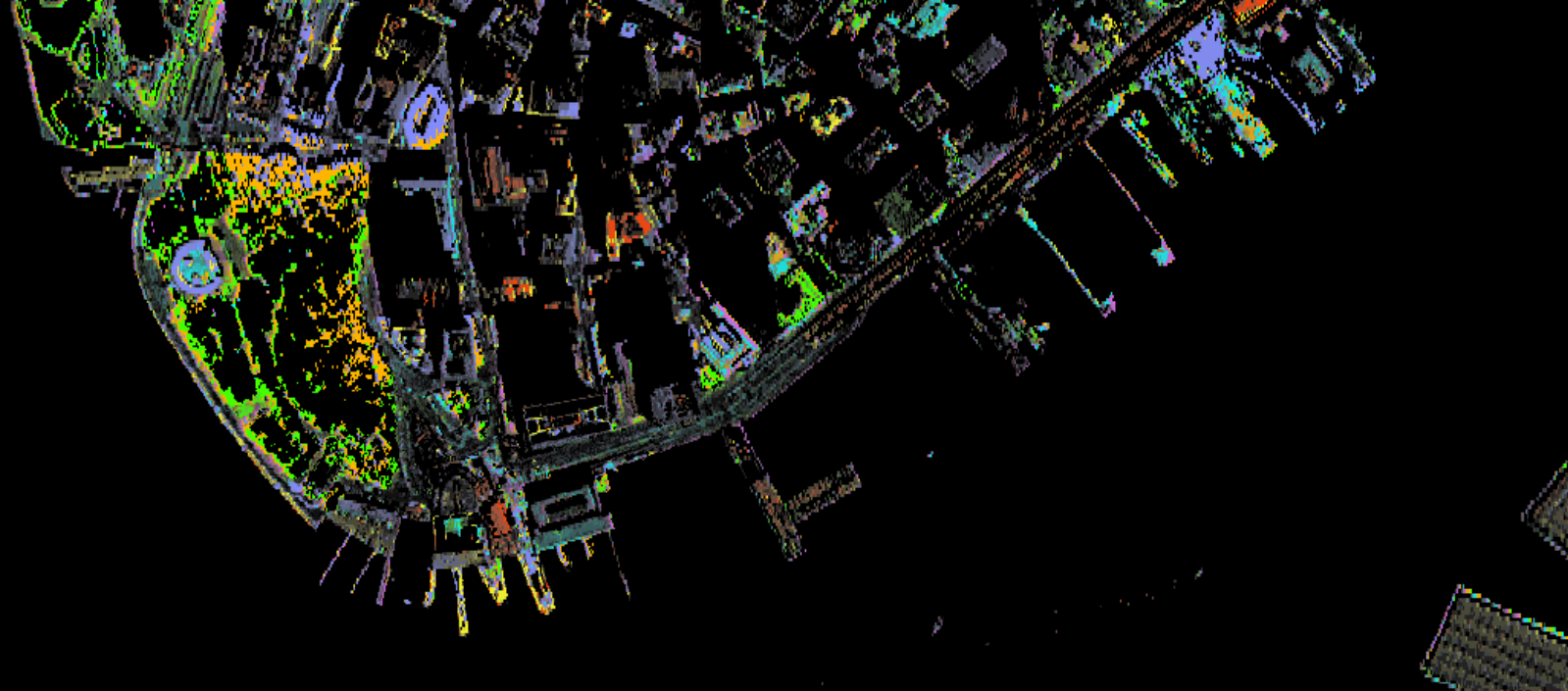
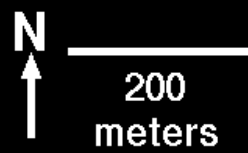


Image sampling:
1.7 meters/pixel



SCALED REFLECTANCE

0.6

0.4

0.2

0.0

Gypsum Wall
board
GDS 524

Cement
WTC01-37A(c)

Dust WTC01-36

Dust WTC01-15

Dust WTC01-28

Concrete
WTC01-37B

Concrete
WTC01-37Am

WAVELENGTH (μm)

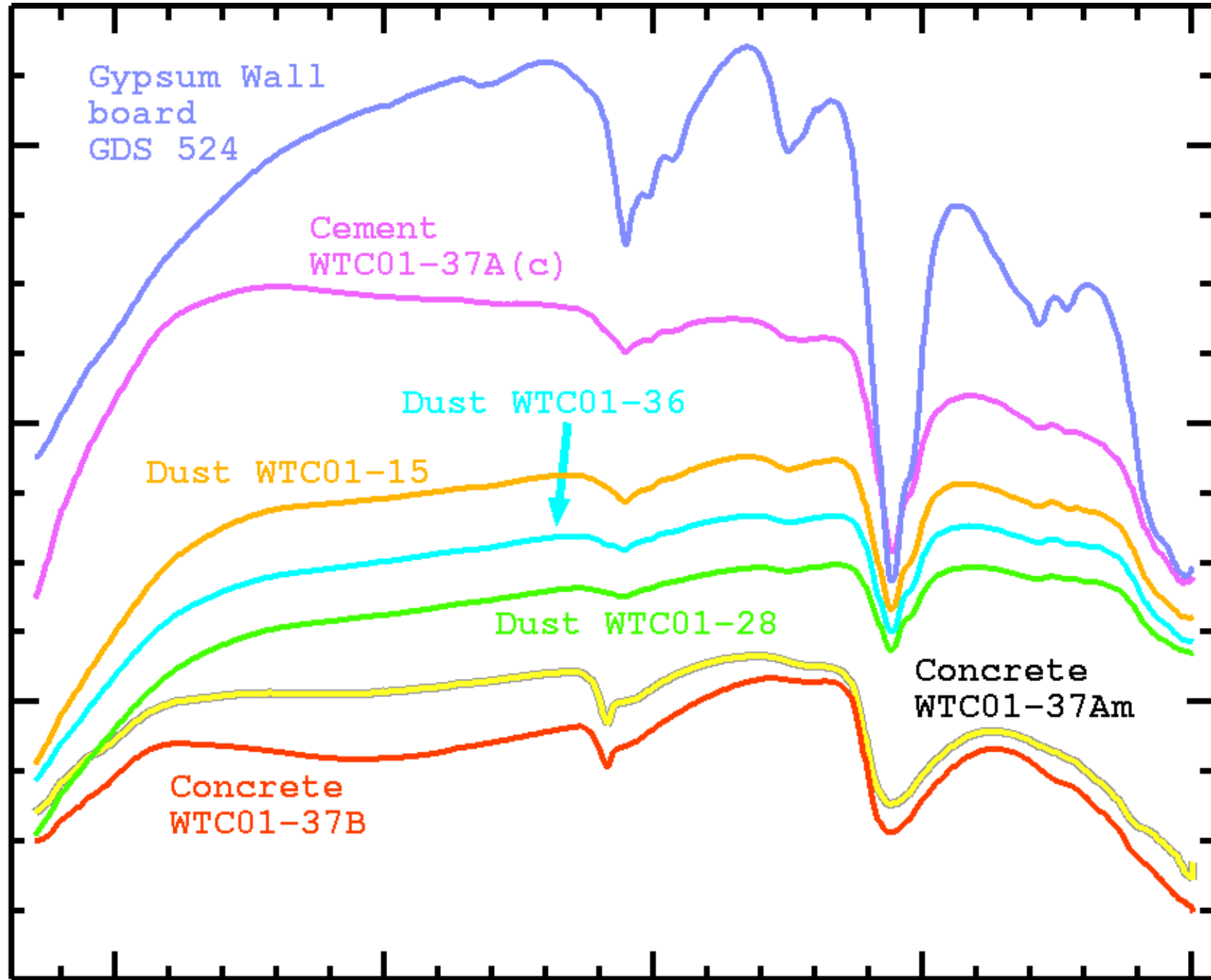
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1.0

1.5

2.0

2.5



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Material Absorption
Feature map (features
near 1-micron):

Ferric-bearing:

1 2 3

Ferric and/or
Ferrous-bearing:

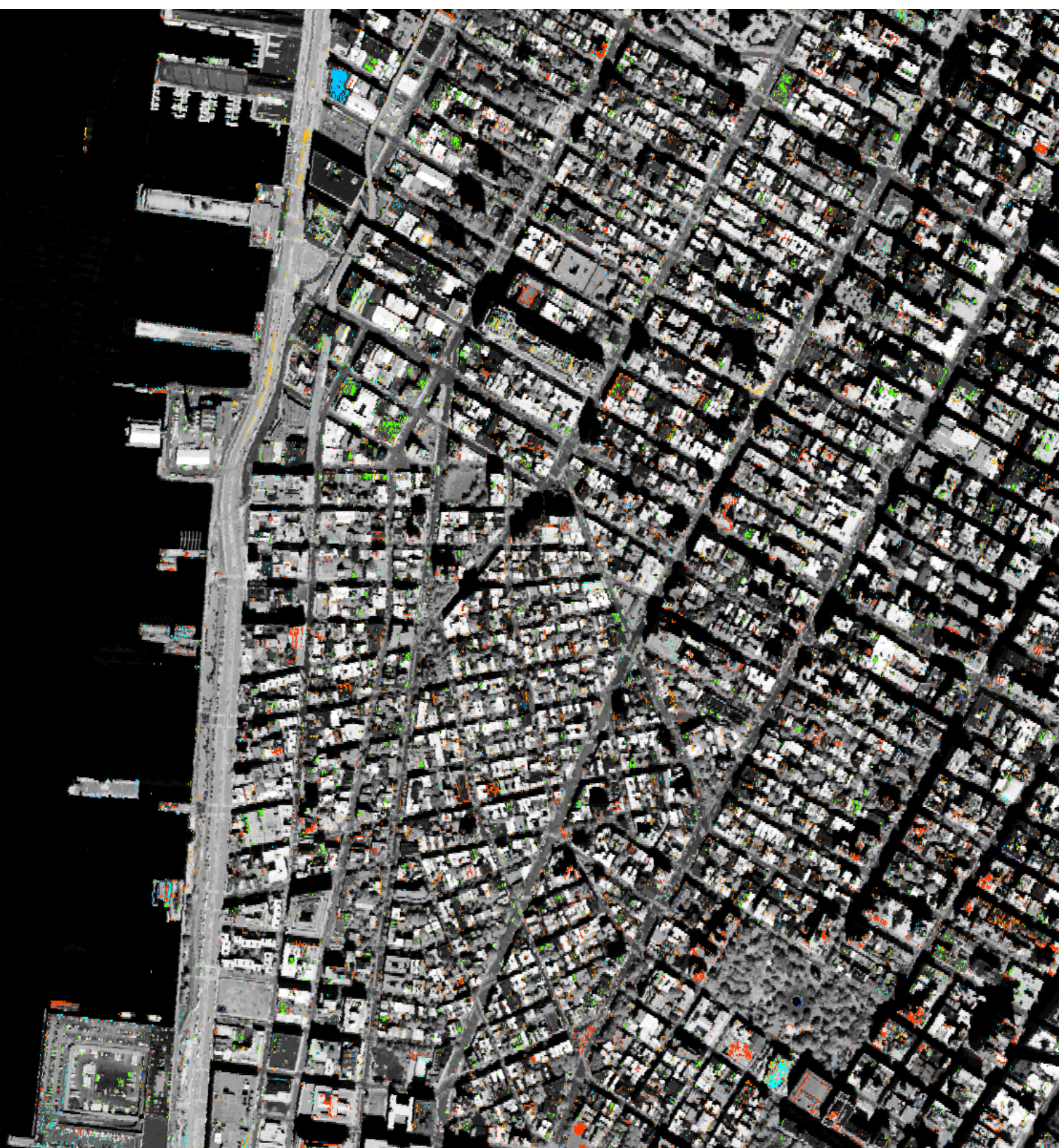
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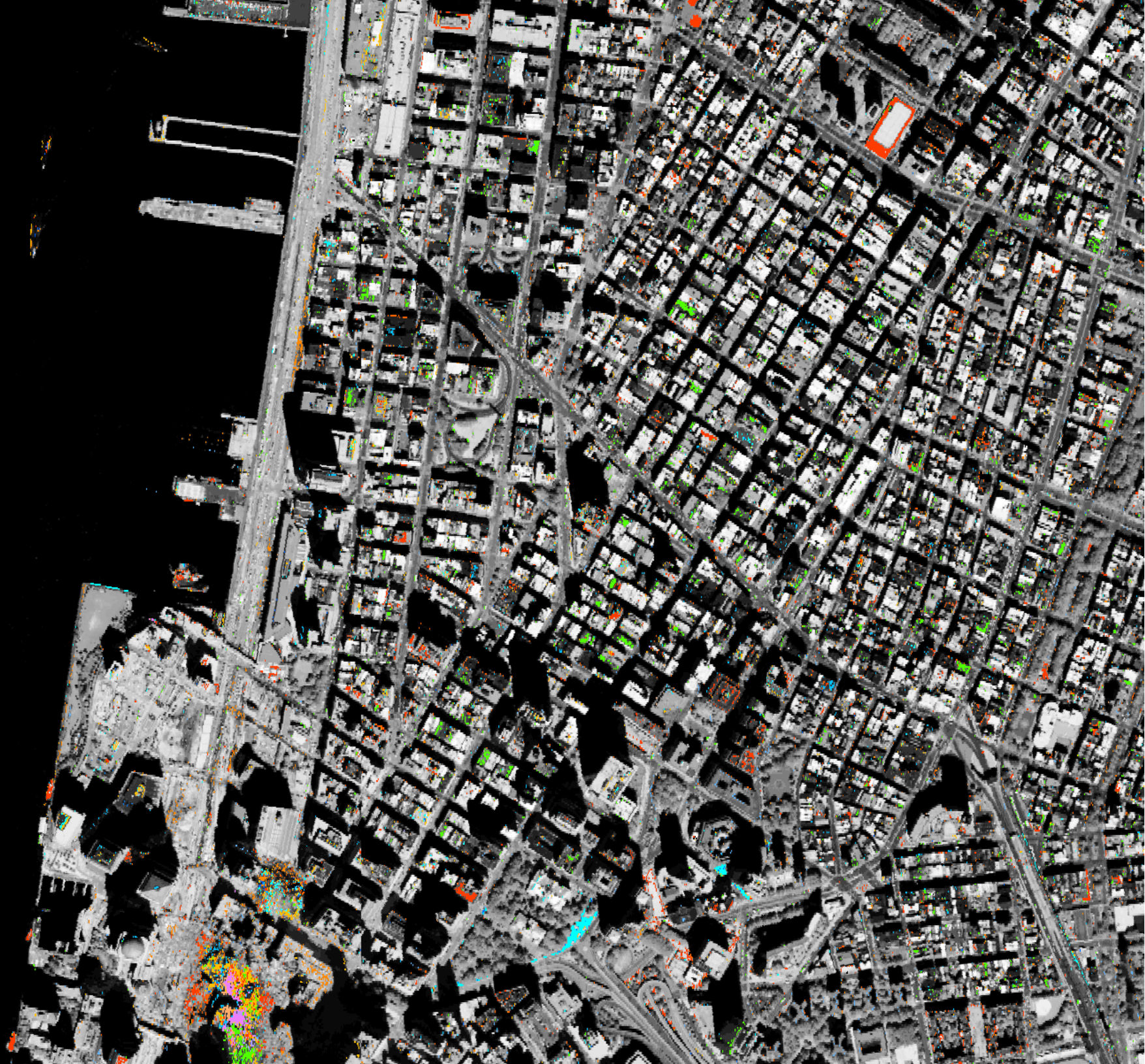
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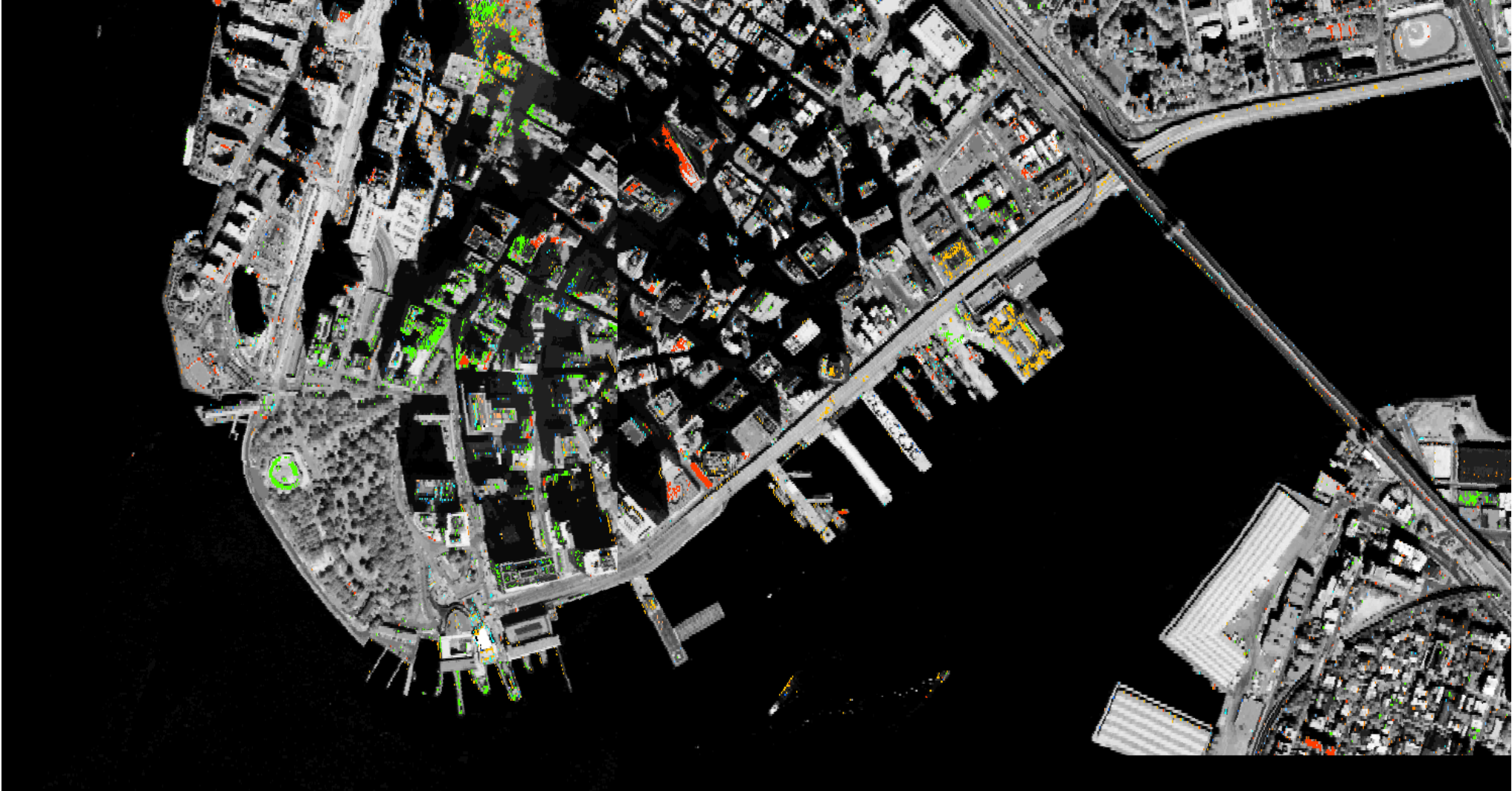
8 9 10
11 12 13
7

Image sampling:
1.7 meters/pixel

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↑
200
meters







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Material Absorption
Feature map (features
near 1-micron):

Ferric-bearing:

1 2 3

Ferric and/or
Ferrous-bearing:

4 5 6

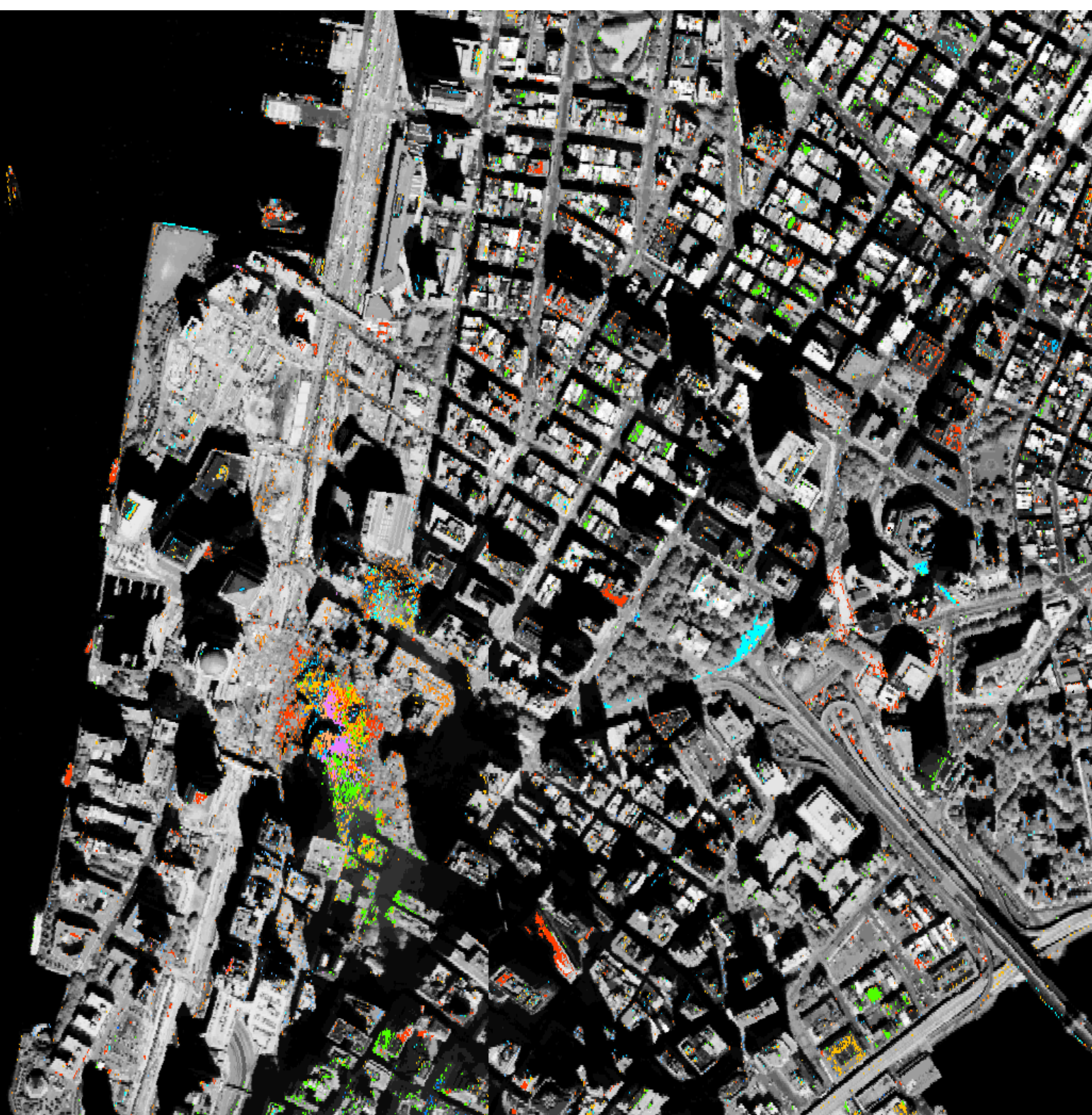
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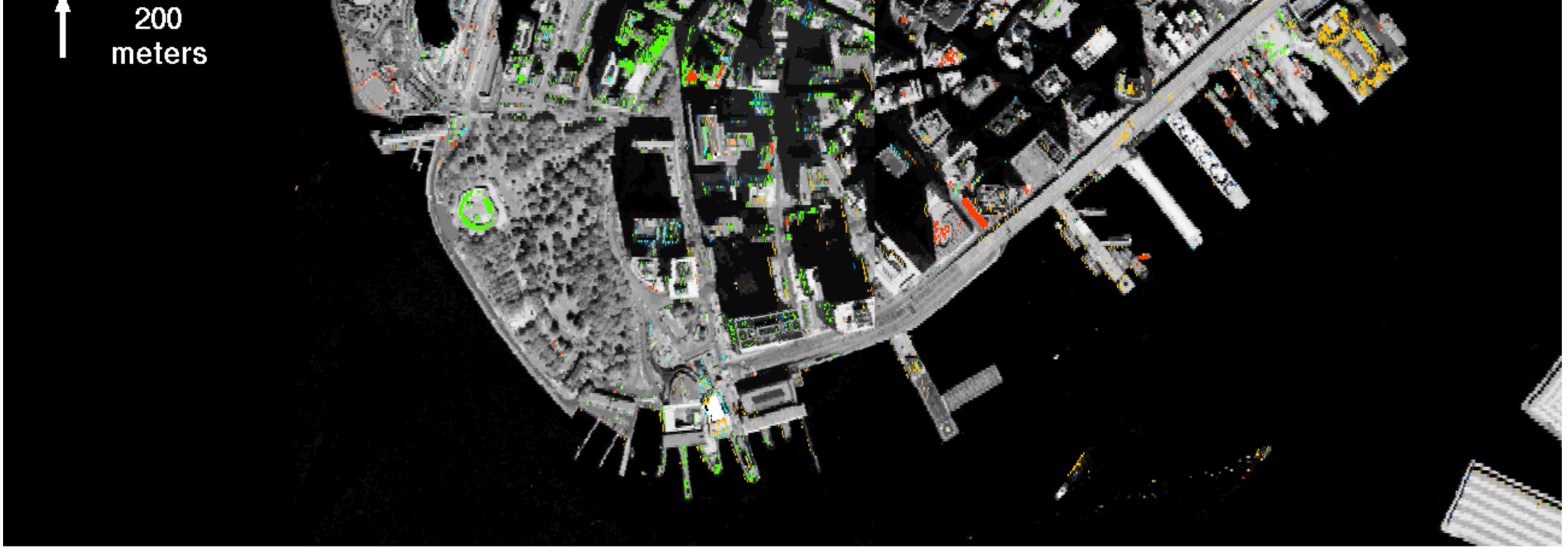
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11 12 13

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USGS
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Tetracorder 4.0a8
product

Material Absorption
Feature map (features
near 1-micron):

Ferric-bearing:

1 2 3

Ferric and/or
Ferrous-bearing:

4 5 6

Ferrous-bearing:

8 9 10

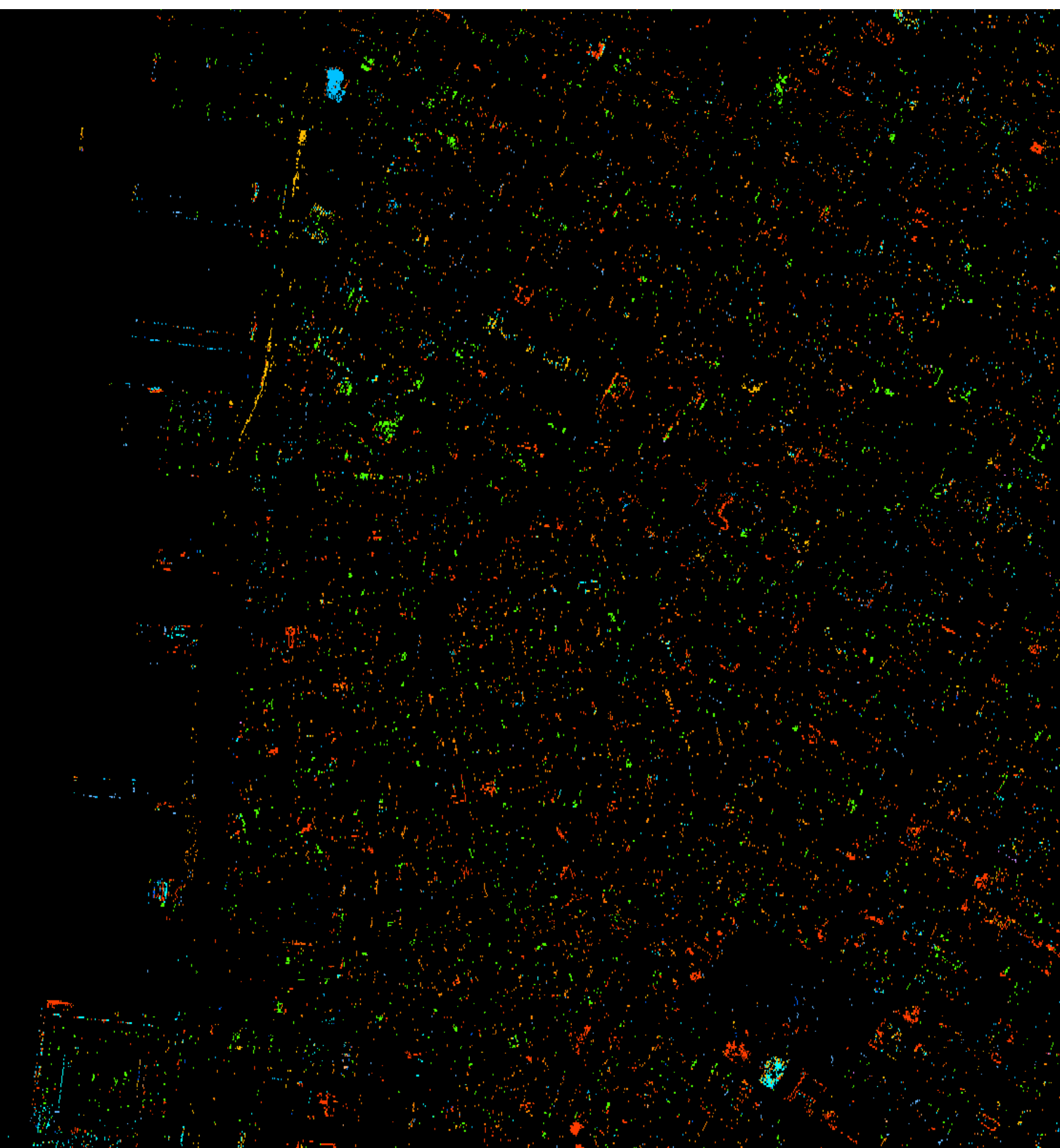
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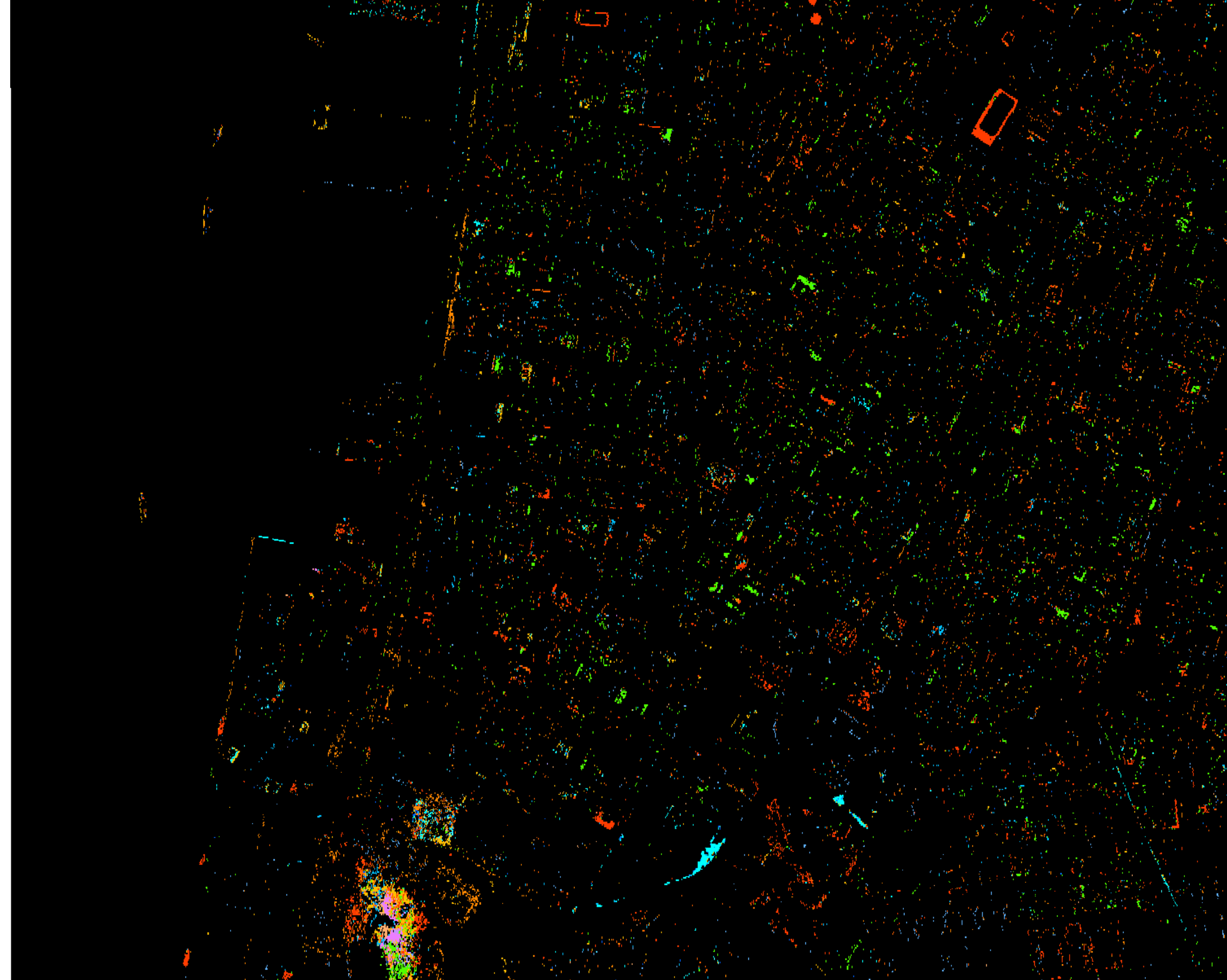
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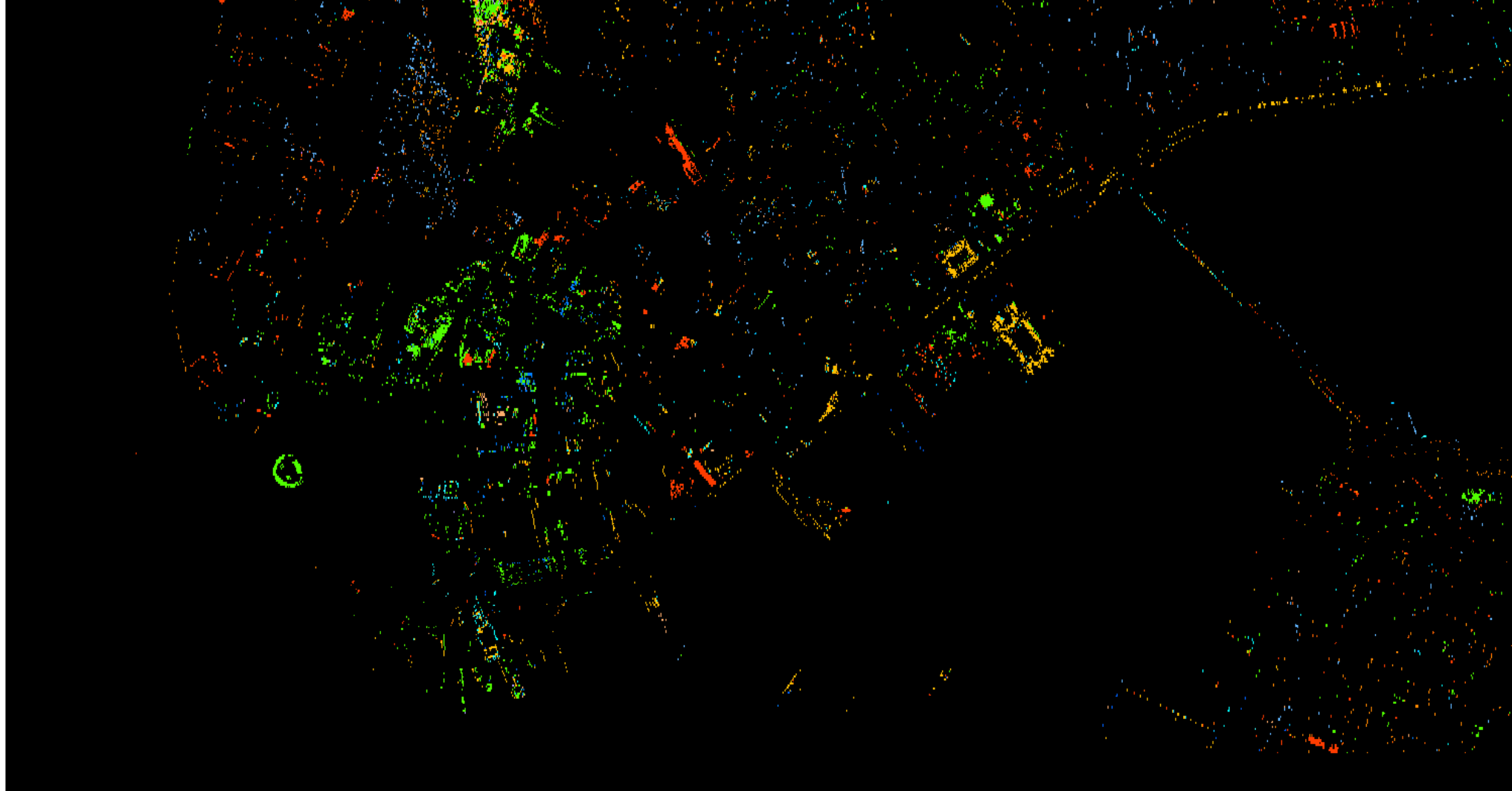
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200
meters







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Sept 16, 2001 16:21 GMT

USGS
Imaging Spectroscopy
Tetracorder 4.0a8
product

Material Absorption
Feature map (features
near 1-micron):

Ferric-bearing:

1

2

3

Ferric and/or
Ferrous-bearing:

4

5

6

Ferrous-bearing:

8

9

10

11

12

13

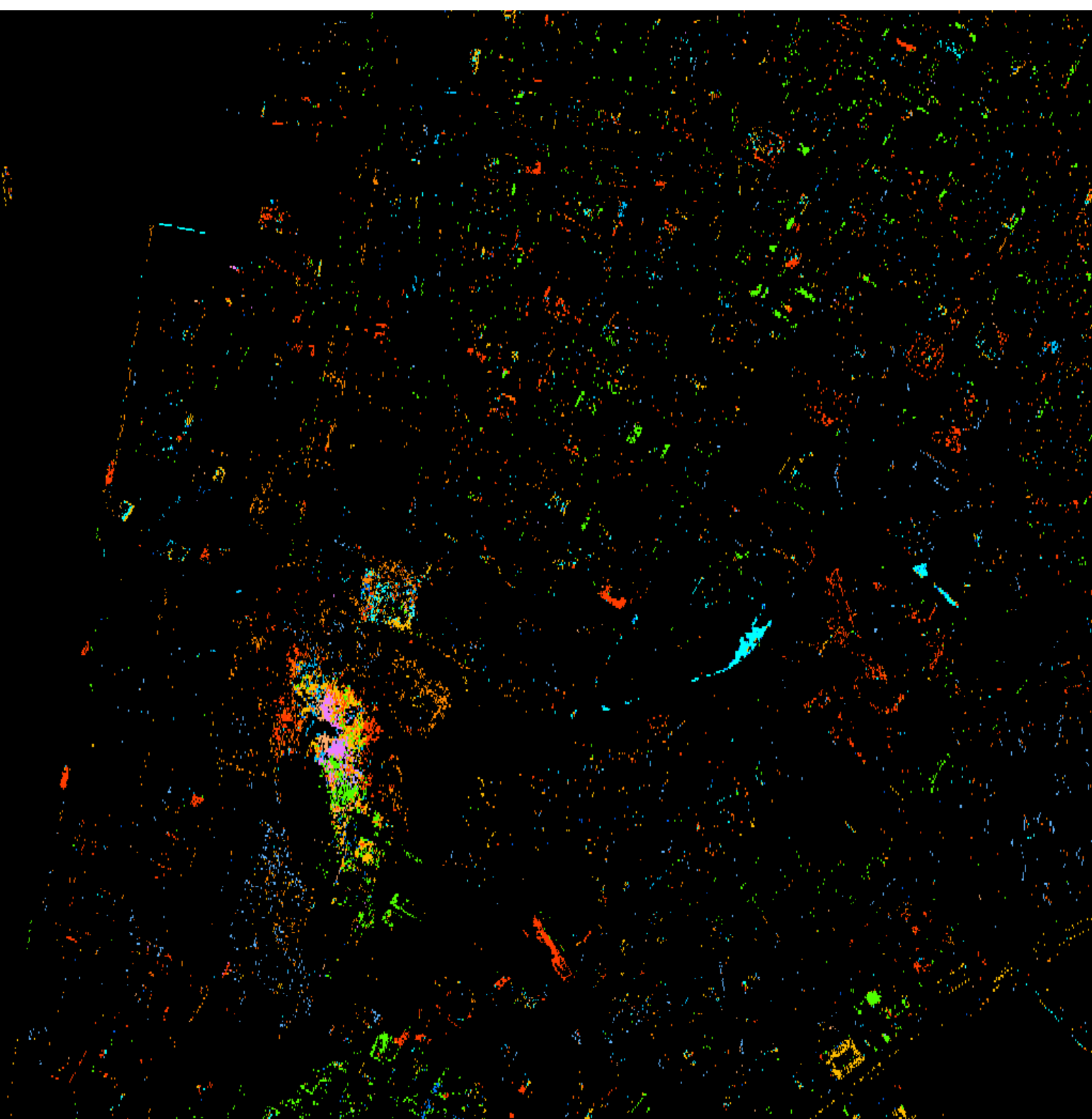
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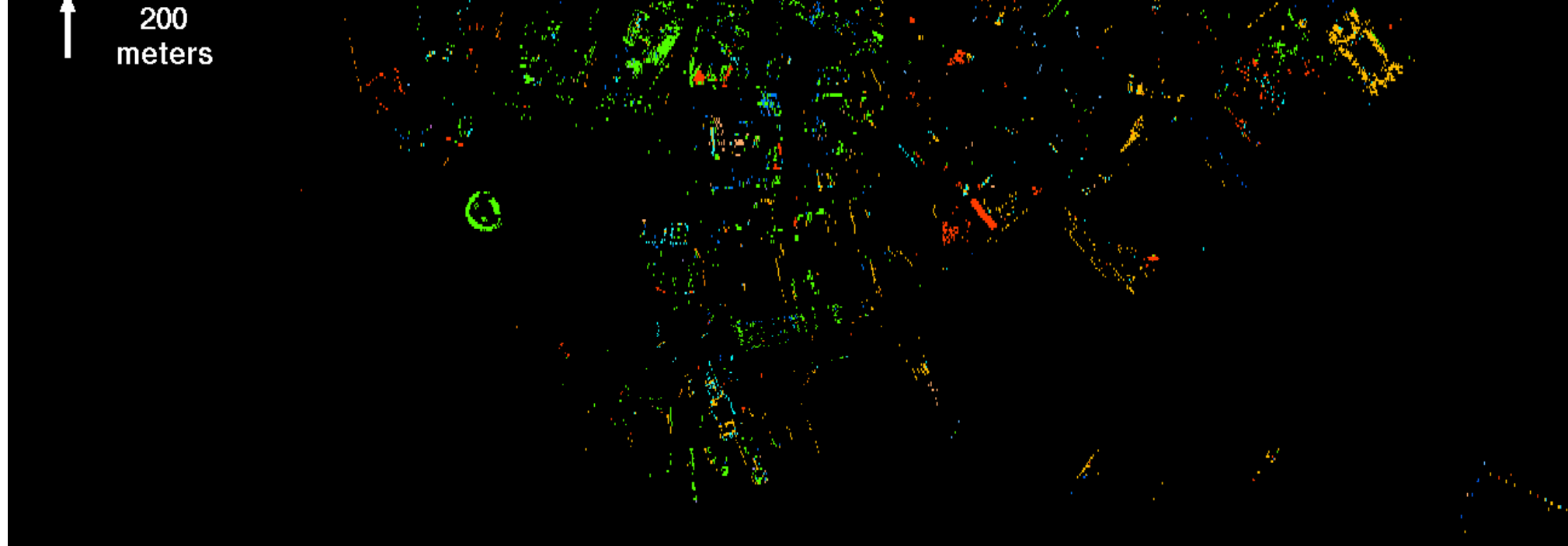
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1.7 meters/pixel

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200





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Sept 16, 2001 16:21 GMT

USGS
Imaging Spectroscopy
Tetracorder 4.0a3
product

Material Absorption
Feature map (features
2 to 2.5 microns):

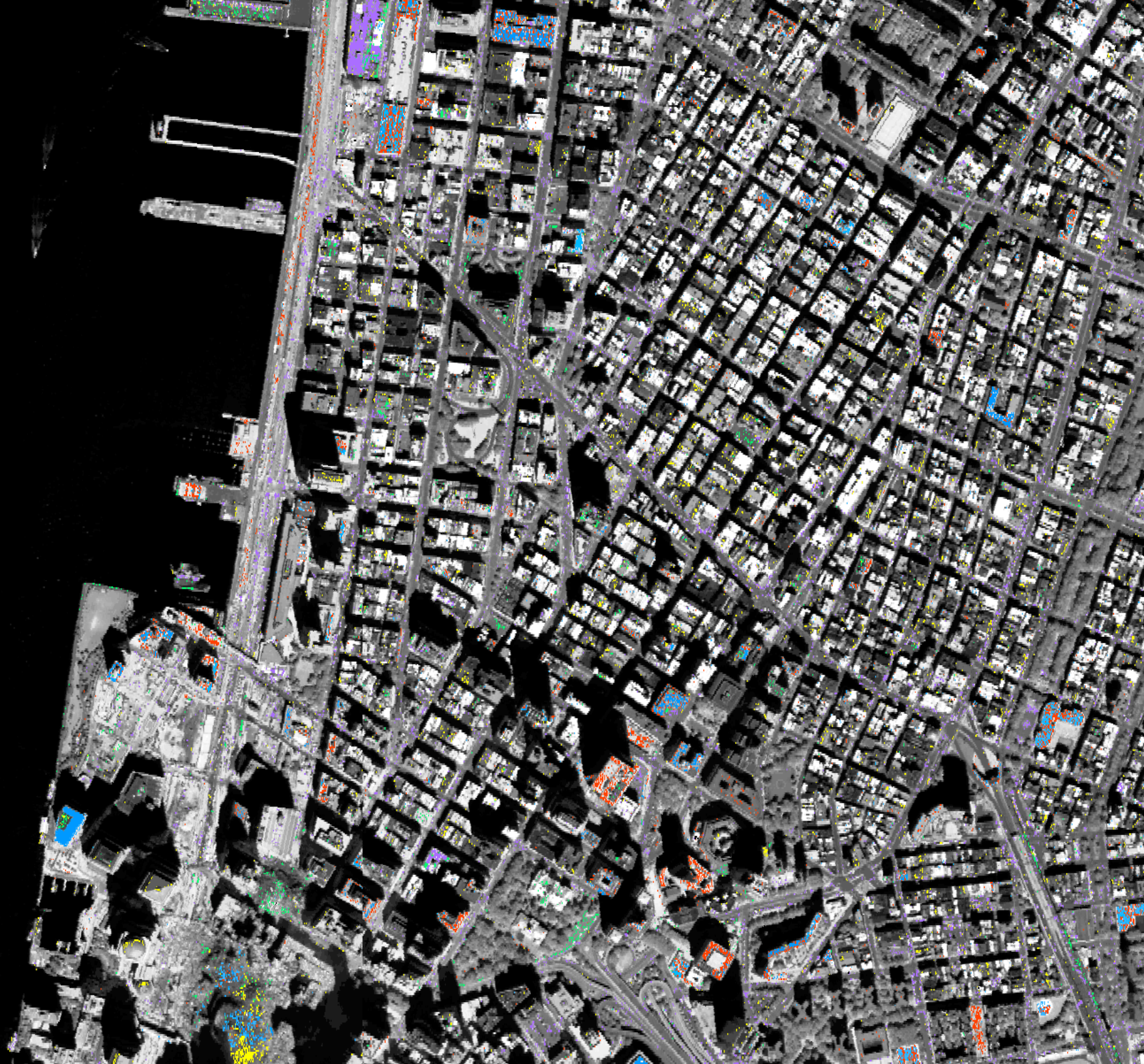
mixtures that
include kaolinite
group minerals
and/or gypsum
(2.2– micron
features)

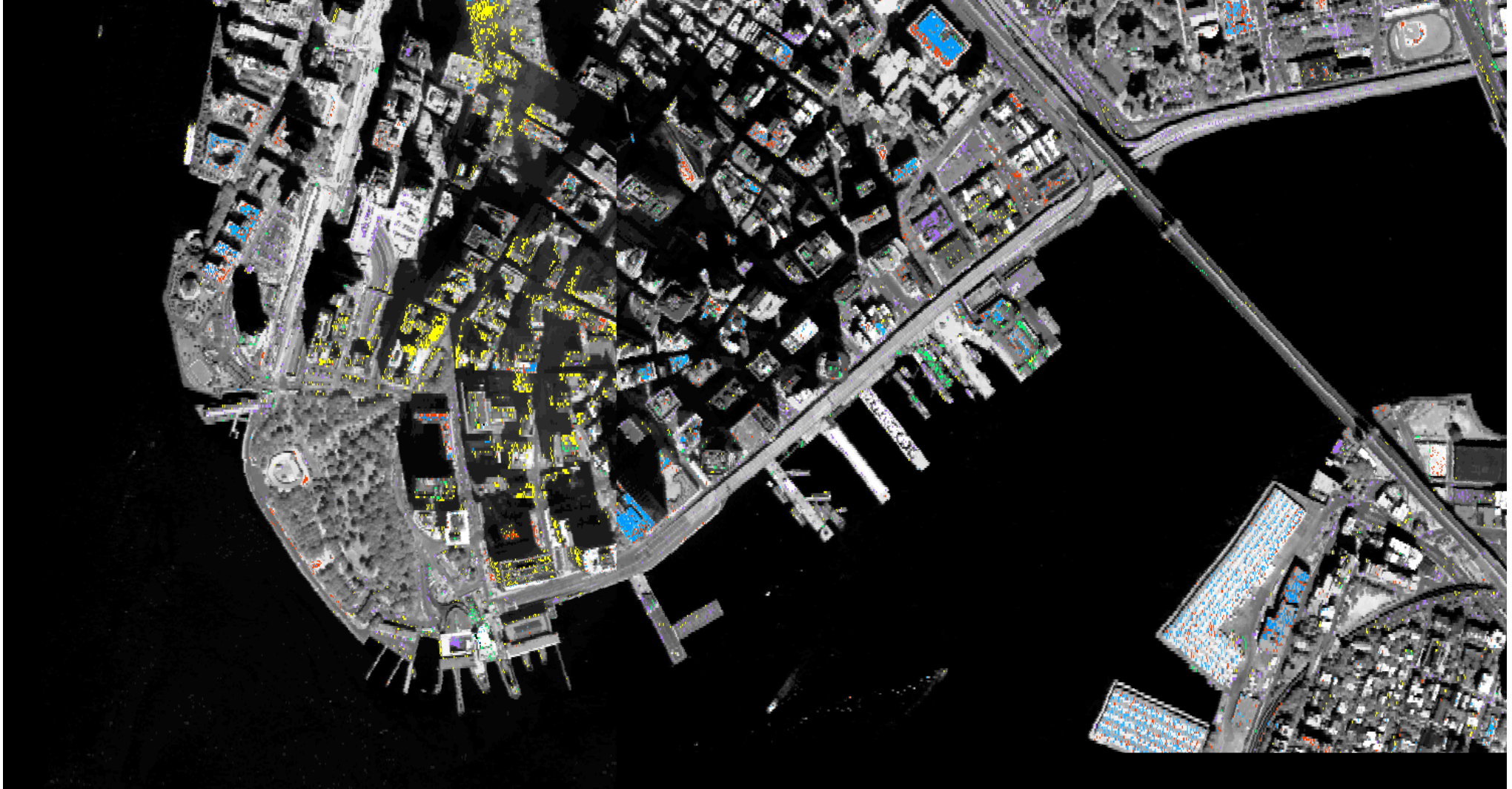
Clays and other
water, OH-bearing or
carbonate-bearing
materials with
spectral features at:

- 2.20 microns
- 2.29 microns
- 2.30 microns
- 2.35 microns

Image sampling:
1.7 meters/pixel







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USGS
Imaging Spectroscopy
Tetracorder 4.0a3
product

Material Absorption
Feature map (features
2 to 2.5 microns):

mixtures that
include kaolinite
group minerals
and/or gypsum
(2.2- micron
features)



Clays and other
water, OH-bearing or
carbonate-bearing
materials with
spectral features at:



2.20 microns



2.29 microns

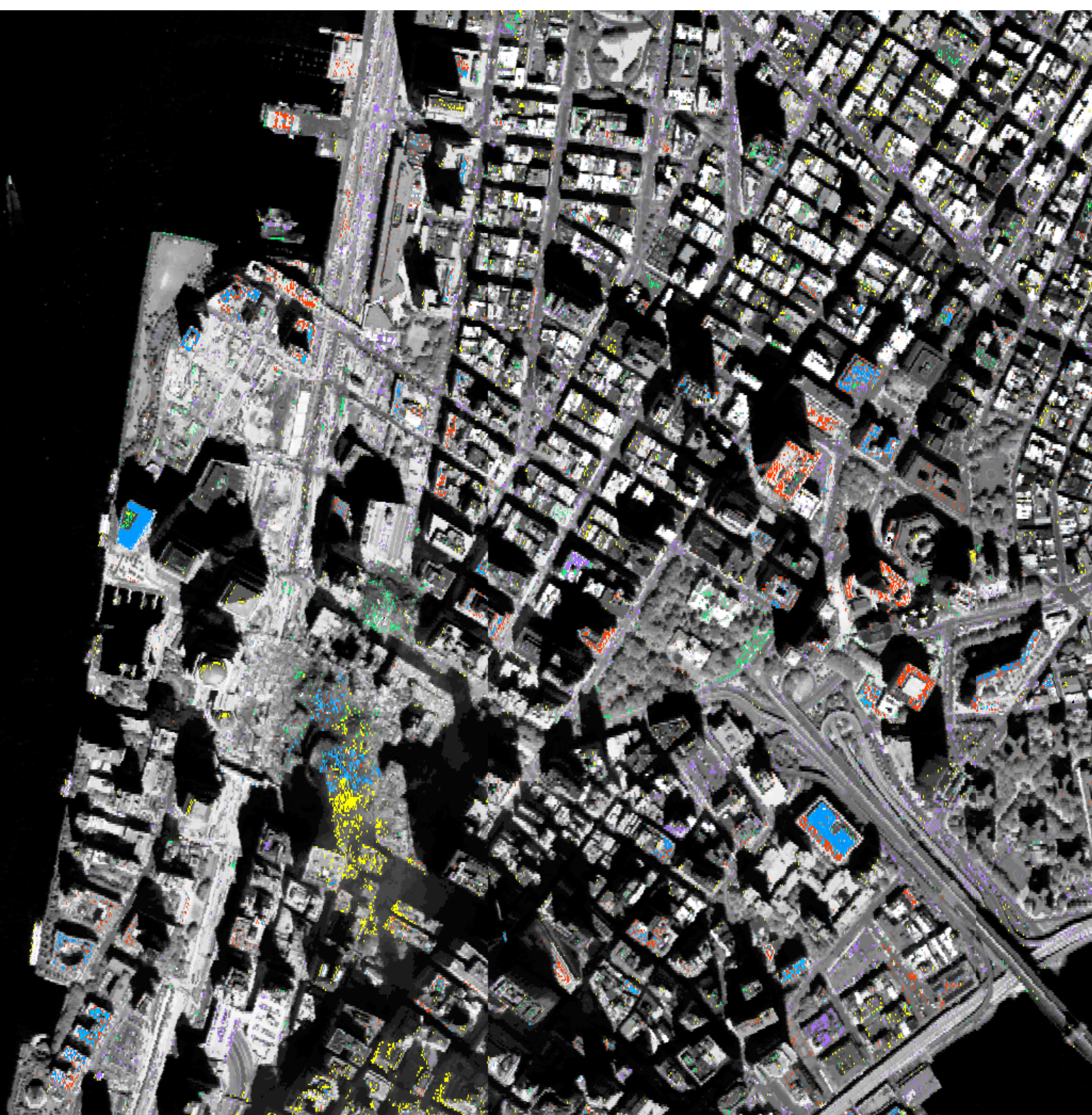


2.30 microns



2.35 microns

Image sampling:
1.7 meters/pixel





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Sept 16, 2001 16:21 GMT

USGS
Imaging Spectroscopy
Tetracorder 4.0a8
product

Material Absorption
Feature map of
organic materials.
Organics include:
plastic, paint, and any
material containing
C-H molecules
(including gasoline and
solvents). Most if not
all detections of organics
here are probably
paints and plastics.

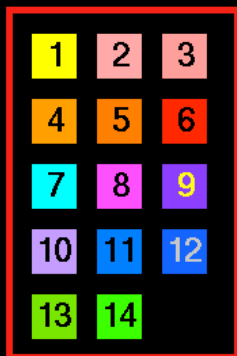
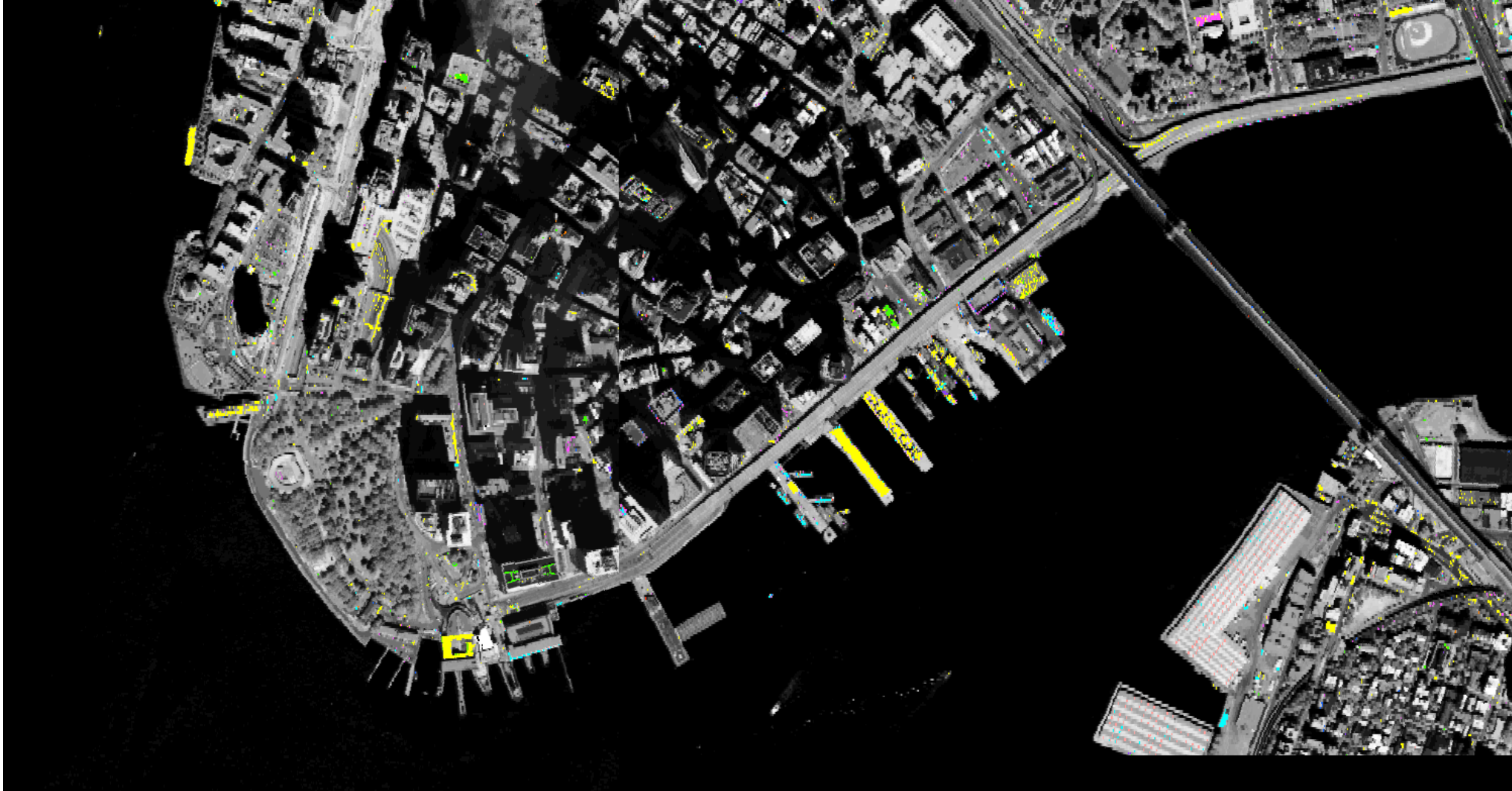


Image sampling:
1.7 meters/pixel







World Trade Center area, New York

U.S. Geological Survey
Clark et al., 2001

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Sept 16, 2001 16:21 GMT

USGS
Imaging Spectroscopy
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product

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Feature map of
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Organics include:
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(including gasoline and
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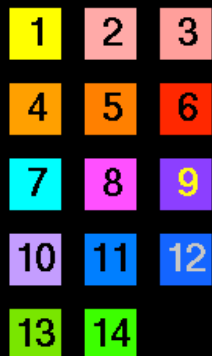
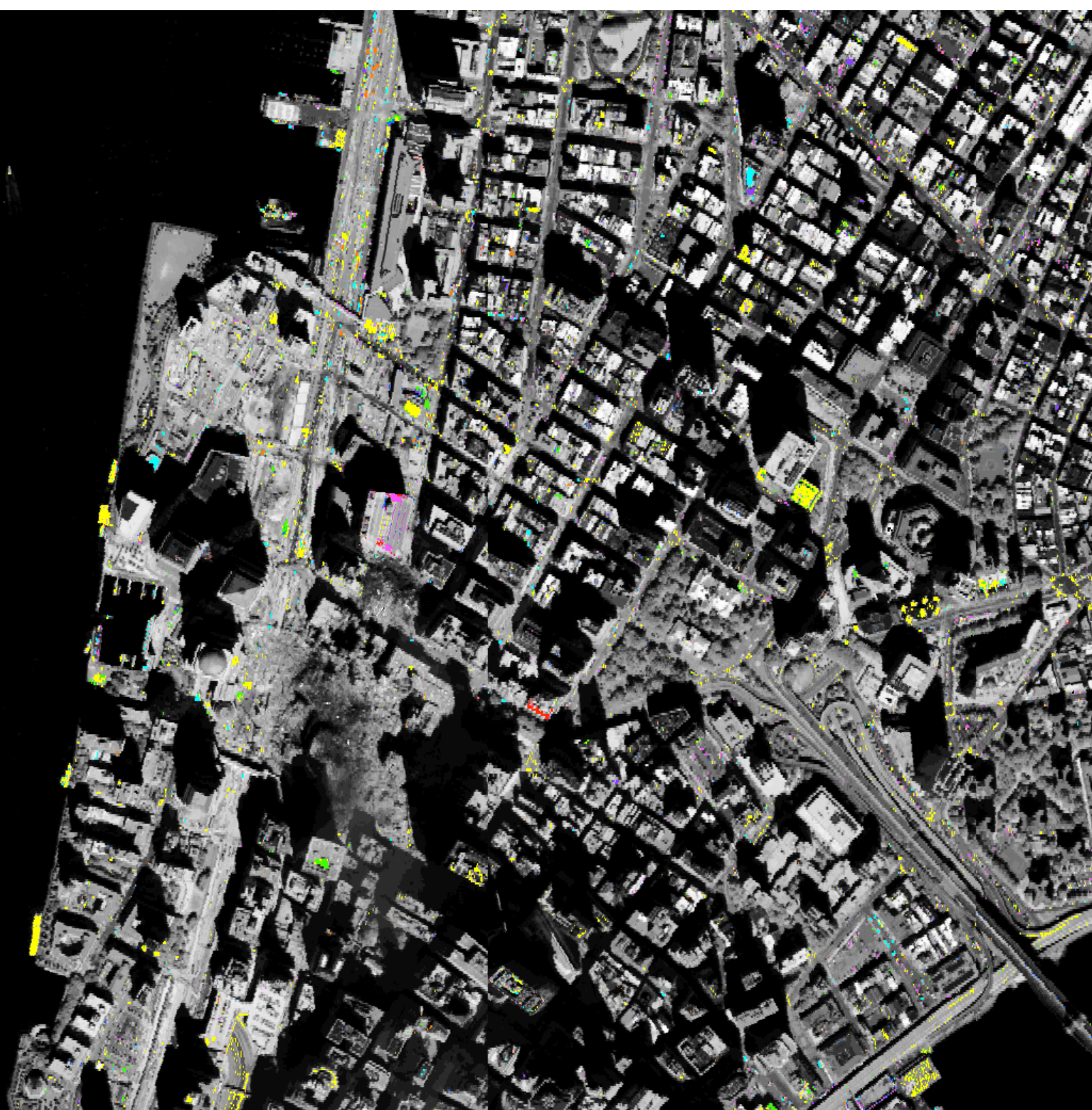
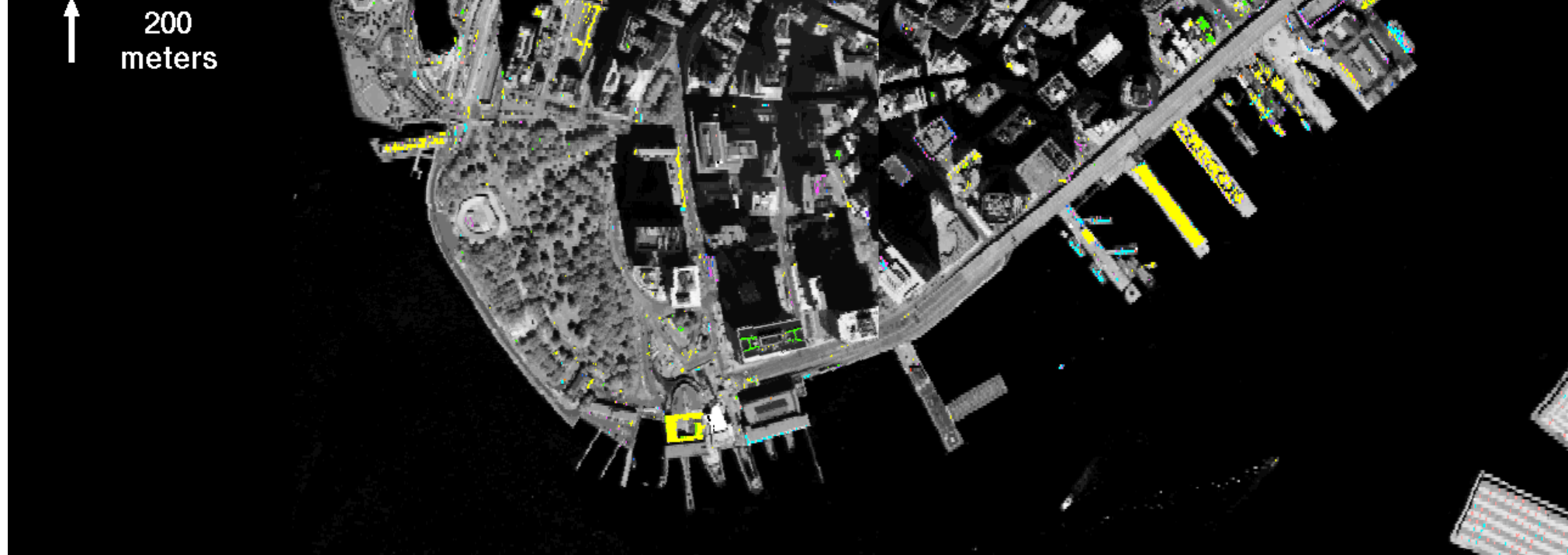
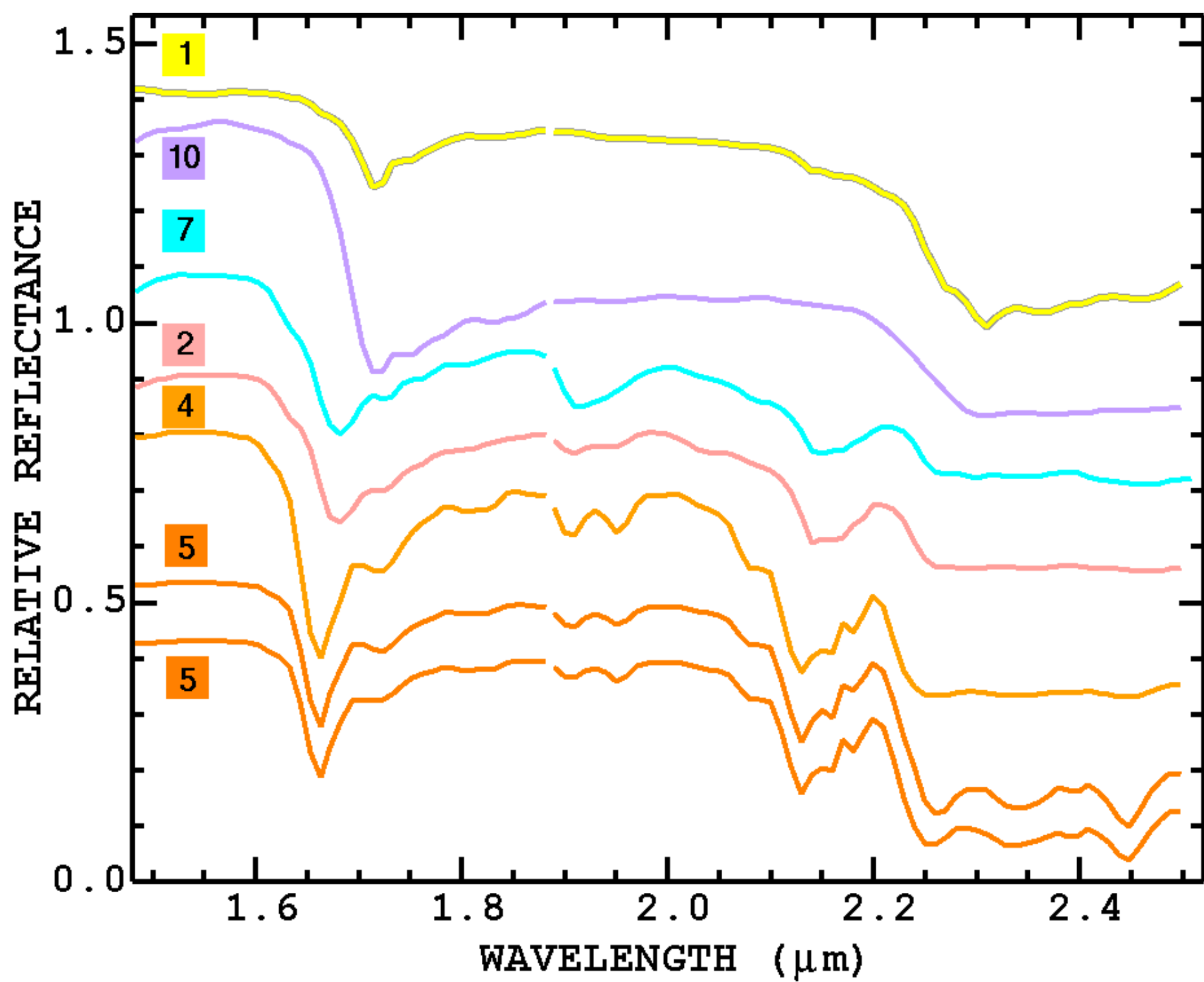


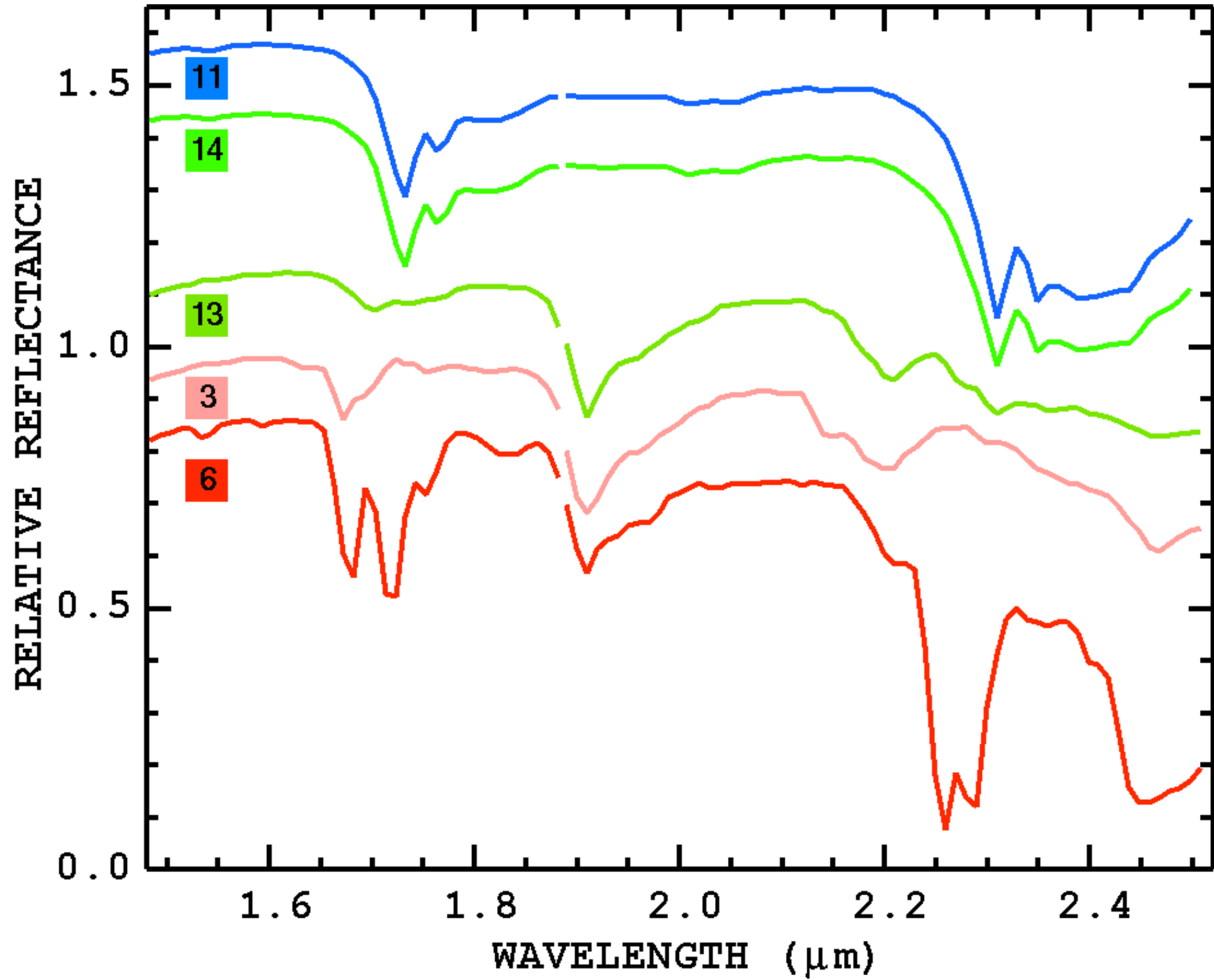
Image sampling:
1.7 meters/pixel



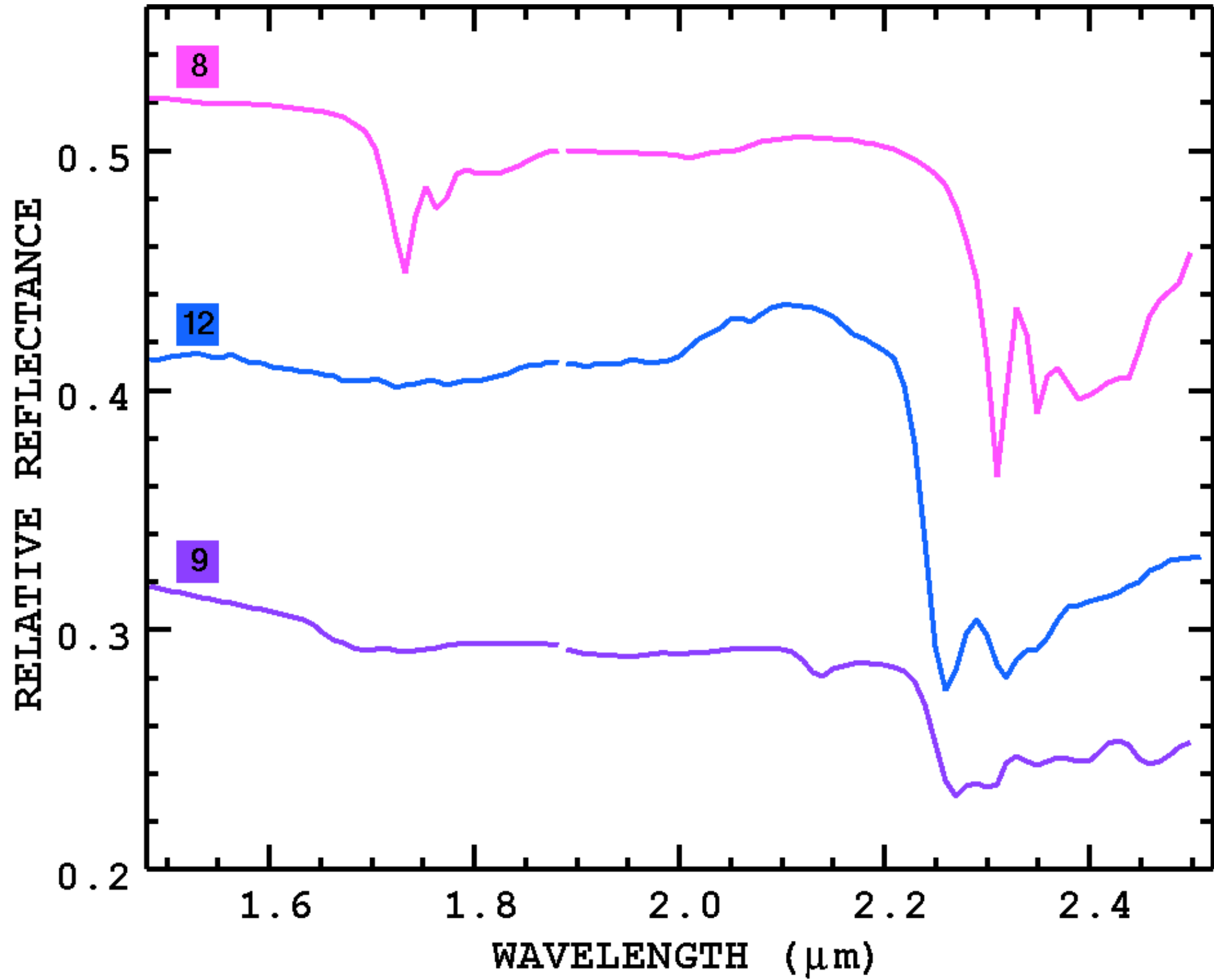




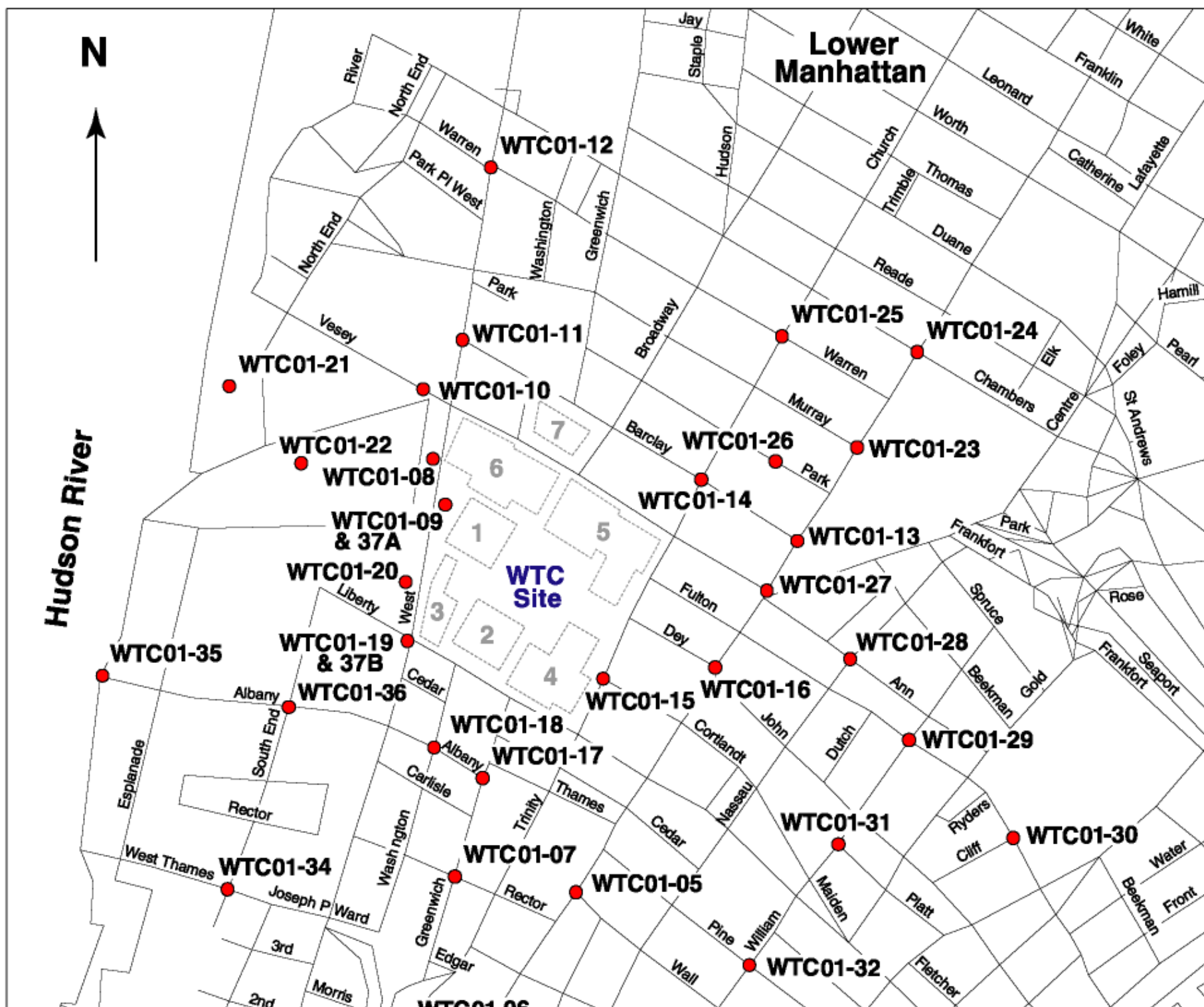
ALVAREZ (1991) (μm)

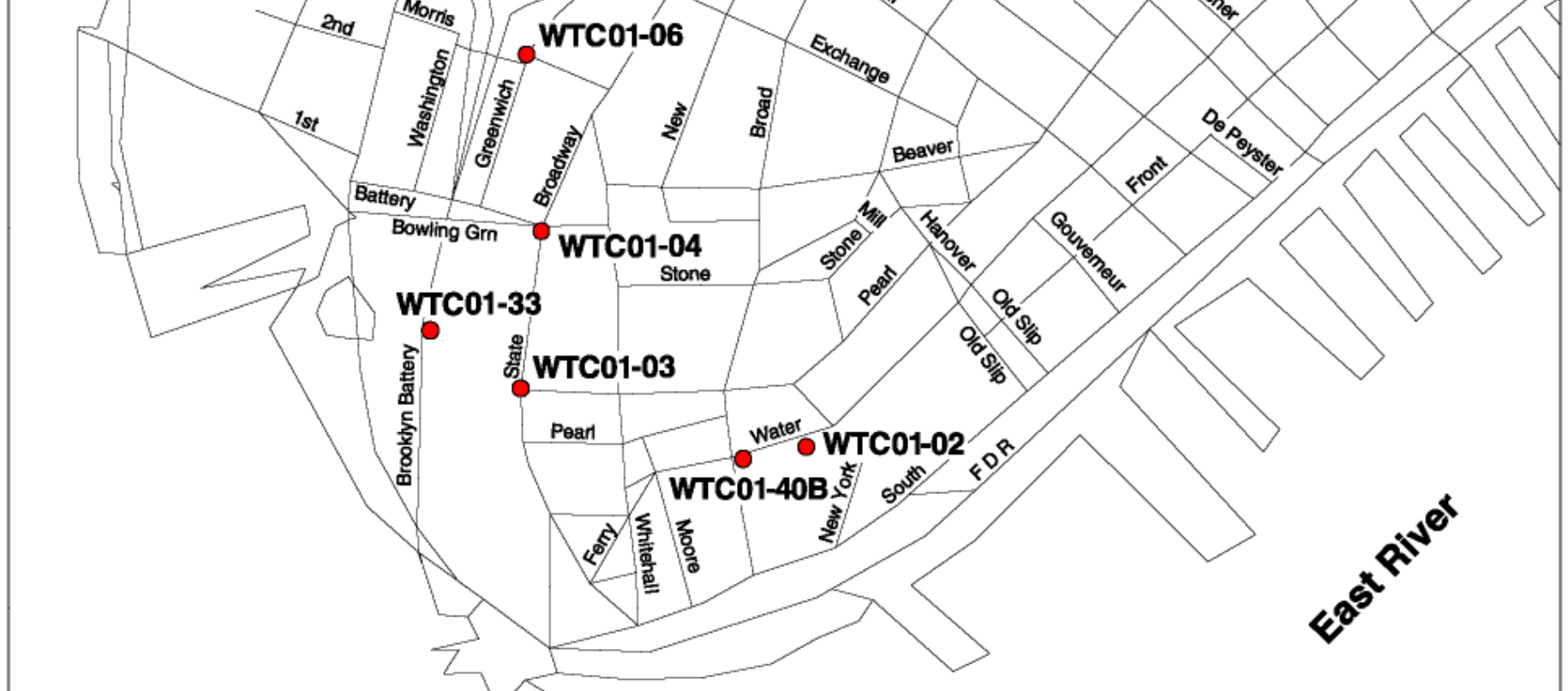


nitrobenzene (μm)



nitrobenzene (μm)





0 0.1 0.2 0.3 0.4
Kilometers

0 0.1 0.2 0.3 0.4
Miles

Base Map Source: 2000 U.S. Census
TIGER / Line Data for New York County



Chemistry Table 1. This Table summarizes data for major elements and all trace elements analyzed in the WTC dust and beam coating samples. Some elements (such as mercury and tin) were not analyzed in these samples. Major elements are listed in percent concentration and trace elements are listed in parts per million concentration. One percent equals 10,000 parts per million.

Chemistry Table 1					
	Outdoor dust samples				
	WTC 01-02	WTC 01-03	WTC01-05	WTC01-06	WTC 01-14
Silicon %	21.2	26.3	11.4	11.4	15.3
Calcium %	15.01	9.58	20.94	20.58	17.65
Magnesium %	3.11	2.23	2.73	2.73	2.83
Sulfur %	1.33	0.87	nm	nm	4.32
Iron %	4.13	2.16	1.41	1.42	1.87
Aluminum %	4.13	2.75	2.75	2.73	2.86
Carbon, organic %	0.98	3.55	nm	nm	3.08
Carbon, Carbonate %	1.24	1.63	nm	nm	1.46
Sodium %	0.82	0.76	0.50	0.50	0.59
Potassium %	0.63	0.69	0.46	0.47	0.56
Titanium %	0.39	0.25	0.24	0.24	0.31
Manganese %	0.15	0.08	0.10	0.10	0.12
Phosphorous %	0.03	0.05	0.03	0.03	0.02
Loss on Ignition %	7.96	13.6	19.6	19.6	18.1
Barium ppm	765	376	nm	nm	461
Strontium ppm	1000	409	nm	nm	643
Zinc ppm	2990	1200	nm	nm	1570
Lead ppm	710	176	nm	nm	276
Copper ppm	438	142	nm	nm	242

Cerium ppm	108	50.9	nm	nm	68.8
Yttrium ppm	58.9	30.2	nm	nm	46.5
Chromium ppm	224	98	nm	nm	116
Nickel ppm	88.4	30.8	nm	nm	28.6
Lanthanum ppm	51	25.8	nm	nm	34.8
Antimony ppm	52.1	26.3	nm	nm	40.2
Vanadium ppm	38.8	42.5	nm	nm	30.6
Molybdenum ppm	25.4	14.5	nm	nm	19.1
Lithium ppm	27.4	17.4	nm	nm	23.2
Thorium ppm	11.2	5.56	nm	nm	7.92
Rubidium ppm	21.2	23.7	nm	nm	25.2
Cobalt ppm	13.9	8.4	nm	nm	7.1
Niobium ppm	11	7.8	nm	nm	9.1
Scandium ppm	8.8	6.6	nm	nm	6.1
Uranium ppm	3.92	1.96	nm	nm	2.89
Cadmium ppm	7.3	3.2	nm	nm	3.4
Arsenic ppm	6.8	3.7	nm	nm	5.1
Gallium ppm	6	5.4	nm	nm	4.1
Beryllium ppm	3.7	2.2	nm	nm	2.9
Silver ppm	1.2	3.8	nm	nm	1.2
Cesium ppm	0.73	0.76	nm	nm	0.88
Bismuth ppm	0.5	0.68	nm	nm	0.56
Thallium ppm	0.1	0.13	nm	nm	0.11

nm - not measured; ppm - parts per million

Chemistry Table 1, continued					
	Outdoor dust samples, continued				
	WTC 01-15	WTC 01-16	WTC01-17	WTC 01-21	WTC 01-22
Silicon %	13.6	17.0	16.0	12.8	17.0
Calcium %	18.58	13.36	17.01	18.94	16.80
Magnesium %	2.64	1.79	2.06	2.68	2.77
Sulfur %	5.40	3.68	nm	5.10	3.70

Iron %	1.87	1.92	1.71	1.49	2.78
Aluminum %	2.59	2.27	2.30	2.73	2.78
Carbon, organic %	2.30	2.51	nm	4.02	2.55
Carbon, Carbonate %	1.48	1.47	nm	1.44	1.31
Sodium %	0.66	0.87	0.93	0.50	0.83
Potassium %	0.49	0.69	0.54	0.50	0.52
Titanium %	0.25	0.26	0.25	0.24	0.29
Manganese %	0.10	0.07	0.07	0.12	0.12
Phosphorous %	0.03	0.02	0.02	0.03	0.03
Loss on Ignition %	17.3	22.8	15.9	21.2	15.3
Barium ppm	405	3670	nm	460	452
Strontium ppm	736	3130	nm	787	710
Zinc ppm	1110	1410	nm	1500	1380
Lead ppm	152	208	nm	278	452
Copper ppm	367	307	nm	153	130
Cerium ppm	64.9	132	nm	77	72
Yttrium ppm	46.1	31.4	nm	54.5	47.6
Chromium ppm	129	95.2	nm	104	111
Nickel ppm	32.9	31.4	nm	31.2	30.6
Lanthanum ppm	32.7	69.9	nm	38.6	35.4
Antimony ppm	30.2	148	nm	33.1	27.5
Vanadium ppm	27.1	24.9	nm	27.9	29.7
Molybdenum ppm	12.1	10	nm	9	6.9
Lithium ppm	22.1	18	nm	23.3	23
Thorium ppm	7.3	5.36	nm	8.48	8.5
Rubidium ppm	21.6	21.6	nm	21	21.1
Cobalt ppm	6.5	6.5	nm	5.3	6.3
Niobium ppm	7.6	6.6	nm	9	9.2
Scandium ppm	5.9	4.4	nm	6.2	6.2
Uranium ppm	2.71	2.3	nm	3.16	3.09
Cadmium ppm	4	3	nm	4.6	3.8

Arsenic ppm	4	4.3	nm	3.6	6.6
Gallium ppm	3.9	4.3	nm	3.9	4
Beryllium ppm	2.4	1.8	nm	2.9	2.9
Silver ppm	1.4	1.5	nm	2.4	1.4
Cesium ppm	0.78	0.87	nm	0.76	0.76
Bismuth ppm	0.25	0.28	nm	0.5	0.43
Thallium ppm	0.11	0.12	nm	0.1	0.1

nm - not measured; ppm - parts per million

Chemistry Table 1, continued

	Outdoor dust samples, continued				
	WTC 01-25	WTC 01-27	WTC 01-28	WTC01-30	WTC01-34
Silicon %	13.2	15.2	13.8	15.1	12.2
Calcium %	20.37	19.51	19.65	19.73	20.51
Magnesium %	3.29	3.04	2.83	3.49	3.01
Sulfur %	4.03	4.29	4.56	nm	nm
Iron %	1.33	1.72	1.80	1.85	1.45
Aluminum %	3.28	3.05	2.95	3.59	2.98
Carbon, organic %	2.94	1.95	2.42	nm	nm
Carbon, Carbonate %	1.87	1.82	1.68	nm	nm
Sodium %	0.62	0.62	0.76	0.71	0.50
Potassium %	0.56	0.50	0.54	0.56	0.51
Titanium %	0.29	0.29	0.26	0.29	0.25
Manganese %	0.15	0.12	0.12	0.14	0.12
Phosphorous %	0.03	0.03	0.02	0.04	0.03
Loss on Ignition %	17.5	14.4	16.7	17.5	18.5
Barium ppm	624	470	491	nm	nm
Strontium ppm	695	701	711	nm	nm
Zinc ppm	1910	1650	1720	nm	nm
Lead ppm	756	204	234	nm	nm
Copper ppm	251	188	218	nm	nm

Cerium ppm	85	77.7	75	nm	nm
Yttrium ppm	61.6	54.9	53.8	nm	nm
Chromium ppm	134	126	106	nm	nm
Nickel ppm	39.2	39.4	26.1	nm	nm
Lanthanum ppm	43.5	39.5	38.4	nm	nm
Antimony ppm	65.8	50.4	51.8	nm	nm
Vanadium ppm	30.5	30	28.9	nm	nm
Molybdenum ppm	30.9	27.1	42	nm	nm
Lithium ppm	28.5	25.2	24.8	nm	nm
Thorium ppm	9.94	9.14	8.48	nm	nm
Rubidium ppm	24	21.7	22.5	nm	nm
Cobalt ppm	7.4	6.2	5.9	nm	nm
Niobium ppm	11	11	10	nm	nm
Scandium ppm	7.1	6.6	6.2	nm	nm
Uranium ppm	3.78	3.36	3.27	nm	nm
Cadmium ppm	7.5	5	5.2	nm	nm
Arsenic ppm	4.2	5	4.8	nm	nm
Gallium ppm	4.3	4.3	4.1	nm	nm
Beryllium ppm	3.6	3.2	3.1	nm	nm
Silver ppm	1.4	1.4	1.7	nm	nm
Cesium ppm	0.83	0.77	0.76	nm	nm
Bismuth ppm	0.67	0.4	0.48	nm	nm
Thallium ppm	0.1	0.09	0.11	nm	nm

nm - not measured; ppm - parts per million

Chemistry Table 1, continued

	Indoor dust samples		Girder coatings		
	WTC 01-20	WTC 01-36	WTC 01-08	WTC 01-09	
Silicon %	14.2	11.7	15.0	15.5	
Calcium %	19.44	21.30	20.73	26.01	
Magnesium %	2.59	2.88	6.94	3.23	
Sulfur %	5.51	5.77	1.39	1.23	

Iron %	1.25	1.38	1.25	0.55	
Aluminum %	2.55	2.86	2.92	3.56	
Carbon, organic %	2.68	2.32	2.48	2.45	
Carbon, Carbonate %	1.27	1.50	1.89	1.86	
Sodium %	1.16	0.58	0.12	0.16	
Potassium %	0.46	0.46	0.28	0.32	
Titanium %	0.25	0.23	0.21	0.28	
Manganese %	0.10	0.11	0.14	0.19	
Phosphorous %	0.02	0.02	0.01	0.01	
Loss on Ignition %	15.7	16.9	15.8	13	
Barium ppm	390	438	317	472	
Strontium ppm	706	823	444	378	
Zinc ppm	1330	1400	57.4	101	
Lead ppm	153	159	9.13	11.7	
Copper ppm	176	95	10.3	12.8	
Cerium ppm	61.6	70.2	202	356	
Yttrium ppm	44.1	52.6	134	243	
Chromium ppm	94	107	153	86.5	
Nickel ppm	29.8	28.5	202	22.6	
Lanthanum ppm	31.3	35.6	102	175	
Antimony ppm	38.9	33.9	0.56	1.2	
Vanadium ppm	25	28.6	30.5	40.1	
Molybdenum ppm	19	16.1	0.85	1.2	
Lithium ppm	21.9	24.9	25.2	36.4	
Thorium ppm	7.25	8.64	17.9	30.7	
Rubidium ppm	18.9	21.1	8	8.2	
Cobalt ppm	5	5.3	12.3	1.7	
Niobium ppm	8	9	4.4	6.3	
Scandium ppm	5.4	6.4	9.2	9.8	
Uranium ppm	2.7	3.23	4.72	7.57	
Cadmium ppm	4.2	5.8	0.11	0.21	

Arsenic ppm	3.5	3.8	< 2	< 2	
Gallium ppm	3.6	4	2.8	4.2	
Beryllium ppm	2.5	3.1	4	4.2	
Silver ppm	3.5	1.6	1.8	0.96	
Cesium ppm	0.72	0.78	0.18	0.22	
Bismuth ppm	0.64	0.82	0.008	0.01	
Thallium ppm	0.09	0.09	0.02	0.02	

nm - not measured; ppm - parts per million

Chemistry Table 1, continued					
	minimum	maximum	mean*		
Silicon %	11.4	26.3	14.8		
Calcium %	9.58	26.01	18.36		
Magnesium %	1.79	6.94	2.88		
Sulfur %	0.87	5.77	3.11		
Iron %	0.55	4.13	1.63		
Aluminum %	2.27	4.13	2.90		
Carbon, organic %	0.98	4.02	2.48		
Carbon, Carbonate %	1.24	1.89	1.55		
Sodium %	0.12	1.16	0.57		
Potassium %	0.28	0.69	0.50		
Titanium %	0.21	0.39	0.26		
Manganese %	0.07	0.19	0.11		
Phosphorous %	0.01	0.05	0.02		
Loss on Ignition %	7.96	22.8	16.35		
Barium ppm	317	3670	533.38		
Strontium ppm	378	3130	726.61		
Zinc ppm	57.4	2990	1004.70		
Lead ppm	9.13	756	166.75		
Copper ppm	10.3	438	136.31		
Cerium ppm	50.9	356	91.23		

Yttrium ppm	30.2	243	57.45		
Chromium ppm	86.5	224	116.61		
Nickel ppm	22.6	202	37.77		
Lanthanum ppm	25.8	175	45.96		
Antimony ppm	0.56	148	24.84		
Vanadium ppm	24.9	42.5	30.67		
Molybdenum ppm	0.85	42	11.34		
Lithium ppm	17.4	36.4	24.00		
Thorium ppm	5.36	30.7	9.31		
Rubidium ppm	8	25.2	19.01		
Cobalt ppm	1.7	13.9	6.36		
Niobium ppm	4.4	11	8.34		
Scandium ppm	4.4	9.8	6.63		
Uranium ppm	1.96	7.57	3.29		
Cadmium ppm	0.11	7.5	2.80		
Arsenic ppm	3.5	6.8	***		
Gallium ppm	2.8	6	4.15		
Beryllium ppm	1.8	4.2	2.96		
Silver ppm	0.96	3.8	1.66		
Cesium ppm	0.18	0.88	0.64		
Bismuth ppm	0.008	0.82	0.28		
Thallium ppm	0.02	0.13	0.08		

*Geometric mean for all parameters except pH; ***Geometric mean not calculated due to one or more samples having concentrations below detection limit; ppm - parts per million

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URL: <<http://pubs.usgs.gov/of/2001/ofr-01-0429/chem1/WTCchemistrytable.html>>

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Evaluation of World Trade Center dusts and girder coatings using a simulated precipitation leaching procedure

A subset of the loose dust samples and samples of material coating girders collected from around the World Trade Center was subjected to chemical leach tests to examine potential release of metals from the dusts and beam coatings. The USGS leach test is a modification of a test described in detail in Hageman and Briggs (2000). This leach test and the one developed by Hageman and Briggs (2000) are modifications of the US EPA 1312 (Synthetic Precipitation Leaching Procedure, or SPLP) method. The USGS tests were originally designed as a screening method to quickly assess potential metal release from mine wastes.

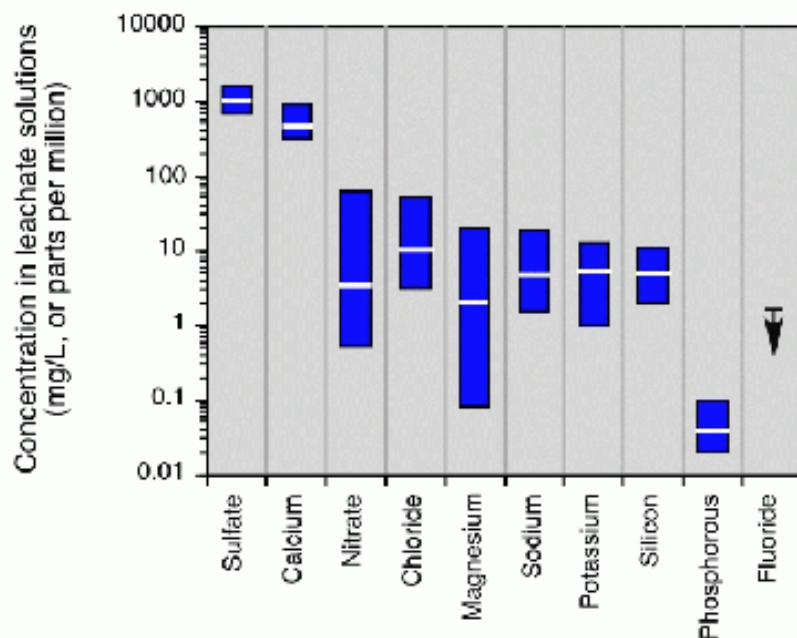
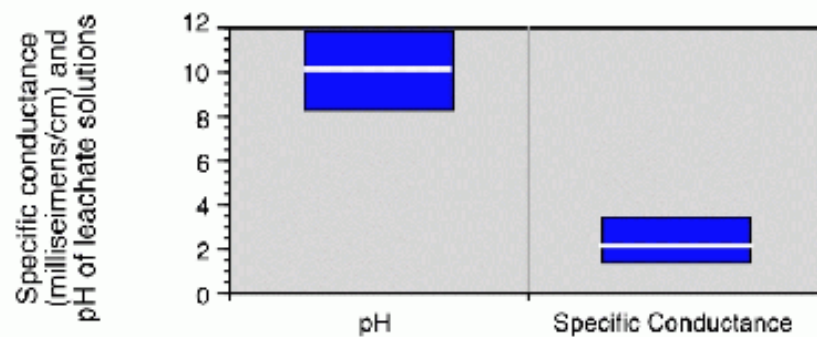
As applied to the materials from the World Trade Center, these leach tests can be used to infer the potential for release of various metals, anions, and cations from the dusts as a result of rainfall or interactions with water used in fire fighting or street washing. The test also provides an indication of metals that might be bioavailable should the dusts be inhaled, ingested, or discharged into ecosystems.

For this leach test, deionized (DI) water (pH ~5.5) is used as the extractant. Dust samples were leached at a 1:20 ratio (2.5 grams dust / 50 milliliters DI water). A representative subsample of each dust sample was weighed on a balance. Each dust sample was then placed in a 125 milliliter (ml) high-density polyethylene (HDPE) bottle to which 50.0 ml DI water was added. Each sample was then shaken for 5 minutes. Following shaking, the solution was allowed to settle for 5 minutes. Leachate solutions were then filtered using plastic syringes and 0.45 micrometer pore size nitrocellulose membrane filters. Sub-samples of the leachate were collected and preserved for further analysis.

The procedure uses deionized water as the extractant solution rather than the synthetic acid rain used in the EPA 1312 method. It also uses a 5 minute agitation rather than an 18-hour agitation. Hence, it is possible that the concentrations of soluble metals measured with this test would be less than those measured using EPA 1312 method. However, it is likely that the leach procedure used in this study successfully reveals the metals likely to be mobilized from the dusts and girder coatings. A comparative study between the EPA Method 1312 (SPLP) procedure and this simplified leach can be found in Hageman and Briggs (2000).

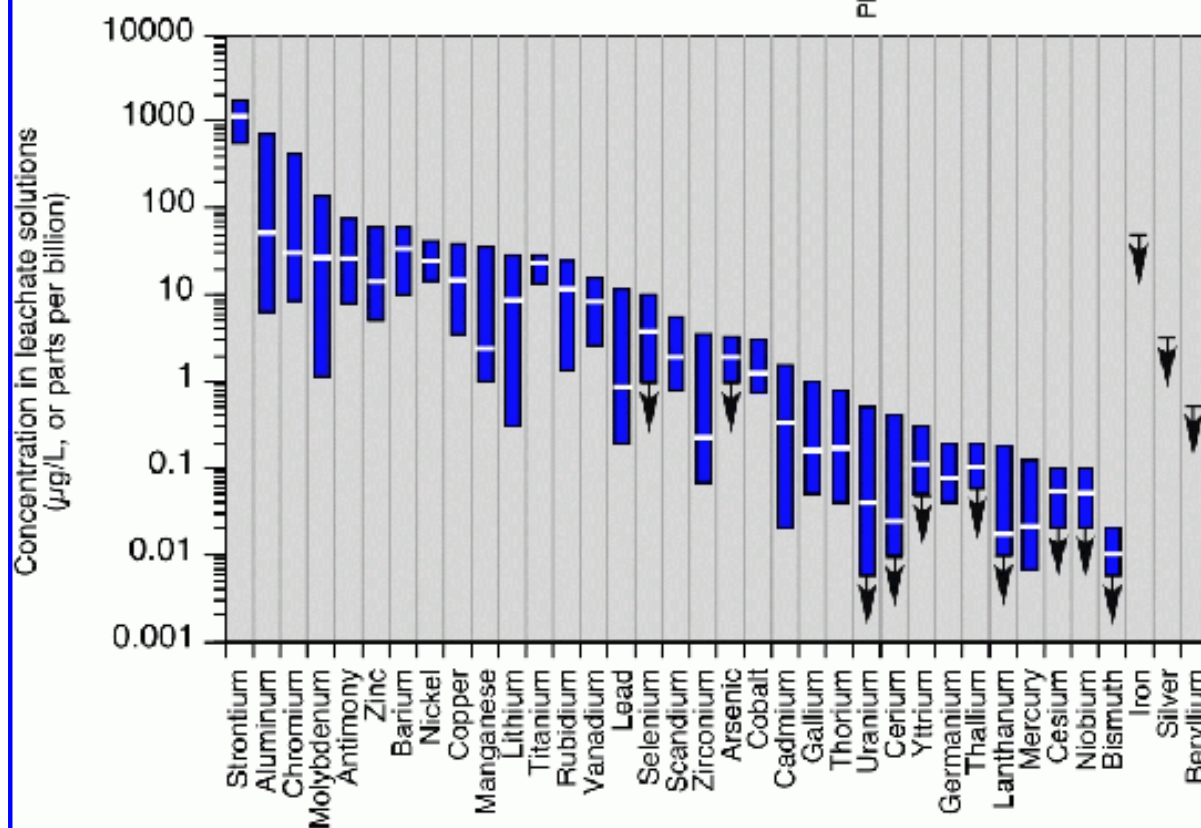
The leachate samples were analyzed for major cations and trace metals by Inductively-Coupled Plasma-Mass Spectrometry (ICP-MS) following the protocols outlined by Lamothe et al. (1999) and for anions by ion chromatography. The elements measured by the chemical analyses are those routinely measured by the USGS for studies of rocks, sediments, soils, and environmental samples.

Leachate solutions for a subset of the dust samples were also analyzed for dissolved mercury concentrations. For these samples, an aliquot was filtered using a syringe and disposable 0.45 micrometer pore size nitrocellulose filter, and then acidified and preserved by the addition of a 1 percent sodium dichromate/concentrated nitric acid solution in a ratio of 1:19 (one part sodium dichromate/nitric acid solution to 19 parts water sample). Leachate samples were stored in nitric acid-washed, flint glass bottles with Teflon lined lids. Samples were then analyzed for mercury using a Lachat QuikChem Mercury Analyzer with fluorescence detector. This method has a lower reporting limit of 5 part per trillion (ng/L). Quality assurance-quality control information for the process and the chemical analyses are available upon request.



Concentration range for leachate solution samples (white bar shows mean)

1 or more samples with concentration below the analytical detection limit, shown by the horizontal black bar



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[KB image](#)

Leach Figure 1. Plots showing the ranges (blue boxes) and means (horizontal white bars) in pH and specific conductance (upper plot), major cations and anions (middle plot), and trace elements (lower plot)

Leach Figure 2

Indoor samples

Girder coatings

Lower Manhattan

Hudson River

East River

WTC Site

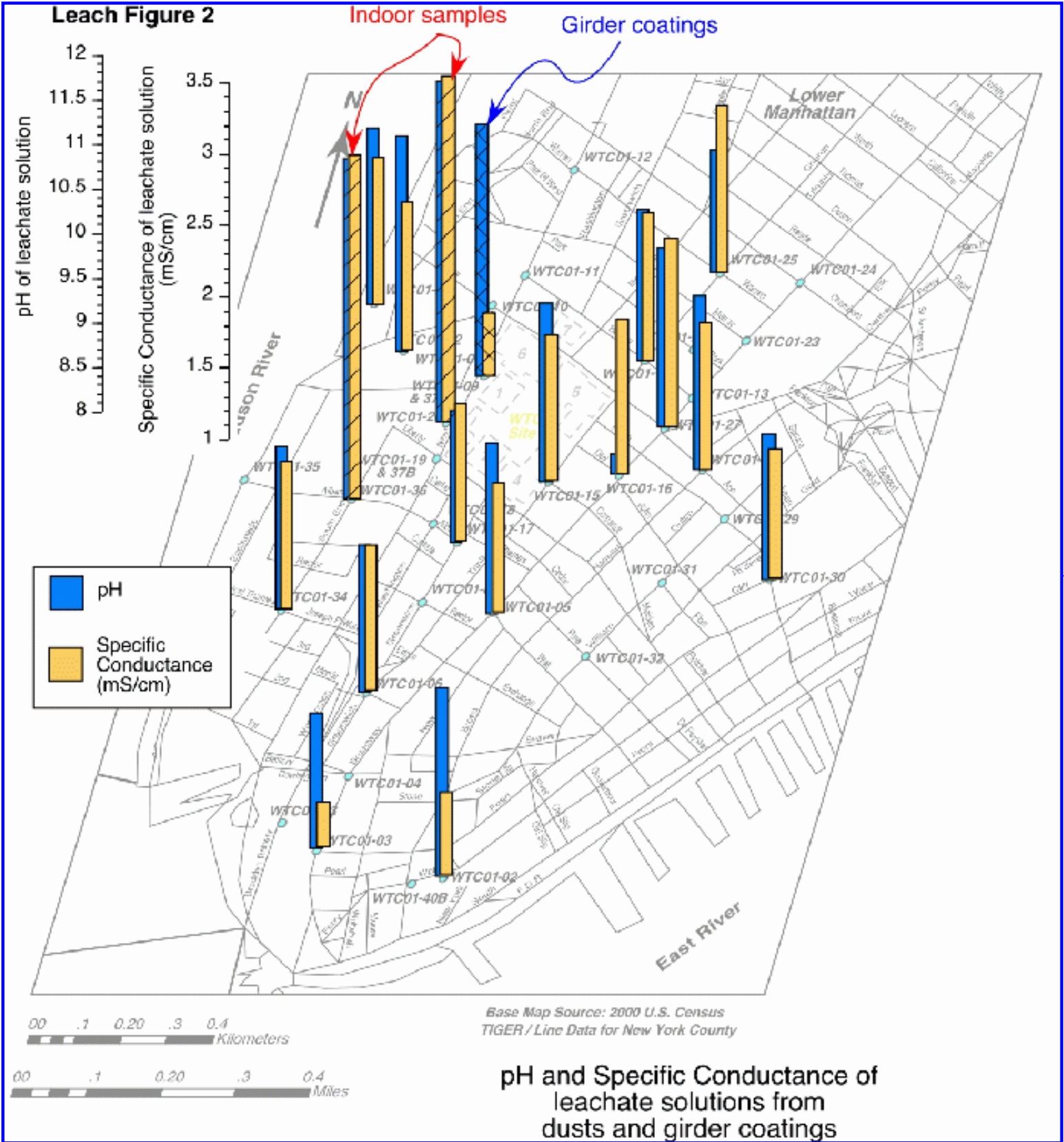
WTC01-01, **WTC01-02**, **WTC01-03**, **WTC01-04**, **WTC01-05**, **WTC01-06**, **WTC01-07**, **WTC01-08**, **WTC01-09**, **WTC01-10**, **WTC01-11**, **WTC01-12**, **WTC01-13**, **WTC01-14**, **WTC01-15**, **WTC01-16**, **WTC01-17**, **WTC01-18**, **WTC01-19 & 37B**, **WTC01-20**, **WTC01-21**, **WTC01-22**, **WTC01-23**, **WTC01-24**, **WTC01-25**, **WTC01-26**, **WTC01-27**, **WTC01-28**, **WTC01-29**, **WTC01-30**, **WTC01-31**, **WTC01-32**, **WTC01-33**, **WTC01-34**, **WTC01-35**

pH

Specific Conductance (mS/cm)

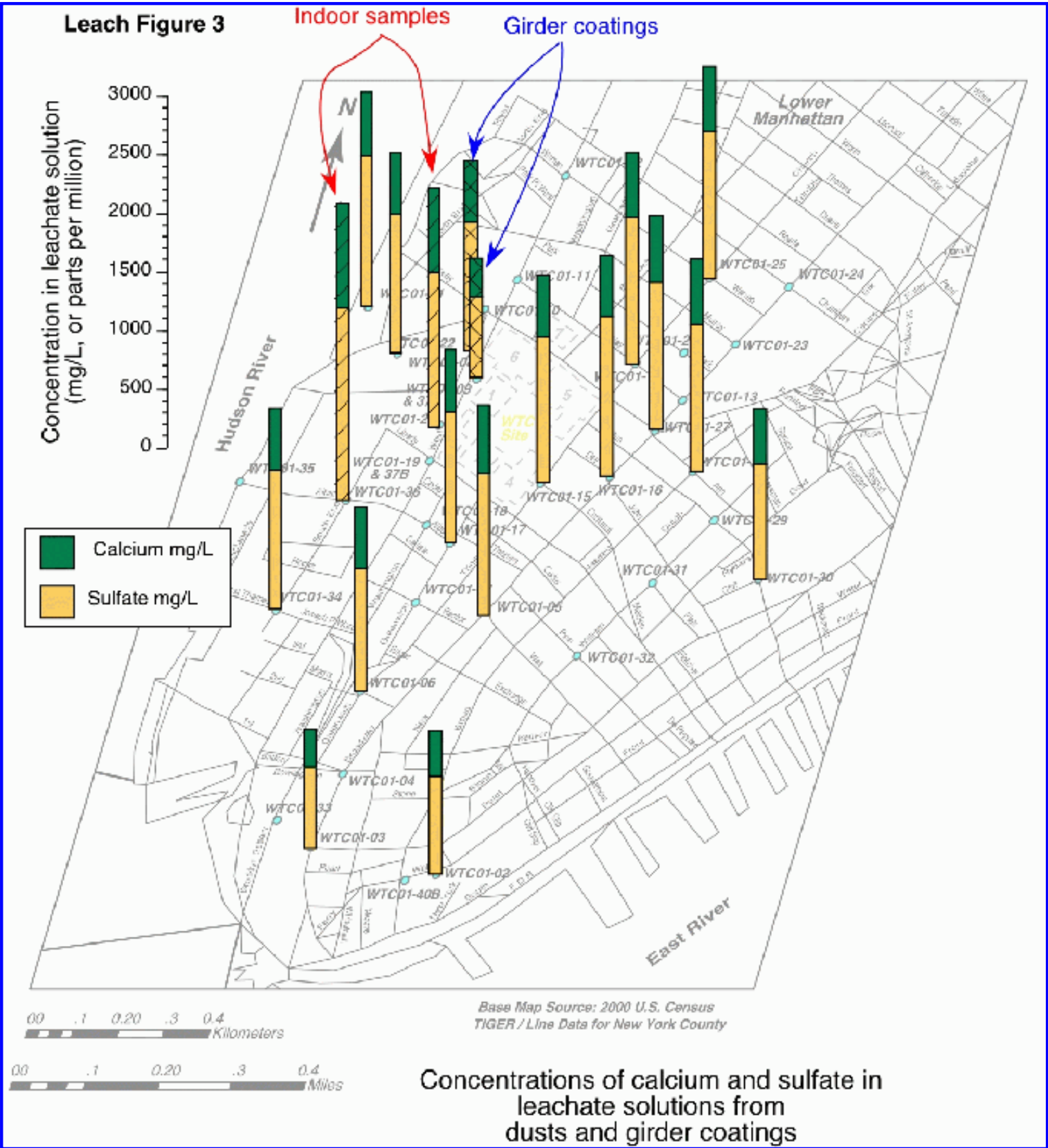
**Base Map Source: 2000 U.S. Census
TIGER/Line Data for New York County**

**pH and Specific Conductance of
leachate solutions from
dusts and girder coatings**



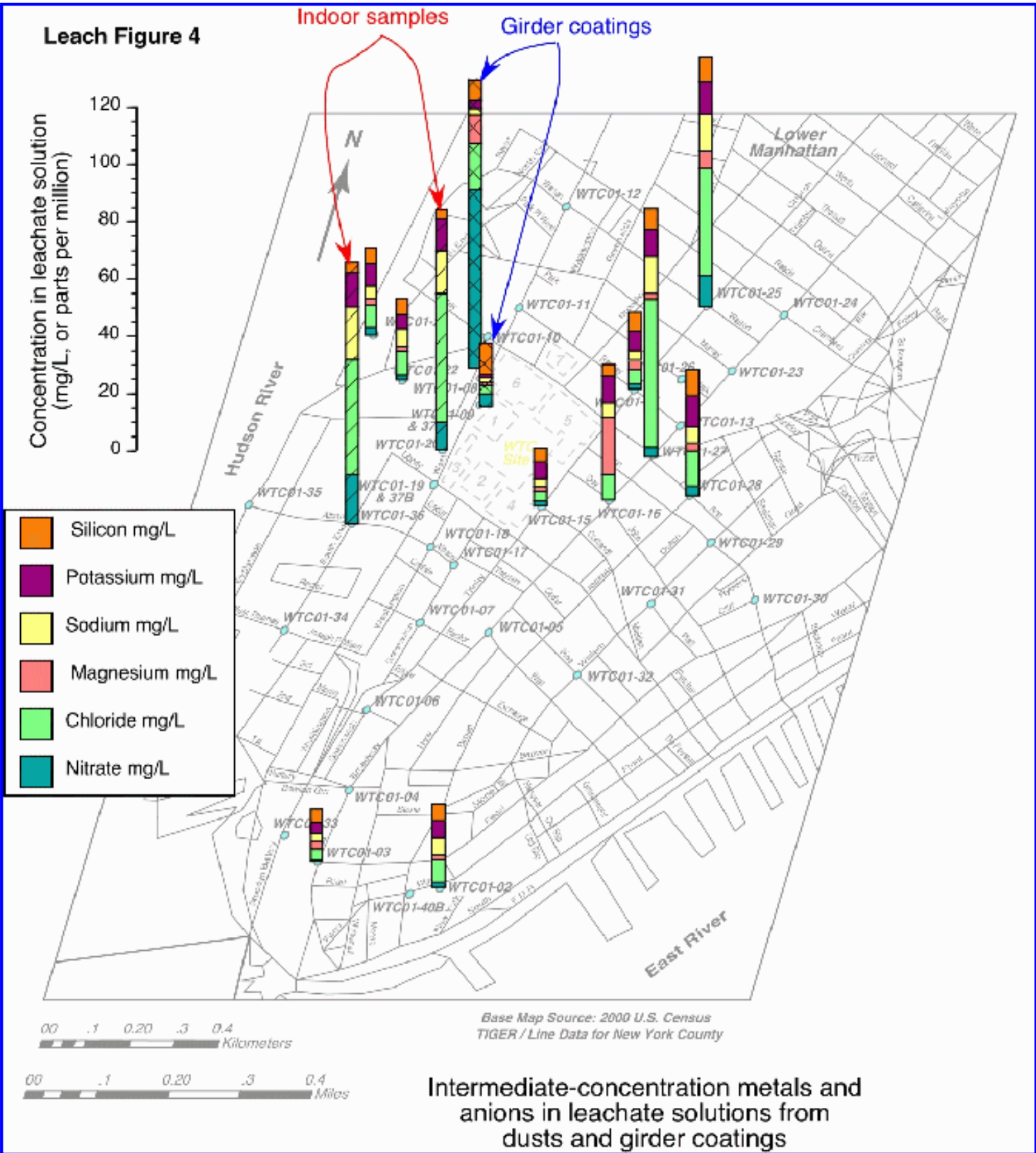
[Larger 207 KB image](#)

Leach Figure 2. Map of lower Manhattan showing variations in pH (blue columns) and specific conductance (yellow columns) of leachate solutions from the various dusts and girder coating samples. Dust samples collected indoors are indicated by the single hatch pattern and girder coating samples by the cross-hatch pattern; all others are dust samples collected outdoors.



[Larger 210 KB image](#)

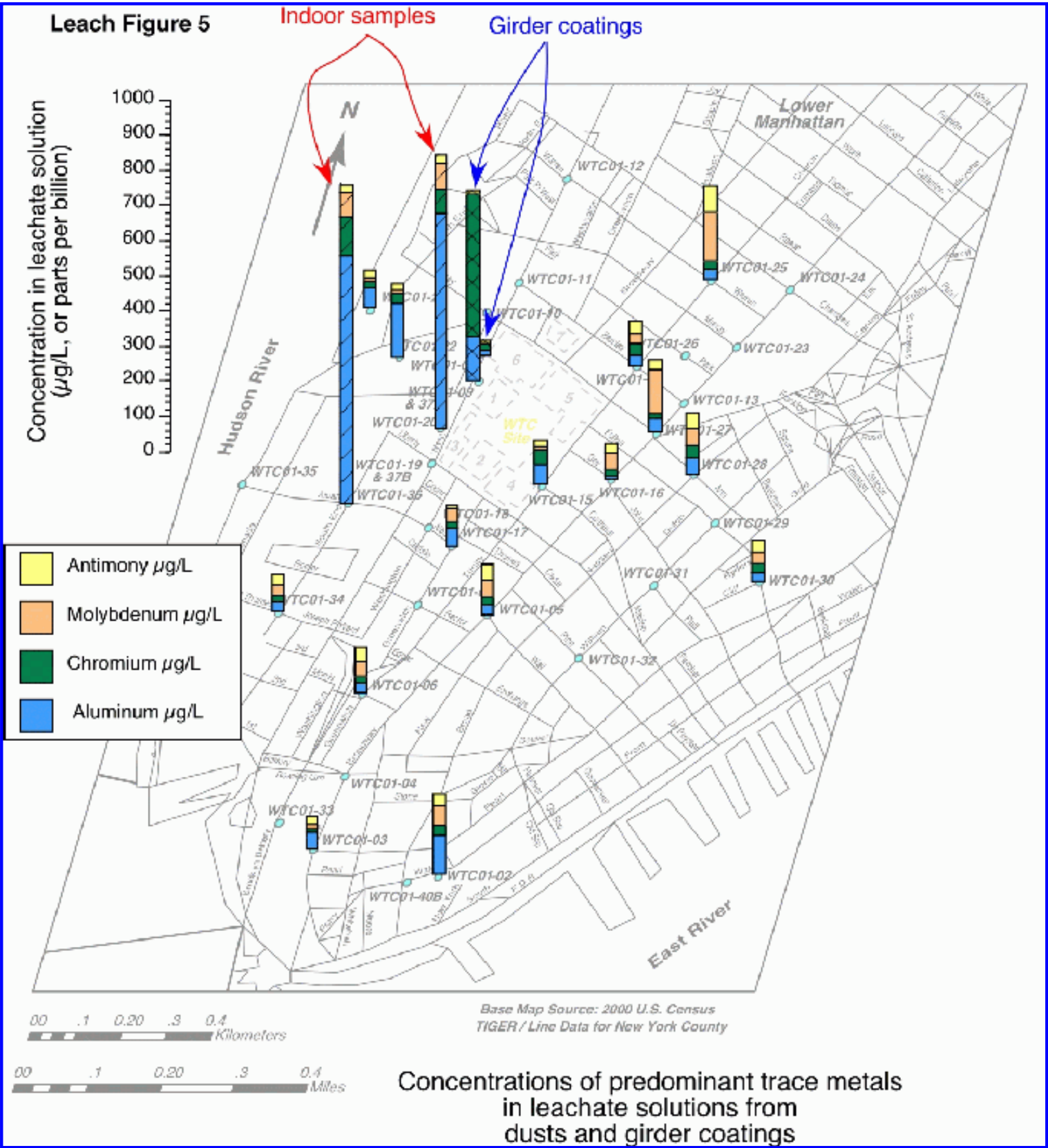
Leach Figure 3. Map of lower Manhattan showing variations (as stacked bar charts) in major cation and anion concentrations of leachate solutions derived from the various dusts and girder coating samples. Dust samples collected indoors are indicated by the single hatch pattern and girder coating samples by the cross-hatch pattern; all others are dust samples collected outdoors.



[Larger 202 KB image](#)

Leach Figure 4. Map of lower Manhattan showing variations (as stacked bar charts) of metals and anions

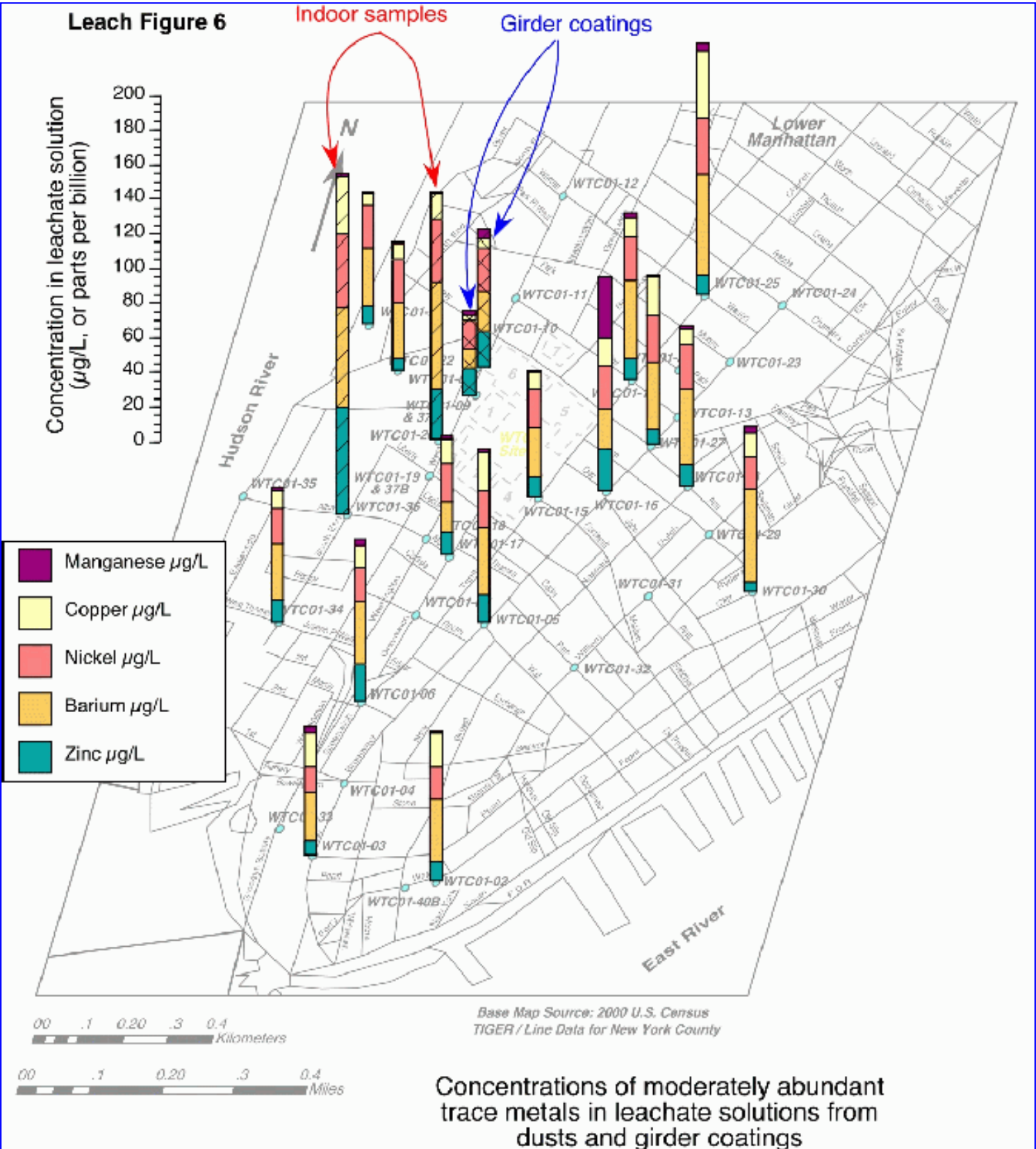
present in intermediate concentrations in leachate solutions derived from the various dusts and girder coating samples. Dust samples collected indoors are indicated by the single hatch pattern and girder coating samples by the cross-hatch pattern; all others are dust samples collected outdoors. Note changes in scale of the concentration axis of the plots between this figure and leach figures 2-6.



[Larger 206 KB image](#)

Leach Figure 5. Map of lower Manhattan showing variations (as stacked bar charts) in concentrations of

predominant trace metals and metalloids for leachate solutions derived from the various dusts and girder coating samples. Dust samples collected indoors are indicated by the single hatch pattern and girder coating samples by the cross-hatch pattern; all others are dust samples collected outdoors. Note changes in scale of the concentration axis of the plots between this figure and leach figures 2-6.



[Larger 214 KB image](#)

Leach Figure 6. Map of downtown Manhattan showing variations (as stacked bar charts) in

concentrations of less abundant trace metals and metalloids for leachate solutions derived from the various dusts and girder coating samples. Dust samples collected indoors are indicated by the single hatch pattern and girder coating samples by the cross-hatch pattern; all others are dust samples collected outdoors. Note changes in scale of the concentration axis of the plots between this figure and leach figures 2-5.

Results

Results of the leach tests are summarized in [Leach Table 1](#), and in Leach Figures 1-6. The metal concentrations summarized in Leach Table 1 may not represent truly dissolved material, because the nitrocellulose filter (0.45 micrometer pore size) used to filter the leachate fluids prior to analysis will not filter out metals present in very small particles or colloids.

Interpretation

In general, the leachate solutions developed moderately alkaline to alkaline pH values (8.2 - 11.8), and high specific conductances (1.31 - 3.41 milliSiemens/cm, indicating high dissolved solids). Alkalinities of the leachate solutions were not measured due to insufficient sample volume, but are by inference from the pH and specific conductances, likely to be quite high. The leachate solutions are composed primarily of sulfate, bicarbonate, carbonate, and calcium, with lesser concentrations of the major cations sodium, potassium, and magnesium.

The alkaline pH of the leach solutions, coupled with the high concentrations of calcium, carbonate, and sulfate, are consistent with an origin resulting primarily from the dissolution of concrete, glass fibers, gypsum, and other material in the dusts. The leach fluids with the highest pH and highest specific conductance are from dust samples collected indoors (including WTC01-20, collected indoors from the gymnasium across West Street from the World Trade Center, and WTC01-36, which was collected in a 30th-floor apartment in a building southwest of the WTC). The higher specific conductances and pH values of indoor dust samples indicate that the outdoor samples have already experienced some leaching by rainfall and water used for fighting fires and street cleaning between September 11 and the time that the samples were collected. Leach solutions from the indoor dust samples also contain slightly less sulfate, but greater calcium, than leach solutions from several outdoor dust samples (Leach Figure 2). This suggests that dissolution of concrete or glass fibers is greater in the indoor dusts than in the outdoor dusts, and is another indication that the outdoor dusts have already undergone some leaching by rainfall or wash waters.

Heavy metals and metalloids are present in low to quite high concentrations in many of the leach solutions ([Leach Table 1](#), Leach Figure 1). Mercury is present in generally low concentrations in the leachate solutions from outdoor dust samples (near 10 nanograms per liter, or parts per trillion). Mercury concentrations in leachate solutions from indoor dust samples (as high as 130 nanograms per liter), although low compared to concentrations of other metals in the leachate solutions, are relatively high compared to mercury concentrations measured in many types of environmental water samples. Arsenic, cobalt, cadmium, thorium, and uranium are present in relatively low concentrations in the leachate solutions (maximum concentrations of 3.3, 3.2, 1.6, 0.5, and 0.5 micrograms per liter, $\mu\text{g/L}$, respectively). Lead, selenium, and vanadium are present in moderate concentrations (maximum concentrations of 11.5, 10.5, and 16.1 $\mu\text{g/L}$, respectively). Metals or metalloids present in relatively high concentrations in the leachate solutions include (maximum concentrations listed in parentheses): aluminum (702 $\mu\text{g/L}$), chromium (403 $\mu\text{g/L}$), antimony (74 $\mu\text{g/L}$), molybdenum (140 $\mu\text{g/L}$), barium (62 $\mu\text{g/L}$), manganese (35 $\mu\text{g/L}$), copper (39 $\mu\text{g/L}$), and zinc (62 $\mu\text{g/L}$).

Of the various major and trace elements, aluminum is leached in greatest amounts from the indoor dust samples relative to outdoor dust samples. This indicates that the indoor dusts, in addition to having a greater proportion of reactive concrete, also contain some sort of reactive aluminum-bearing material. This material has presumably been partly to largely leached from the outdoor dusts by rain water and wash water.

Leachate solution from one of the beam coating samples (WTC01-09) contain unusually high amounts of chromium (408 $\mu\text{g/L}$). As noted in the SEM section, the mineralogy of this sample is generally similar to those of the dust samples in overall mineralogy. However, the source of the leachable chromium in the

material is currently unknown.

The source of the metals and metalloids in the leach solutions is unclear, but many components of the dust and debris are possible sources, including particles from concrete, aggregate, gypsum wallboard, glass fibers, construction steel, wiring, computer equipment, etc.

The results of the leach tests also show that metals are not leached from the dusts and beam coating samples in proportion to their total concentrations in the samples (compare concentrations in Leach Table 1 with those in Chemistry Table 1 from the previous section). For example, chromium, molybdenum, and antimony are leached in relatively high amounts from the samples, but occur in relatively low total concentrations in the samples. In part, these trace elements are likely being leached in greater proportions from the samples due to their enhanced solubilities in alkaline solutions. It is also possible that they are being leached more aggressively because they may occur in materials that are more readily dissolved in alkaline solutions. In contrast, iron, zinc and lead, which are relatively more abundant in the samples (Chemistry Table 1), are leached in proportionally quite low amounts from the samples (Leach Table 1). These metals are generally less mobile in alkaline solutions, and may also occur in materials that are not readily soluble in alkaline solutions.

Summary and potential environmental implications

Results of the leach tests indicate that the dusts released from the WTC collapse, when exposed rainwater or wash water, likely produce slightly alkaline to quite alkaline, calcium-sodium-potassium-sulfate-bicarbonate-carbonate solutions. At least some heavy metals and metalloids may be readily leached from the dusts: aluminum, chromium, antimony, molybdenum, and barium are generally leached in the greatest amounts, but other metals such as zinc, copper, manganese, titanium, vanadium, lead and mercury are also leached in measurable quantities. It is unclear if these heavy metals and metalloids may be leached in sufficient quantities to be of environmental or health concern. These results indicate that continued EPA monitoring of runoff water quality is warranted. Continued rainfall will likely continue to decrease the amounts of metals and alkalinity that can be released from the outdoor dusts.

The results of the leach tests also indicate that cleanup of dusts should be done with appropriate respiratory protection to prevent possible inhalation of alkaline material with potentially bioavailable heavy metals and metalloids. This is especially true for cleanup of dusts from indoor localities that have not been exposed to rainfall.

[NEXT Section of Report: Integration of Results and Conclusions](#)

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Leach Table 1. Table summarizing analytical results for solutions leached from WTC dust and beam coating samples. Details of the leach test methods are summarized in the text.

Leach Table 1					
	Outdoor dust samples				
	WTC-01-2	WTC-01-3	WTC-01-05	WTC-01-06	WTC-01-14
pH	10.1	9.51	9.9	9.65	9.68
Specific Conductance mS/cm	1.58	1.31	1.9	2.01	2.03
Chloride mg/L	7.8	3.7	nm	nm	5.1
Fluoride mg/L	<.8	<.8	nm	nm	<1.6
Nitrate mg/L	1.5	0.5	nm	nm	1.4
Calcium mg/L	388	314	577	523	544
Magnesium mg/L	1.75	2.83	3.2	3.65	3.52
Potassium mg/L	6	3.8	7.71	6.33	6.9
Silicon mg/L	5.8	4.5	8.1	5.9	6.4
Phosphorous mg/L	0.05	0.1	0.04	0.03	0.05
Sodium mg/L	6.1	2.84	7.69	5.76	3.05
Sulfate mg/L	834	694	1210	1040	1250
Aluminum µg/L	111	44.6	24.3	26	30.3
Antimony µg/L	33.1	22.9	46.3	42	35.9
Arsenic µg/L	1	1	< 3	< 3	1
Barium µg/L	36.5	28.4	38.3	36	45.1
Beryllium µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Bismuth µg/L	< 0.005	0.01	< 0.005	< 0.005	0.01
Cadmium µg/L	0.44	0.26	1.08	0.82	0.37

Cerium µg/L	< 0.01	0.03	0.02	0.02	0.01
Cesium µg/L	0.08	0.05	0.04	0.04	0.06
Chromium µg/L	25.9	9	25.1	18.2	31.4
Cobalt µg/L	1.23	0.72	1.04	1.02	1.15
Copper µg/L	19.2	19.8	22.4	13.5	11.4
Gallium µg/L	0.23	0.1	0.1	0.1	0.1
Germanium µg/L	0.07	0.09	0.1	0.08	0.07
Iron µg/L	< 50	< 50	< 50	< 50	< 50
Lanthanum µg/L	< 0.01	0.01	< 0.01	0.01	< 0.01
Lead µg/L	0.64	0.5	0.5	0.51	0.97
Lithium µg/L	11.2	4.1	11.2	9.4	9.8
Manganese µg/L	1	3.2	2	3.8	2.3
Mercury ng/L	nm	nm	18	7	nm
Molybdenum µg/L	56.8	14	45.7	42.2	30.8
Nickel µg/L	18.1	14.4	21.4	19.4	25.2
Niobium µg/L	< 0.02	0.03	0.1	0.1	0.02
Rubidium µg/L	12.6	8.08	12.4	12.9	14.1
Scandium µg/L	1.8	1.3	2.2	1.9	1.9
Selenium µg/L	2.5	1	< 5	< 5	1.9
Silver µg/L	< 3	< 3	nm	nm	< 3
Strontium µg/L	834	561	1150	1100	1230
Thallium µg/L	< 0.05	< 0.05	0.2	0.06	< 0.05
Thorium µg/L	0.04	0.09	0.8	0.37	0.06
Titanium µg/L	17.9	13.4	18.9	18.7	25.7
Uranium µg/L	0.03	0.15	0.08	0.09	0.06
Vanadium µg/L	6.2	6	11.8	8.8	9.7
Yttrium µg/L	< 0.01	< 0.01	0.08	0.08	0.11
Zinc µg/L	10.7	7.7	15.6	20.9	11.6
Zirconium µg/L	0.07	0.1	0.5	0.3	0.08

nm - not measured; ppm - parts per million; mg/L - milligrams per liter; µg/L - micrograms per liter; ng/L - nanograms per liter; mS/cm - milliSiemens per centimeter

Leach Table 1, continued

	Outdoor dust samples, continued				
	WTC-01-15	WTC-01-16	WTC-01-17	WTC-01-21	WTC-01-22
pH	10	8.22	9.47	9.98	10.4
Specific Conductance mS/cm	2.01	2.08	1.96	2.02	2.02
Chloride mg/L	3.4	8.5	nm	7.8	8.1
Fluoride mg/L	<1.6	<1.6	nm	<1.6	<1.6
Nitrate mg/L	1.5	<1.6	nm	2.4	1.5
Calcium mg/L	528	526	517	549	529
Magnesium mg/L	1.71	20.2	2.54	2.61	2.12
Potassium mg/L	5.9	9.2	4.83	7.7	5.2
Silicon mg/L	4.9	4.3	2	5.8	5.4
Phosphorous mg/L	0.02	0.03	< 0.01	0.04	0.05
Sodium mg/L	2.65	5.09	4.81	4.11	5.69
Sulfate mg/L	1230	1350	1110	1270	1170
Aluminum µg/L	53.9	6.33	50.6	53.6	153
Antimony µg/L	15.3	28.6	11.2	21.2	17
Arsenic µg/L	< 1	2	< 3	1	< 1
Barium µg/L	28.9	23.2	17.5	33.9	32.2
Beryllium µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Bismuth µg/L	0.01	0.01	< 0.005	0.006	0.01
Cadmium µg/L	0.55	0.39	0.47	0.25	0.16
Cerium µg/L	0.01	0.02	0.02	0.01	0.02
Cesium µg/L	0.05	0.05	0.03	0.06	0.05
Chromium µg/L	42	20.8	17.4	19.3	27.7
Cobalt µg/L	1.02	1.29	1.04	1.16	0.98
Copper µg/L	10.2	15.6	14.4	6.2	9.6
Gallium µg/L	0.1	0.05	0.08	0.2	0.27
Germanium µg/L	0.06	0.1	0.05	0.05	0.04
Iron µg/L	< 50	< 50	< 50	< 50	< 50

Lanthanum µg/L	< 0.01	0.01	< 0.01	< 0.01	< 0.01
Lead µg/L	1.5	0.4	0.3	1.1	0.68
Lithium µg/L	6.4	11.2	6.9	7.4	7.8
Manganese µg/L	1.2	35.1	1.7	1.4	1
Mercury ng/L	nm	nm	8	nm	nm
Molybdenum µg/L	10.6	46.3	35.5	10.7	7.42
Nickel µg/L	22.2	25	21.9	24.6	24.8
Niobium µg/L	0.02	0.02	0.07	0.04	0.04
Rubidium µg/L	12.4	14.1	8.91	14.1	10
Scandium µg/L	1.5	1.2	0.8	1.7	1.5
Selenium µg/L	< 1	3	< 5	2.2	1.6
Silver µg/L	< 3	< 3	nm	< 3	< 3
Strontium µg/L	1060	999	1000	1020	943
Thallium µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Thorium µg/L	0.06	0.24	0.2	0.1	0.17
Titanium µg/L	24.8	25.1	19.4	25.9	24
Uranium µg/L	0.03	0.52	0.01	0.02	0.02
Vanadium µg/L	6.6	6.5	2.7	8	5.5
Yttrium µg/L	0.1	0.1	0.05	0.1	0.07
Zinc µg/L	10.6	24.1	12.7	9.6	6.5
Zirconium µg/L	0.2	0.2	0.09	0.2	0.2

nm - not measured; ppm - parts per million; mg/L - milligrams per liter; µg/L - micrograms per liter; ng/L - nanograms per liter; mS/cm - milliSiemens per centimeter

Leach Table 1, continued

	Outdoor dust samples, continued				
	WTC-01-25	WTC-01-27	WTC-01-28	WTC-01-30	WTC-01-34
pH	9.37	10	9.93	9.63	9.8
Specific Conductance mS/cm	2.16	2.31	2.02	1.9	2.02
Chloride mg/L	37	52	12	nm	nm

Fluoride mg/L	<1.6	<1.6	<1.6	nm	nm
Nitrate mg/L	11	3	3.2	nm	nm
Calcium mg/L	558	568	553	461	524
Magnesium mg/L	6.15	2.01	2.85	5.27	3.2
Potassium mg/L	11.7	9.7	11.3	3.22	5.06
Silicon mg/L	8.1	7.2	8.6	5	4.2
Phosphorous mg/L	0.06	0.04	0.04	0.02	0.02
Sodium mg/L	12.9	12.7	5.57	4.28	2.76
Sulfate mg/L	1240	1240	1250	986	1180
Aluminum µg/L	23.8	33.4	45	22.6	27.8
Antimony µg/L	73.6	25.5	43.6	35.5	33.5
Arsenic µg/L	3.2	3	2	< 3	< 3
Barium µg/L	58.4	38.6	43.5	53.9	32.4
Beryllium µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Bismuth µg/L	0.01	0.01	0.007	< 0.005	< 0.005
Cadmium µg/L	1.56	0.38	0.54	1.06	1.04
Cerium µg/L	0.02	0.02	0.02	0.02	0.02
Cesium µg/L	0.08	0.05	0.1	0.04	0.03
Chromium µg/L	24.4	15.7	34.5	26.1	16.2
Cobalt µg/L	3.18	1.17	1.25	0.72	0.87
Copper µg/L	39	21.5	9	14	10.6
Gallium µg/L	0.1	0.2	0.2	0.1	0.1
Germanium µg/L	0.2	0.05	0.08	0.09	0.08
Iron µg/L	< 50	< 50	< 50	< 50	< 50
Lanthanum µg/L	0.01	< 0.01	0.02	0.01	< 0.01
Lead µg/L	11.5	0.4	0.83	0.2	0.5
Lithium µg/L	29.7	24.3	11.2	9.6	7.9
Manganese µg/L	4.9	1	2	3.3	1.8
Mercury ng/L	nm	nm	nm	12	10
Molybdenum µg/L	140	126	50.4	30.6	27.9
Nickel µg/L	32.1	27	25.9	18.1	20.7
Niobium µg/L	0.03	0.06	0.03	0.07	0.06

Rubidium µg/L	19.3	14.9	25	9.26	10.8
Scandium µg/L	2.2	2.1	2.5	1.6	1.4
Selenium µg/L	7.4	8.8	3.5	< 5	< 5
Silver µg/L	< 3	< 3	< 3	nm	nm
Strontium µg/L	1240	1440	1160	1540	1070
Thallium µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Thorium µg/L	0.13	0.16	0.08	0.12	0.1
Titanium µg/L	25.5	25	26.3	16.5	18.9
Uranium µg/L	0.13	0.008	0.04	0.09	0.03
Vanadium µg/L	13.2	16.1	12.2	7.2	7
Yttrium µg/L	0.11	0.09	0.12	0.08	0.07
Zinc µg/L	11	8.4	12.1	5.3	12.2
Zirconium µg/L	0.2	0.2	0.2	0.2	0.1

nm - not measured; ppm - parts per million; mg/L - milligrams per liter; µg/L - micrograms per liter; ng/L - nanograms per liter; mS/cm - milliSiemens per centimeter

Leach Table 1, continued

	Indoor dust samples		Girder coatings		
	WTC-01-20	WTC-01-36	WTC-01-8	WTC-01-9	
pH	11.8	11.8	INS	10.8	
Specific Conductance mS/cm	3.41	3.4	INS	1.43	
Chloride mg/L	45	40	16	3	
Fluoride mg/L	<1.6	<1.6	<.8	<.8	
Nitrate mg/L	9.1	17	62	4.1	
Calcium mg/L	718	888	528	336	
Magnesium mg/L	0.11	0.08	10.3	1.1	
Potassium mg/L	10.9	12.3	3	1	
Silicon mg/L	3.4	3.2	6.7	11.3	
Phosphorous mg/L	0.09	0.09	< 0.01	< 0.01	
Sodium mg/L	15.3	18.3	2.1	1.54	

Sulfate mg/L	1320	1640	1090	674	
Aluminum µg/L	611	702	10.8	121	
Antimony µg/L	20.8	17.1	8.72	7.97	
Arsenic µg/L	3.3	3.3	< 3	< 3	
Barium µg/L	61.7	57.2	22.8	10.4	
Beryllium µg/L	< 0.05	< 0.05	< 0.05	< 0.05	
Bismuth µg/L	0.02	< 0.005	< 0.005	< 0.005	
Cadmium µg/L	0.18	0.18	0.02	0.02	
Cerium µg/L	< 0.01	0.01	0.26	0.4	
Cesium µg/L	0.09	0.08	0.02	< 0.01	
Chromium µg/L	69.4	109	18	408	
Cobalt µg/L	1.84	2.21	1.27	0.75	
Copper µg/L	15.1	33.6	5.6	3.5	
Gallium µg/L	0.59	0.97	0.08	0.38	
Germanium µg/L	0.05	0.07	0.1	< 0.02	
Iron µg/L	< 50	< 50	< 50	< 50	
Lanthanum µg/L	0.01	0.01	0.05	0.18	
Lead µg/L	5.8	10.9	0.4	0.3	
Lithium µg/L	18.5	19.5	1.3	0.3	
Manganese µg/L	1.3	1.7	5.5	2.1	
Mercury ng/L	130	125			
Molybdenum µg/L	73.8	72.9	1.74	1.18	
Nickel µg/L	36.2	42.6	24.9	16.6	
Niobium µg/L	0.08	0.05	0.08	< 0.02	
Rubidium µg/L	17.7	20.8	3.54	1.35	
Scandium µg/L	1.2	2.1	3.6	5.5	
Selenium µg/L	10.5	10.3	< 5	< 5	
Silver µg/L	< 3	< 3	< 3	< 3	
Strontium µg/L	1420	1690	990	758	
Thallium µg/L	0.08	< 0.05	< 0.05	< 0.05	
Thorium µg/L	0.51	0.38	0.52	0.18	
Titanium µg/L	25.5	28.4	24.9	15.3	

Uranium µg/L	0.01	< 0.005	0.02	0.006	
Vanadium µg/L	6.5	7.8	13.8	14.4	
Yttrium µg/L	0.13	0.16	0.31	0.27	
Zinc µg/L	28.4	61.8	20.1	15.8	
Zirconium µg/L	0.4	0.4	3.7	0.2	

nm - not measured; ppm - parts per million; mg/L - milligrams per liter; µg/L - micrograms per liter; ng/L - nanograms per liter; mS/cm - milliSiemens per centimeter

Leach Table 1, continued

	minimum	maximum	mean*		
pH	8.22	11.8	10.00		
Specific Conductance mS/cm	1.31	3.41	2.03		
Chloride mg/L	3	52	11.27		
Fluoride mg/L	<1.6	<1.6	***		
Nitrate mg/L	0.5	62	3.69		
Calcium mg/L	314	888	519.83		
Magnesium mg/L	0.08	20.2	2.27		
Potassium mg/L	1	12.3	6.03		
Silicon mg/L	2	11.3	5.43		
Phosphorous mg/L	0.02	0.1	0.04		
Sodium mg/L	1.54	18.3	5.16		
Sulfate mg/L	674	1640	1121.72		
Aluminum µg/L	6.33	702	49.68		
Antimony µg/L	7.97	73.6	24.37		
Arsenic µg/L	1	3.3	1.83		
Barium µg/L	10.4	61.7	33.90		
Beryllium µg/L	< 0.05	< 0.05	***		
Bismuth µg/L	0.006	0.02	0.01		
Cadmium µg/L	0.02	1.56	0.33		
Cerium µg/L	0.01	0.4	0.02		
Cesium µg/L	0.02	0.1	0.05		

Chromium µg/L	9	408	29.50		
Cobalt µg/L	0.72	3.18	1.17		
Copper µg/L	3.5	39	13.21		
Gallium µg/L	0.05	0.97	0.15		
Germanium µg/L	0.04	0.2	0.07		
Iron µg/L	<50	<50	***		
Lanthanum µg/L	0.01	0.18	0.02		
Lead µg/L	0.2	11.5	0.83		
Lithium µg/L	0.3	29.7	7.91		
Manganese µg/L	1	35.1	2.31		
Mercury ng/L	7	130	21.26		
Molybdenum µg/L	1.18	140	25.54		
Nickel µg/L	14.4	42.6	23.46		
Niobium µg/L	0.02	0.1	0.05		
Rubidium µg/L	1.35	25	11.02		
Scandium µg/L	0.8	5.5	1.82		
Selenium µg/L	1	10.5	3.58		
Silver µg/L	< 3	< 3	***		
Strontium µg/L	561	1690	1083.10		
Thallium µg/L	0.06	0.2	0.10		
Thorium µg/L	0.04	0.8	0.16		
Titanium µg/L	13.4	28.4	21.65		
Uranium µg/L	0.006	0.52	0.04		
Vanadium µg/L	2.7	16.1	8.24		
Yttrium µg/L	0.05	0.31	0.11		
Zinc µg/L	5.3	61.8	13.38		
Zirconium µg/L	0.07	3.7	0.22		

*Geometric mean for all parameters except pH; ***Geometric mean not calculated due to one or more samples having concentrations below detection limit; nm - not measured; ppm - parts per million; mg/L - milligrams per liter; µg/L - micrograms per liter;

ng/L - nanograms per liter; mS/cm - milliSiemens per centimeter

ins - insufficient leachate solution volume to measure pH and conductivity

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OFR 01-0429: World Trade Center USGS Integration of Results and Conclusions

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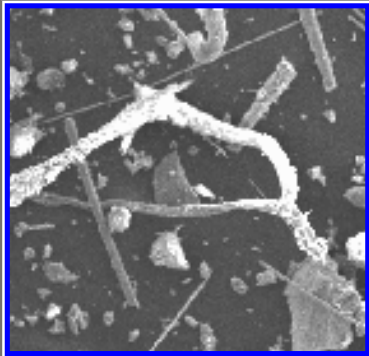
The results of analyses completed so far show a consistent picture: the samples are largely composed of gypsum, cellulose, and miscellaneous materials common in a building, with minor asbestiform minerals. However, one sample analyzed, the coating on a steel beam, indicates the presence of a significant abundance of chrysotile asbestos (as much as 20% by volume). The confirmed abundant chrysotile sample and the potential pockets of chrysotile indicated in the AVIRIS mineral maps indicates that asbestos can be found in localized concentrations. Thus, appropriate precautions should be taken when handling debris, especially coatings on metal beams.

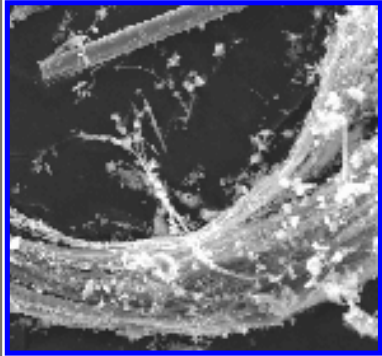
Sample results are summarized in Table 1, below. To see the full resolution SEM image and description, click on the image in the table. In the spectroscopy column in the table below, CH indicates organic compounds, including paints and plastics. Fe²⁺ indicates minerals or materials containing ferrous iron. Amounts are qualitative and indicate (from low to high) trace as (tr), weak as (wk), and strong as (str). No indication indicates between weak and strong.

The composition of samples collected in the WTC area, as indicated by spectroscopy, XRD, SEM, and from the visual examination during splitting of the samples, show similarities, yet each sample shows differences. Thus, while the samples appear to be a "grey dust", the data indicate the dust was not well mixed. The sample analyses and the AVIRIS mapping results agree in this regard.

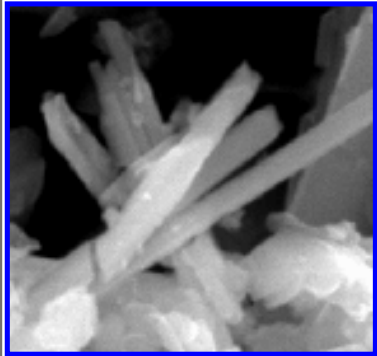
Table 1

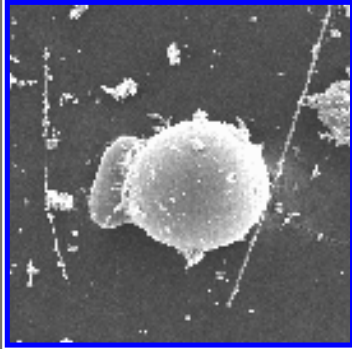
Sample Number	Spectroscopy	XRD	SEM	Leach pH	Location
WTC01-01 (calibration)					asphalt from NJ
WTC01-02	gypsum, muscovite (tr), CH, Fe ²⁺	Quartz - Minor Calcite - Minor Gypsum - Minor Dolomite - Trace Anhydrite - Trace Orthoclase - Trace *Major amorphous material		10.1	Water & Vietnam Vet. Plaza 4506052N 583559E

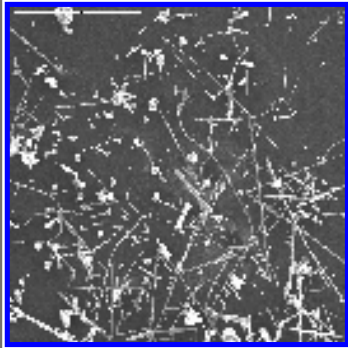
WTC01-03	gypsum, muscovite (tr), CH, Fe ²⁺ (wk)	Quartz - Major Gypsum - Minor Calcite - Minor Anhydrite - Trace *Major amorphous material		9.51	Battery Park, east central 4506123N 583217E drainage disc
WTC01-04	gypsum, muscovite and/or portlandite (tr), CH, Fe ²⁺ (wk)	Calcite - Major Gypsum - Minor Anhydrite - Minor Quartz - Trace Muscovite - Trace Microcline - Trace *Major amorphous material			Battery Park, NE end 4506284N 583233E
WTC01-05	gypsum, muscovite and/or portlandite (tr), CH, Fe ²⁺ (wk)	Calcite - Major Quartz - Minor Gypsum - Minor Anhydrite - Minor Calcium Sulfate Hydrate - Trace *Major amorphous material		9.9	Broadway & Wall St. from Bank of NY
WTC01-06	gypsum, muscovite and/or portlandite (tr), CH, Fe ²⁺	Calcite - Minor Quartz - Minor Gypsum - Minor Anhydrite - Minor Muscovite - Trace Calcium Sulfate Hydrate - Trace *Major amorphous material		9.65	Greenwich & Morris
WTC01-07	gypsum, muscovite and/or portlandite (tr), CH, Fe ²⁺	Gypsum - Minor Calcite - Minor Quartz - Minor Anhydrite - Minor Muscovite - Trace Microcline - Trace *Major amorphous material			Rector & Greenwich from sidewalk

WTC01-08	chrysotile gypsum CH, Fe ²⁺ (str)	Calcite - Minor Chrysotile - Minor Gypsum - Minor Talc - Trace Anhydrite - Trace Microcline - Trace Rozenite - Trace *Possible trace rozenite *Major amorphous material			West End & Vesey, steel girder
WTC01-09	gypsum, muscovite, CH, Fe ²⁺ (str)	Calcite - Minor Gypsum - Minor Thaumasite - Minor Quartz - Trace Calcium Silicate - Trace Larnite - Trace *Major amorphous material		10.8	West End & Vesey, steel girder
WTC01-10	gypsum, muscovite (tr), CH, chrysotile (tr) Fe ²⁺	Gypsum - Minor Calcite - Minor Quartz - Minor Anhydrite - Trace Muscovite - Trace *Major amorphous material			West End & Vesey
WTC01-11	gypsum, muscovite (tr), CH, Fe ²⁺	Quartz - Minor Gypsum - Minor Calcite - Minor Anhydrite - Minor Microcline Trace Muscovite - Trace Chrysotile - Trace Calcium Sulfate - Trace *Major amorphous material			West End & Barclay
WTC01-12	gypsum, muscovite (tr), CH, Fe ²⁺	Quartz - Minor Calcite - Minor Gypsum - Minor Anhydrite - Minor Muscovite - Trace Chrysotile - Trace *Major amorphous material			West End & Warren

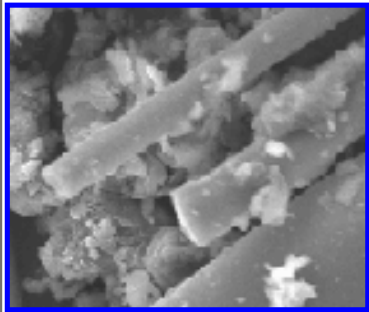
WTC01-13	gypsum, muscovite (tr), CH, Fe ²⁺ (wk) possible trace chrysotile	Quartz - Minor Calcite - Minor Gypsum - Minor Anhydrite - Minor Muscovite - Trace *Major amorphous material			Broadway & Barclay
WTC01-14	gypsum, muscovite, CH, Fe ²⁺ (wk), chrysotile (wk)	Gypsum - Minor Calcite - Minor Quartz - Minor Anhydrite - Trace Muscovite - Trace *Major amorphous material		9.68	Church & Barclay from a windowsill
WTC01-15	gypsum, muscovite, CH, Fe ²⁺ (wk) possible trace chrysotile	Gypsum - Major Anhydrite - Minor Quartz - Minor Calcite - Minor Muscovite - Trace *Major amorphous material		10	Maiden Ln. & Church
WTC01-16	gypsum, muscovite and/or portlandite (tr), CH, Fe ²⁺ (wk)	Quartz - major Gypsum - Major Calcite - Minor Anhydrite - Trace Albite - Trace Orthoclase - Trace *Major amorphous material		8.22	Broadway & Dey
WTC01-17	gypsum, muscovite and/or portlandite (tr), CH, Fe ²⁺	Quartz - Minor Gypsum - Minor Calcite - Minor Anhydrite - Minor Calcium Sulfate Hydrate - Trace Muscovite - Trace *Major amorphous material		9.47	Greenwich & Albany

WTC01-18	gypsum, portlandite (tr), CH, Fe ²⁺ (wk)	Gypsum - Minor Calcite - Minor Quartz - Minor Muscovite - Minor Anhydrite - Minor Portlandite - Trace Bassanite - Trace Chrysotile - Trace *Possible trace chrysotile *Major amorphous material			Washington & Albany
WTC01-19	gypsum, muscovite (tr), CH, Fe ²⁺ (wk)	Gypsum - Minor Calcite - Minor Quartz - Minor Muscovite - Trace Anhydrite - Trace Bassanite - Trace *Major amorphous material			South End & Ceder
WTC01-20	gypsum, muscovite and/or portlandite (tr), CH, chrysotile (tr), Fe ²⁺ (wk)	Quartz - Minor Calcite - Minor Gypsum - Minor Anhydrite - Minor Portlandite - Trace Bassanite - Trace Muscovite - Trace Clinochrysotile - Trace *Very slight possibility of a trace of chrysotile *Portlandite and bassanite are trace to minor *Major amorphous material		11.8	Liberty & South End 2 World Financial Center: indoor sample

WTC01-21	gypsum, muscovite, CH, chrysotile (tr) Fe ²⁺ (wk)	Gypsum - Minor Quartz - Minor Calcite - Minor Anhydrite - Minor Microcline - Trace Clinochrysotile - Trace Muscovite *possible trace Chrysotile *Major amorphous material		9.98	Directly West of WTC at ferry dock and ped. mall
WTC01-22	gypsum, muscovite, CH, Fe ²⁺ (wk)	Gypsum - Major Anhydrite - Minor Quartz - Minor Calcite - Minor Muscovite - Trace Paragonite - Trace Lizardite - Trace Magnesionhornblende - Trace Clinochrysotile - Trace *possible trace (<.5%) chrysotile and/or Lizardite *trace amphibole (<.5%) *Major amorphous material		10.4	1/2 way between WTC and Ferry Dock along ped. mall from a windowsill
WTC01-23	gypsum, muscovite (tr), CH, chrysotile (tr) Fe ²⁺ (wk)	Gypsum - Minor Muscovite - Minor Calcite - Minor Quartz - Minor Anhydrite - Trace Bassanite - Trace *Major amorphous material			Broadway & Murray

WTC01-24	gypsum, muscovite (tr), CH, chrysotile (tr) Fe ²⁺ (wk)	Gypsum - Minor Calcite - Minor Anhydrite - Minor Dolomite - Minor Muscovite - Minor Quartz - Trace Microcline - Trace Calcium Sulfate - Trace *Major amorphous material			Broadway & Chambers
WTC01-25	gypsum, muscovite/ illite, CH, chrysotile (tr) Fe ²⁺ (wk)	Calcite - Minor Quartz - Minor Gypsum - Minor Anhydrite - Minor Dolomite - Trace Illite - Trace *Major amorphous material		9.37	Church & Warren
WTC01-26	gypsum, muscovite (tr), CH, Fe ²⁺ (wk)	Calcite - Minor Gypsum - Minor Anhydrite - Minor Muscovite - Minor Quartz - Trace Dolomite - Trace Microcline - Trace Calcium Sulfate - Trace Chrysotile - Trace *Major amorphous material			1/2 way between Broadway and Church on Park
WTC01-27	gypsum, muscovite, CH	Anhydrite - Minor Calcite - Minor Quartz - Minor Gypsum - Minor Orthoclase - Trace Albite - Trace Muscovite - Trace Clinochrysotile - Trace *Major amorphous material		10	Broadway & Vesey

WTC01-28	gypsum, muscovite, CH, chrysotile (wk), Fe ²⁺ (wk)	Calcite - Minor Gypsum - Minor Quartz - Minor Anhydrite - Minor Chrysotile - Trace *Major amorphous material		9.93	Ann & Nassau
WTC01-29	gypsum, muscovite (tr), CH, chrysotile (tr), Fe ²⁺ (wk)	Calcite - Minor Gypsum - Minor Quartz - Minor Anhydrite - Minor Muscovite - Trace Chrysotile - Trace *Major amorphous material			William & Fulton
WTC01-30	gypsum, muscovite, CH, Fe ²⁺	Calcite - Minor Quartz - Minor Dolomite - Minor Anhydrite - Minor Gypsum - Minor Chrysotile - Trace *Possible trace chrysotile *Major amorphous material			Fulton & Cliff St. from on top of a car
WTC01-31	gypsum, muscovite, CH, Fe ²⁺ (wk)	Calcite - Minor Gypsum - Minor Quartz - Minor Anhydrite - Minor Muscovite - Trace Chrysotile - Trace *Major amorphous material			William & Platt
WTC01-32	gypsum, muscovite, CH, Fe ²⁺	Calcite - Minor Gypsum - Minor Quartz - Minor Anhydrite - Minor Muscovite - Trace Chrysotile - Trace *Possible trace chrysotile *Major amorphous material			William & Pine

WTC01-33	gypsum, muscovite (tr), CH, Fe ²⁺ (wk)	Gypsum - Minor Calcite - Minor Quartz - Minor Muscovite - Minor Anhydrite - Trace Magnesiohornblende - Trace Chrysotile - Trace *Major amorphous material			Battery Park, middle
WTC01-34	gypsum, muscovite, CH, chrysotile (tr) Fe ²⁺ (wk)	Quartz - Major Calcite - Minor Gypsum - Minor Anhydrite - Trace *Major amorphous material		9.8	South End & Thames
WTC01-35	gypsum, CH, muscovite, chrysotile (tr) Fe ²⁺	Gypsum - Minor Calcite - Minor Quartz - Minor Anhydrite - Trace Muscovite - Trace Chrysotile - Trace *Major amorphous material			Albany & Hudson River
WTC01-36	gypsum, muscovite and/or portlandite (tr), CH, Fe ²⁺ , possible trace chrysotile	Gypsum - Minor Calcite - Minor Quartz - Minor Anhydrite - Minor Bassanite - Minor Portlandite - Minor Dolomite - Trace Illite - Trace Chrysotile - Trace *possible trace chrysotile *Major amorphous material		11.8	South End & Albany (30th floor): Indoor sample
WTC01-37A	gypsum, muscovite, portlandite, Fe ²⁺	Quartz - Major Albite - Major Portlandite - Minor Magnesiohornblende - Minor Orthoclase - Trace Muscovite - Trace			concrete from WTC area

WTC01-37B	portlandite, Fe ²⁺	Quartz - Major Orthoclase - Minor Portlandite - Minor Albite - Trace Calcite - Trace Magnesiohornblende - Trace Muscovite			concrete from WTC area
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* Amorphous material is not identifiable by XRD, but its presence is detectable.

* "Possible trace chrysotile" means at or near the detection limit with XRD.

The question of asbestos distribution was investigated and the results show an asymmetric distribution pattern (Results Figure 1). More chrysotile was detected in an east-west direction than south. This pattern occurs in both the AVIRIS maps and from field samples (Results Figure 2). While there is a general trend, it is not exclusive, meaning that chrysotile was detected in all directions. It also should be noted that samples obtained next to each other (on the map this means a city block apart) can show different results: one has asbestos, another has no chrysotile above the detection limit.

Composition of samples on a centimeter scale was examined with a spectrometer. Small variations in chrysotile content throughout a sample were observed. Thus from scales of cm to tens of meters, chrysotile content varies. Such variability makes sampling and overall assessment of a site difficult.

The fact that some materials in the WTC debris were observed to contain higher levels of chrysotile (sample WTC01-08) on a steel beam, and that the coatings on the beams have largely been stripped, leads to the question of where did the coatings go and how well distributed/dispersed is the chrysotile? Because a patch of coating showed up to 20% chrysotile, and the field samples and the AVIRIS maps show varying levels of serpentine (chrysotile) leads to the possibility that other patches of chrysotile may exist in the debris. The asymmetry in the AVIRIS iron-bearing materials map may be related to the asymmetry in the asbestiform minerals map. The AVIRIS data and the laboratory analyses of the field samples indicate a lower abundance of chrysotile in the the southern direction from the WTC, the same direction of the increase in iron-bearing materials. The one field sample, WTC01-08, from an iron beam, which had up to 20% chrysotile also contains a strong Fe²⁺ absorption. Thus one might expect a higher chrysotile content in iron-bearing materials. However, this is clearly not the case, at least in general. This may indicate other sources of the chrysotile besides the beam coatings.

AVIRIS imaging spectroscopy mapping provides a synoptic view that samples more area than possible with other methods. The AVIRIS maps shown here represent only a portion of the data collected, and effectively provide data for about 4.7 million sample locations, all obtained within a couple of hours. The sampling includes land, air and water.

The fact that the field sampling missed the highest concentrations of serpentines in the AVIRIS maps shows the limitations of limited sampling methodologies. Ideally, the field sampling team would have the AVIRIS materials maps to guide the field sampling.

Unfortunately, this was not possible in this rapid response case (but we routinely employ such methods in geologic studies where the region does not change rapidly). Even so, the materials maps for this study were produced faster than any other imaging spectroscopy effort to our knowledge. The AVIRIS data were received within 24 hours of acquisition, and the data were initially calibrated to help the field team obtain the final calibration data with real time feedback via cell phone. In this case, scientists in Denver communicated

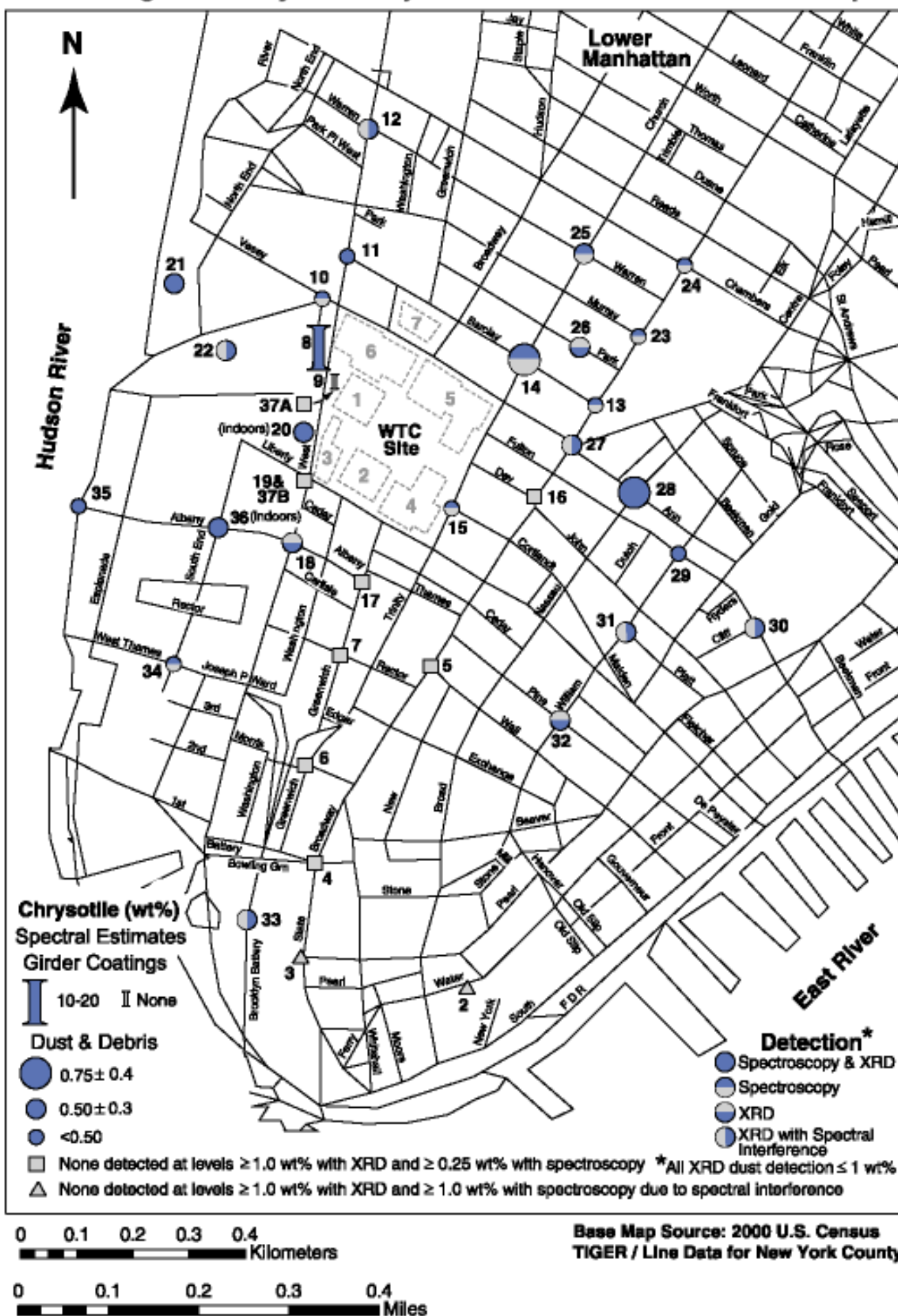
composition of field calibration sites using initially calibrated AVIRIS data (of the parking lot structure) while the field team was investigating where the best portion of the parking lot was located. The real-time feedback resulted in avoidance of portions of the parking lot with strong absorption features, not visible to the human eye, that could have compromised the quality of the final calibration.

With further development of on-board solar calibration targets on the aircraft with the AVIRIS sensor, the refinement of analysis software, the development of more reference spectral libraries, and the use of faster computers, an even faster response is possible in the future. The challenge is formidable. To analyze the data for this study, we used approximately 300 gigabytes of disk space and performed over 50 trillion calculations. The results of the AVIRIS mapping are limited by knowledge of the spectral properties of materials and the detection levels are limited by the sensor signal-to-noise. The detection limits could be substantially improved with existing technology in a new sensor design. The combination of field sampling with laboratory analysis and imaging spectroscopy remote sensing provide a powerful assessment combination. We estimate the analysis effort of this highly experienced team to be 1.8 person years to complete this study plus another 0.6 person-year for the AVIRIS data collection effort. This study includes analysis of 20% of the AVIRIS data from Sept 16, and 7% of the data from Sept 23 (thermal hot spot analysis only).

The scientific data from this study is presented with no assessment of health effects. It is beyond the scope of this study to assess health effects of a fraction of a percent chrysotile asbestos, for example.

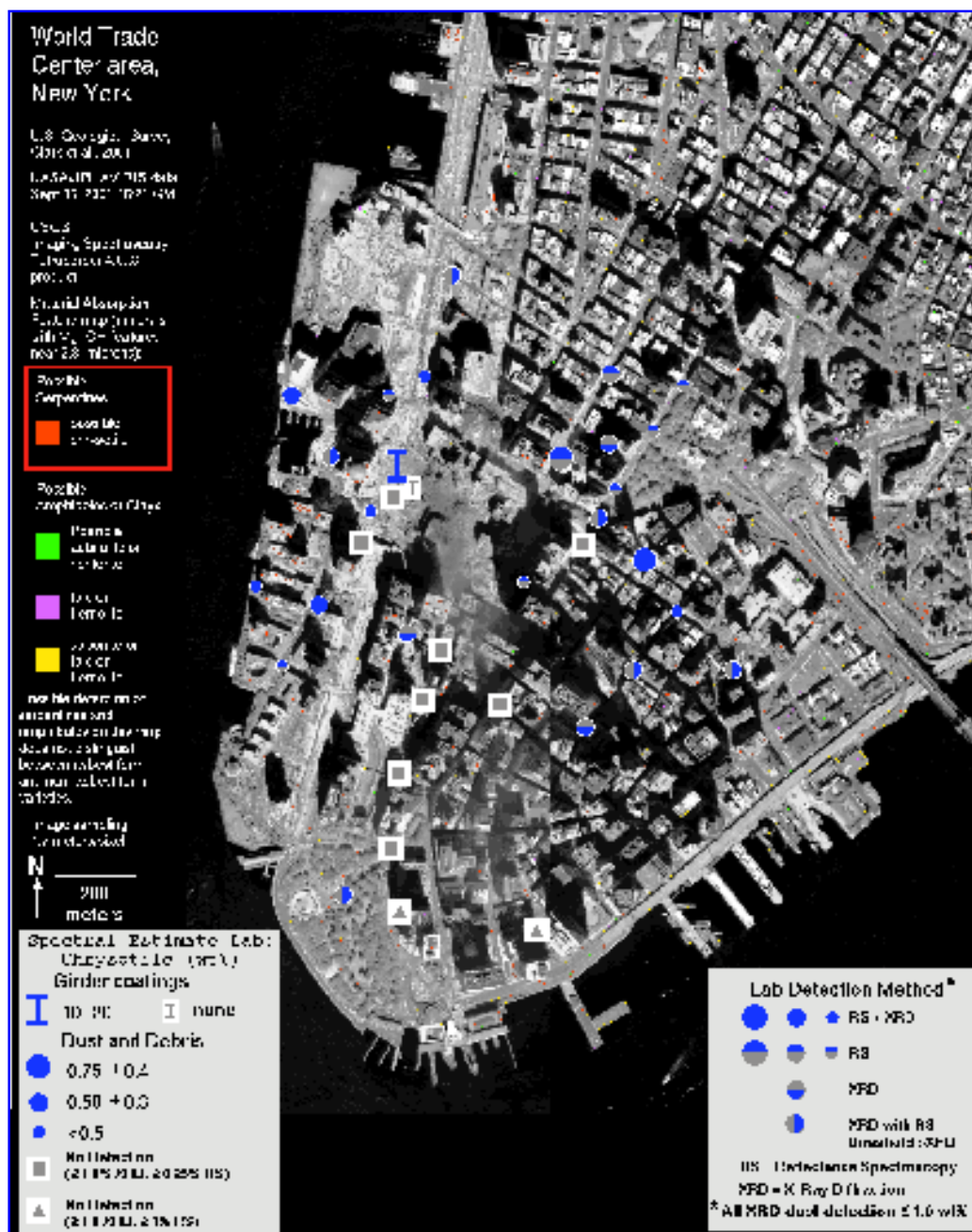
Other Conclusions have already been presented in the Executive Summary.

Chrysotile Content in WTC Surface Samples



[Larger 92 KB image](#)

Results Figure 1. Sample location map coded by asbestos detection.



[Larger 633 KB image](#)

Results Figure 2. WTC Sample analyses from Results Figure 1 are shown plotted on the serpentine/amphibole AVIRIS map. There is a loose correlation of chrysotile locations spread in an east-west direction in both the laboratory analyses and the AVIRIS data.

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Welcome to the AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) Homepage. Please use the menu bar at the top to navigate through our site.

AVIRIS is a proven instrument in the realm of Earth Remote Sensing. It is a unique optical sensor that delivers calibrated images of the upwelling spectral radiance in 224 contiguous spectral channels (bands) with wavelengths from 400 to 2500 nanometers. AVIRIS has been flown on four aircraft platforms: NASA's ER-2 jet, Twin Otter International's turboprop, Scaled Composites' Proteus, and NASA's WB-57. The ER-2 flies at approximately 20 km above sea level, at about 730 km/hr. The Twin Otter aircraft flies at 4km above ground level at 130km/hr. AVIRIS has flown North America, Europe, portions of South America, and most recently, Argentina.

The main objective of the AVIRIS project is to identify, measure, and monitor constituents of the Earth's surface and atmosphere based on molecular absorption and particle scattering signatures. Research with AVIRIS data is predominantly focused on understanding processes related to the global environment and climate change.

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Pitching sun safety at Fenway Park Jul 14 - Boston Red Sox fans learn sun safety at the game on Sunday July 16 and proper ways to protect themselves from excessive sun exposure, the cause of most skin cancers. In 2006 over 1 million cases of skin cancer are expected.

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EPA strengthens clean air rules for dry cleaners Jul 14 - EPA is tightening rules for all dry cleaners that use the chemical perchloroethylene (perc), including a phase-out of the chemical in dry cleaners located in residential buildings. Approximately 28,000 U.S. dry cleaners use perc, which is the only air toxic emitted from the dry cleaning process.

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Thousands of illegal gas-powered imports seized Jul 14 - EPA and U.S. Customs have seized over 11,000 illegal gas-powered vehicles and equipment in the past nine months and fined the importers a total of over \$798,000. Such illegal equipment fails to meet US emissions standards, increasing air pollution and health problems such as asthma.

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Pittsburgh All-Stars homer for recycling Jul 11 - Fans at the All Star baseball game "Recycle On The Go" by depositing their cans and bottles in stadium area bins. Recycling partners such as the City of Pittsburgh encourage people to recycle wherever they go by making recycling easy and convenient.

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Healthcare facilities commit to energy efficiency Jul 11 - The American Society for Healthcare Engineering is joining the Energy Star Challenge to educate members about the environmental and economic benefits of improved energy efficiency. Estimated benefits include saving over \$65 million on energy and preventing nearly 3 million pounds of greenhouse gas emissions.

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Almost \$1 billion for drinking water programs Jul 5 - States, territories and tribes will share more than \$940

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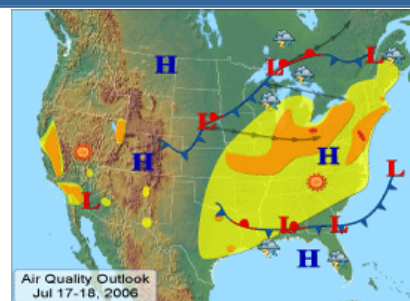
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Unhealthy	Very Unhealthy	Hazardous
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million from three EPA grant programs to support the quality and security of the nation's drinking water. The water supplies for more than 270 million people will benefit from the funding.

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Planning a beach trip?

Contact [your state](#) or [local government office](#) where you



[live](#) for current beach closure information. What you can do to [safely enjoy your beach and protect the beach environment](#).

Help Protect the Environment

At Home
[Save energy](#)
[Use less water](#)
[Reduce/reuse/recycle](#)
[More ...](#)

When Shopping
Get a new computer or other electronics recently? [Reuse or recycle](#) the old ones.

In Your Classroom
[For teachers](#)
[For middle school](#)
[For high school](#)
[More ...](#)

While At Work
[Commute smart](#)
[Reduce energy use](#)
[Reduce/reuse/recycle](#)
[More ...](#)

Don't Top Off!



The summer driving season is here. That's when we use more gasoline for weekend and vacation trips. When you fill up, remember not to top off your gas tank. Topping off can spill gasoline which quickly evaporates. Gasoline vapors can harm your family's health and make ozone pollution and smog worse. [Read more](#). [En español](#)

Be cool by keeping cool: Save energy and money

The average family spends hundreds of dollars to keep cool. But summer heat doesn't have to mean high energy bills. Start now to cool smartly. Seal leaky air gaps around your house. Buy or upgrade to energy-efficient fans and air conditioners. [When is it time to replace?](#)

Hurricane season: Are you prepared?

A devastating storm can happen with little warning. But local governments and individuals should be ready to minimize disaster. Communities can plan for extensive debris cleanup. Ensure the safety of emergency food and drinking water. Residents need to know their area response plan and evacuation routes. Learn more about [preparing for hurricanes](#). [En español](#)

July is UV Safety Month

Ultraviolet, or UV, radiation from the sun is natural. But getting too much of it and too often can lead to serious health problems later, such as skin cancer. Always be safe. Limit everyone's exposure to midday sun - adults and children. Use sunblock of SPF 15 or higher when playing or working outdoors. [Know your sun safety actions steps](#)
[Check your UV forecast](#)
[en español: rayos ultravioletas](#)

? Test Your Enviro-Q ?

Urban areas can be how much warmer than surrounding rural areas?

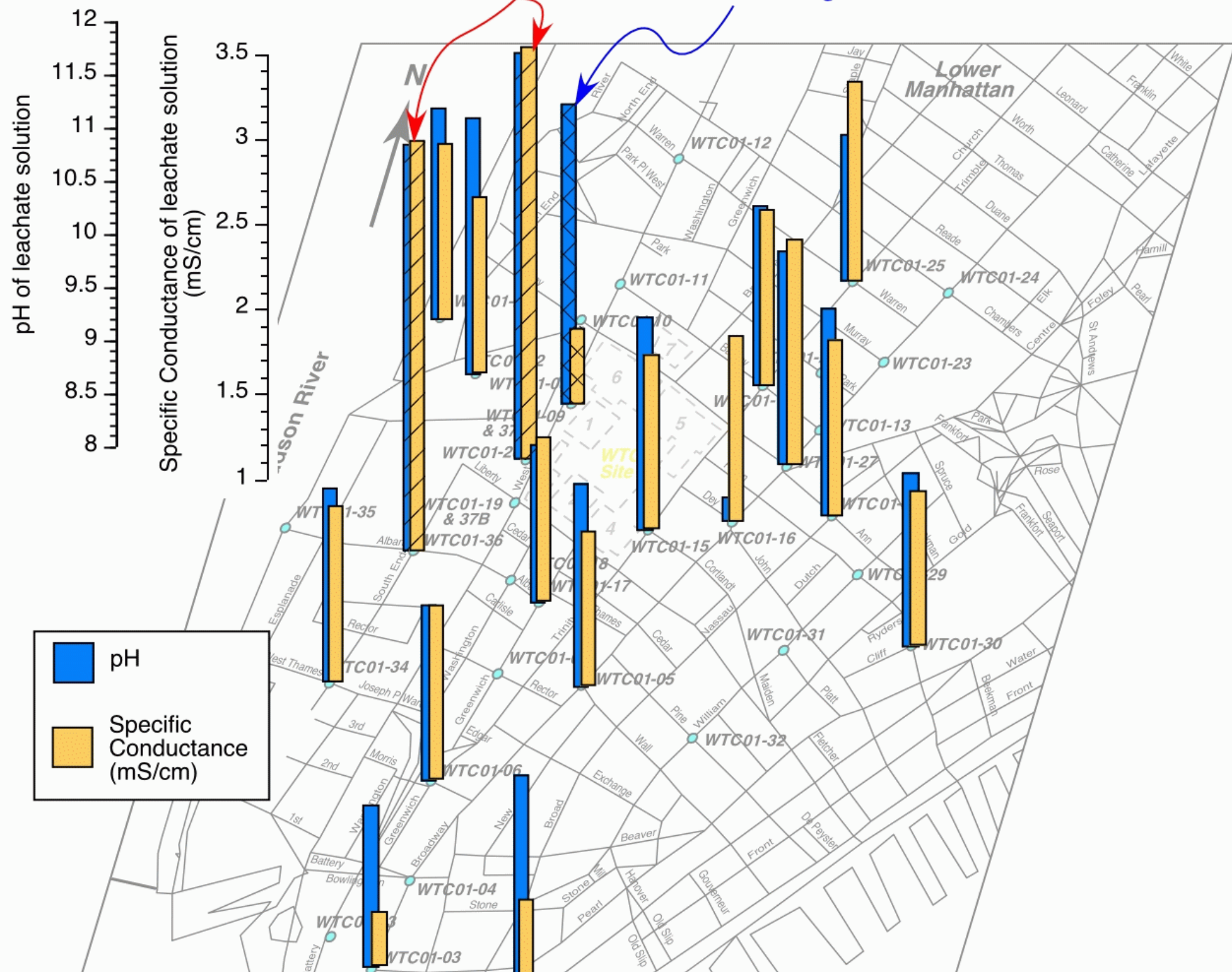
- a. no, colder
- b. about the same
- c. 2-10 F warmer
- d. 15 F warmer

[Answer](#) | [Previous questions](#)



WaterSense educates consumers about smart water choices that save money and maintain high environmental standards. Manufacturers use the WaterSense label to indicate products and services at least 20 percent more efficient than less efficient counterparts. [Tell me more about WaterSense.](#)

Leach Figure 2





Base Map Source: 2000 U.S. Census
TIGER / Line Data for New York County

00 .1 0.20 .3 0.4
Kilometers

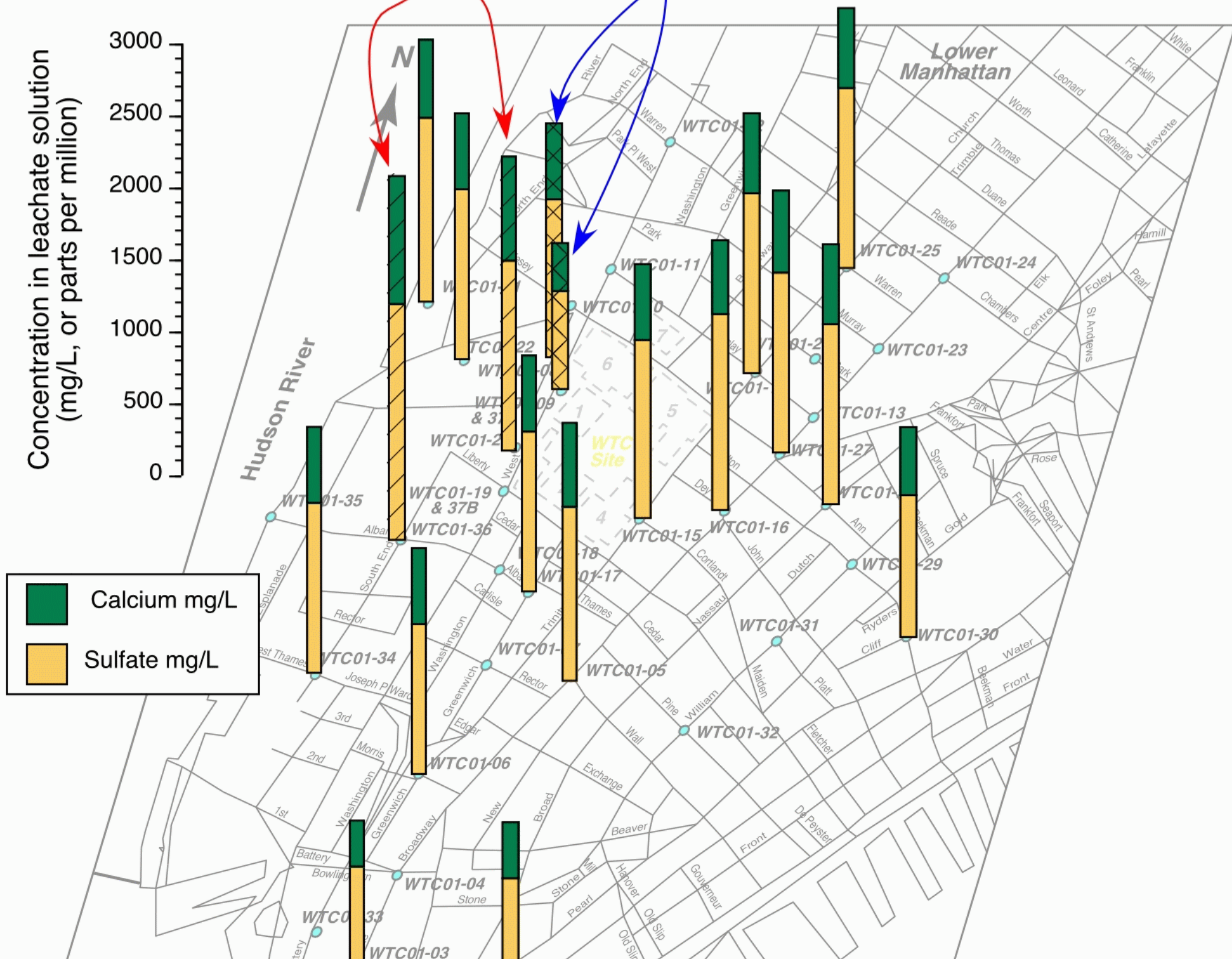
00 .1 0.20 .3 0.4
Miles

pH and Specific Conductance of
leachate solutions from
dusts and girder coatings

Leach Figure 3

Indoor samples

Girder coatings





00 .1 0.20 .3 0.4
Kilometers

Base Map Source: 2000 U.S. Census
TIGER / Line Data for New York County

00 .1 0.20 .3 0.4
Miles

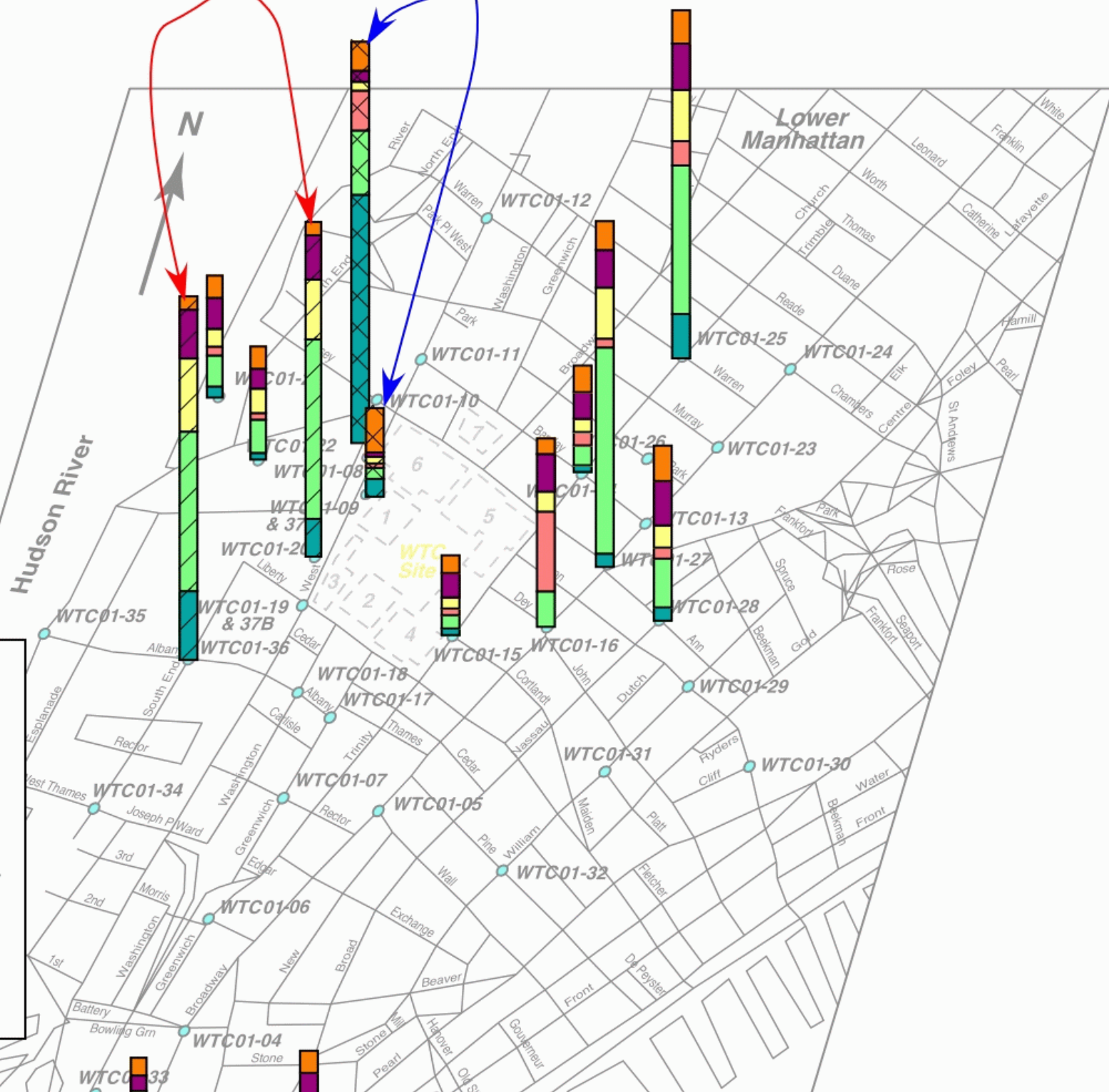
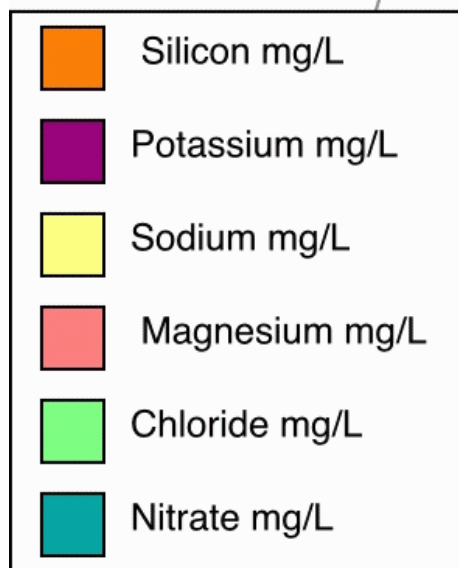
Concentrations of calcium and sulfate in
leachate solutions from
dusts and girder coatings

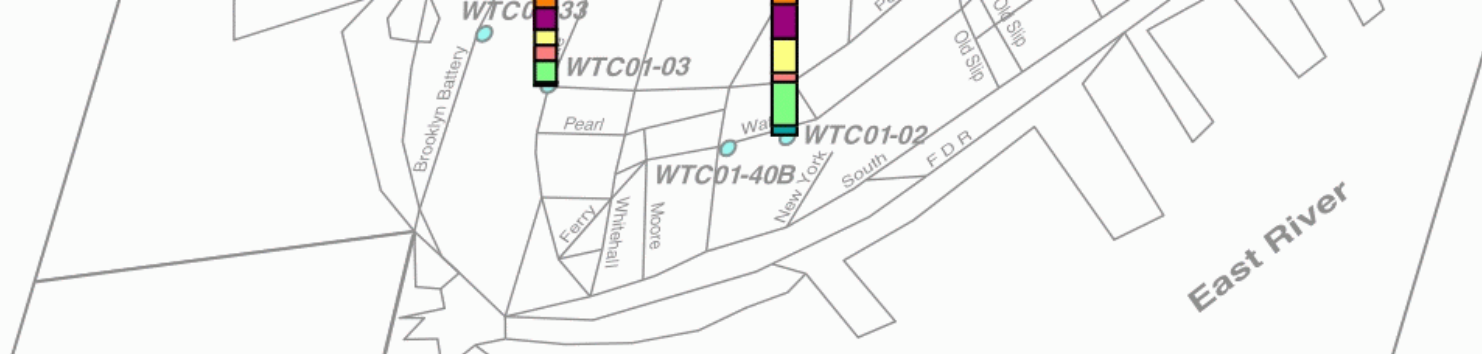
Leach Figure 4

Indoor samples

Girder coatings

Concentration in leachate solution
(mg/L, or parts per million)





00 .1 0.20 .3 0.4
Kilometers

Base Map Source: 2000 U.S. Census
TIGER / Line Data for New York County

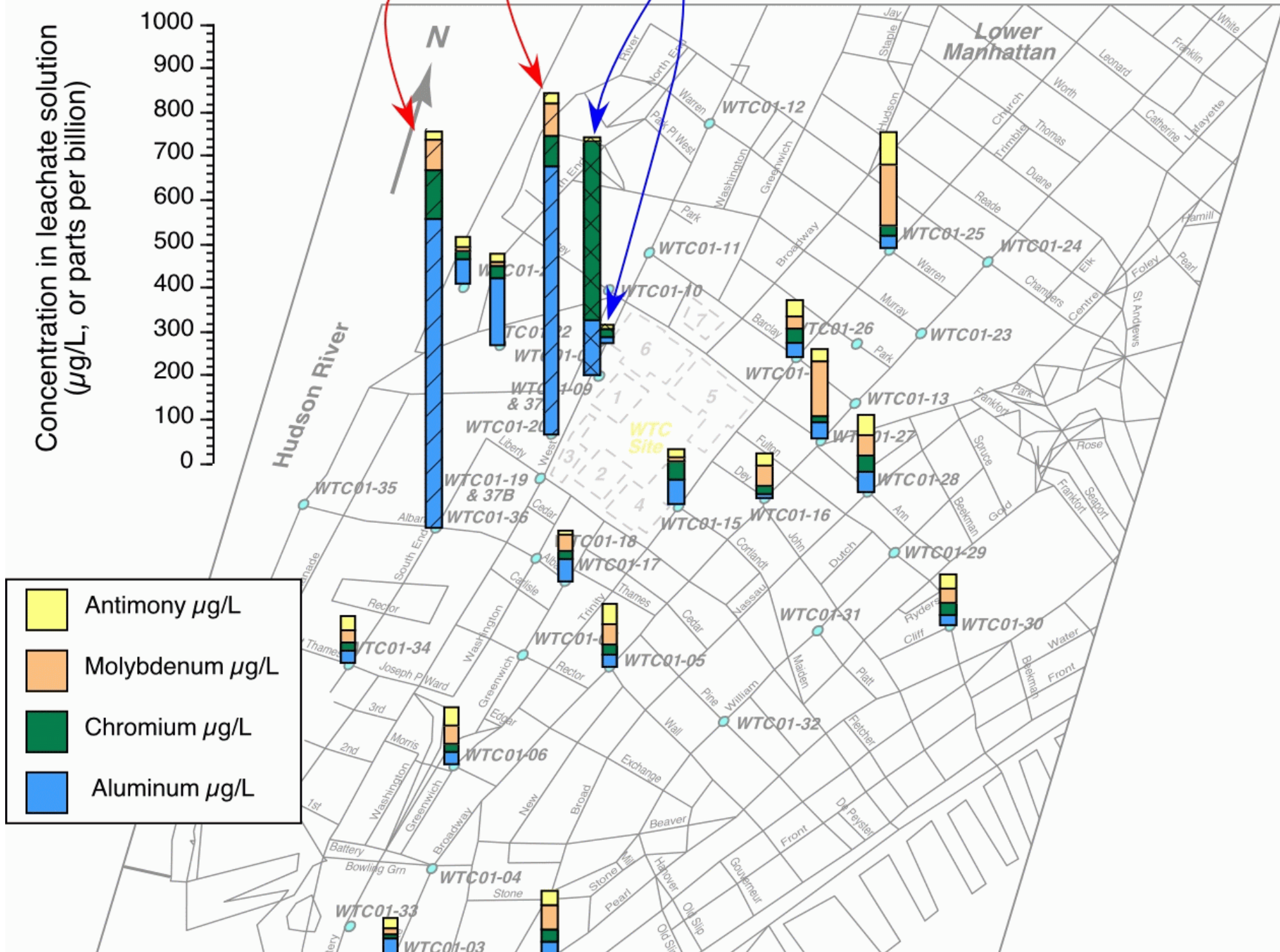
00 .1 0.20 .3 0.4
Miles

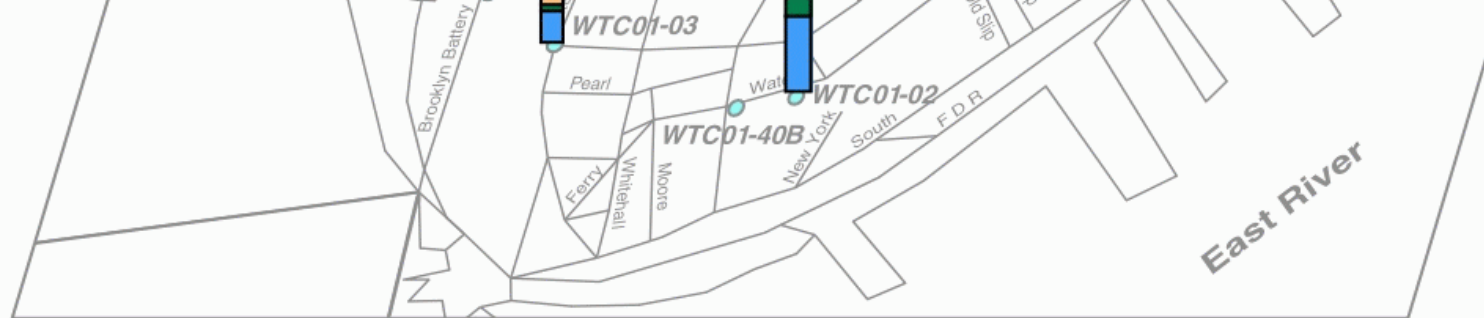
Intermediate-concentration metals and
anions in leachate solutions from
dusts and girder coatings

Leach Figure 5

Indoor samples

Girder coatings





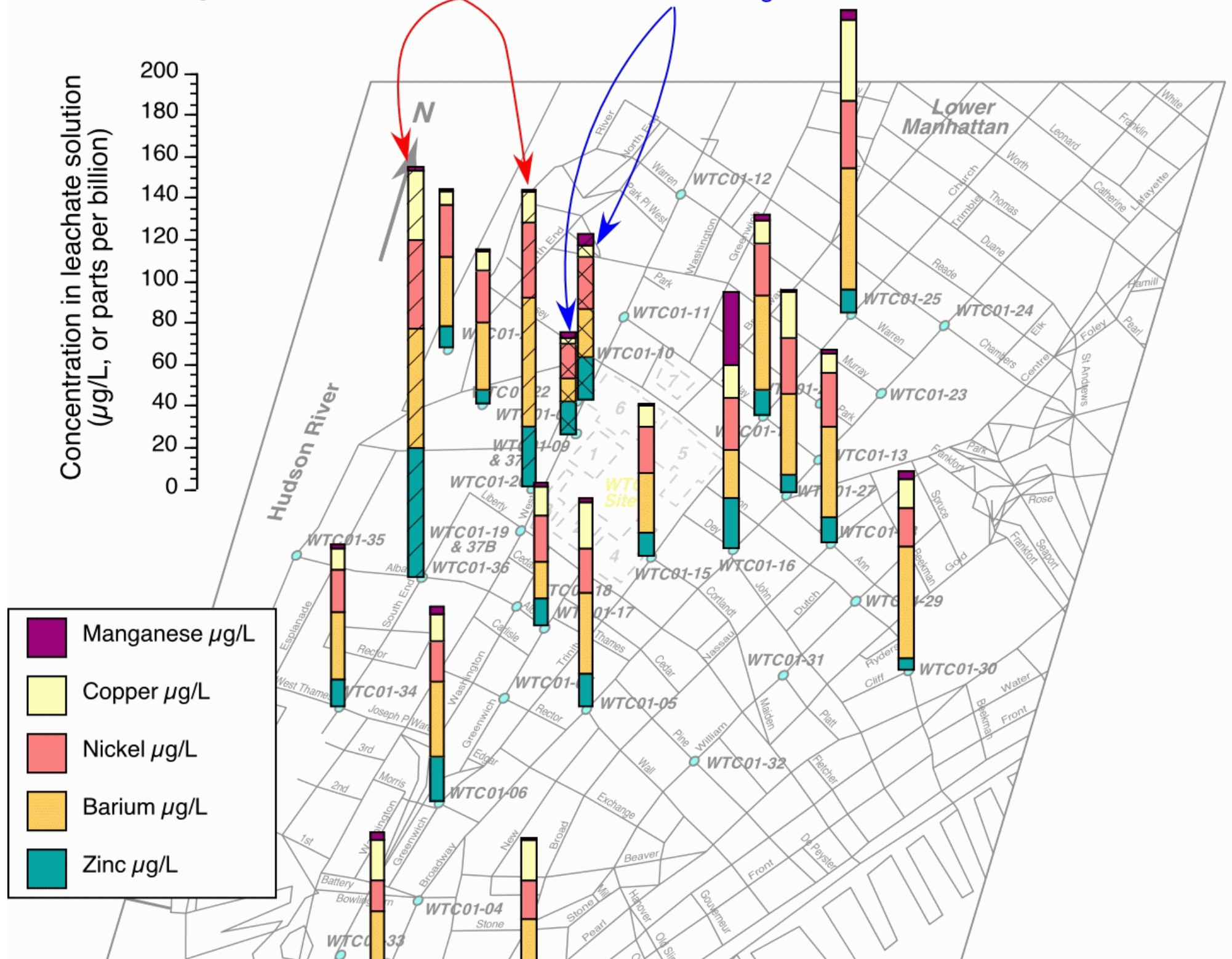
00 .1 0.20 .3 0.4
Kilometers

Base Map Source: 2000 U.S. Census
TIGER / Line Data for New York County

00 .1 0.20 .3 0.4
Miles

Concentrations of predominant trace metals
in leachate solutions from
dusts and girder coatings

Girder coatings





Base Map Source: 2000 U.S. Census
TIGER / Line Data for New York County

00 .1 0.20 .3 0.4
Kilometers

00 .1 0.20 .3 0.4
Miles

Concentrations of moderately abundant
trace metals in leachate solutions from
dusts and girder coatings

OFR 01-0429: Acknowledgements

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The authors would like to extend their great thanks to a number of people who provided extremely helpful technical or policy reviews of all or portions of this report, including: Phil Bethke, Jim Crowley, Marty Goldhaber, Dan Knepper, Kathy Smith, Rich Wanty, Jim Devine, Ed du Bray, Jim Crock, and Warren Day.

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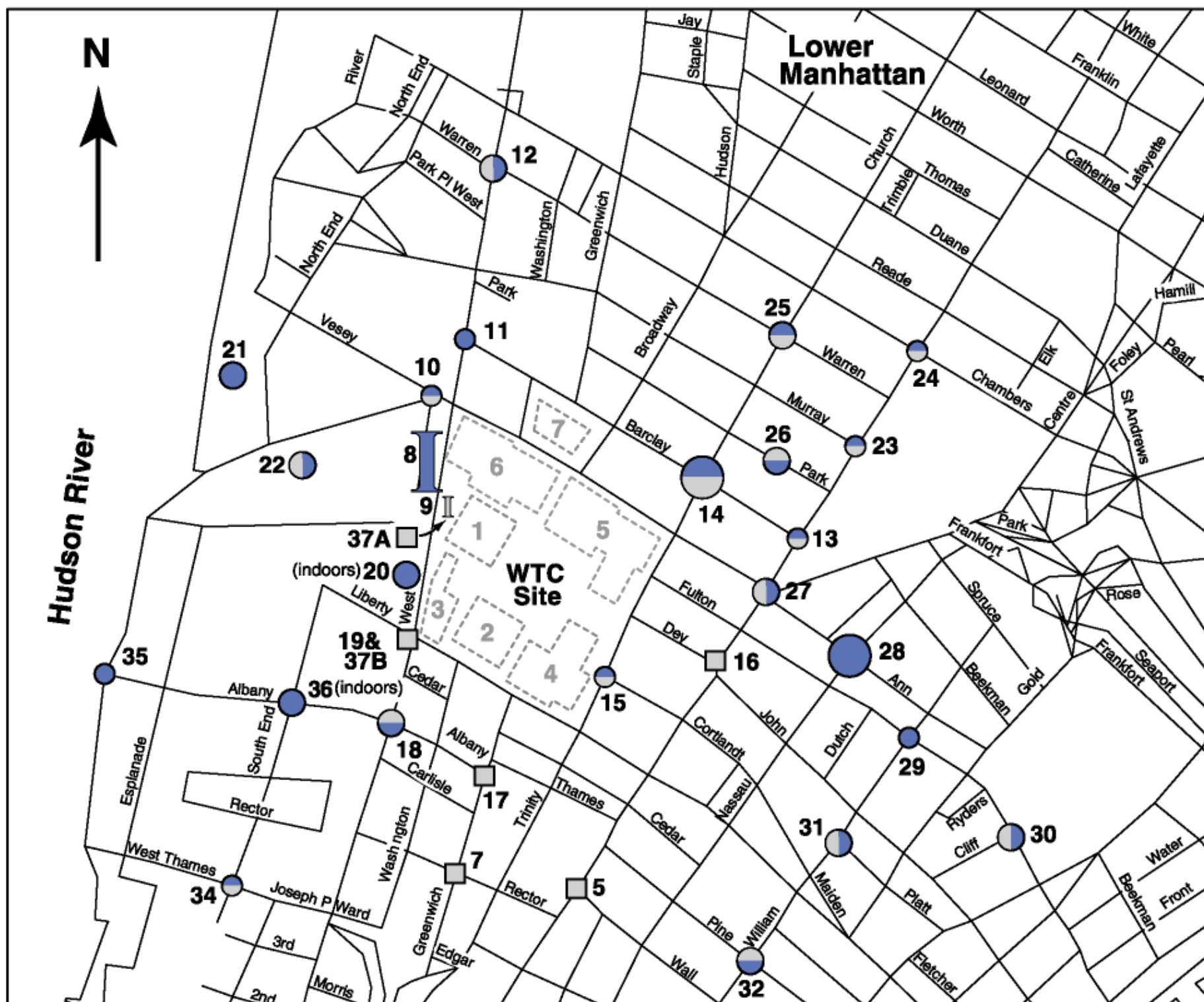
[U.S. Department of the Interior](#) | [U.S. Geological Survey](#)

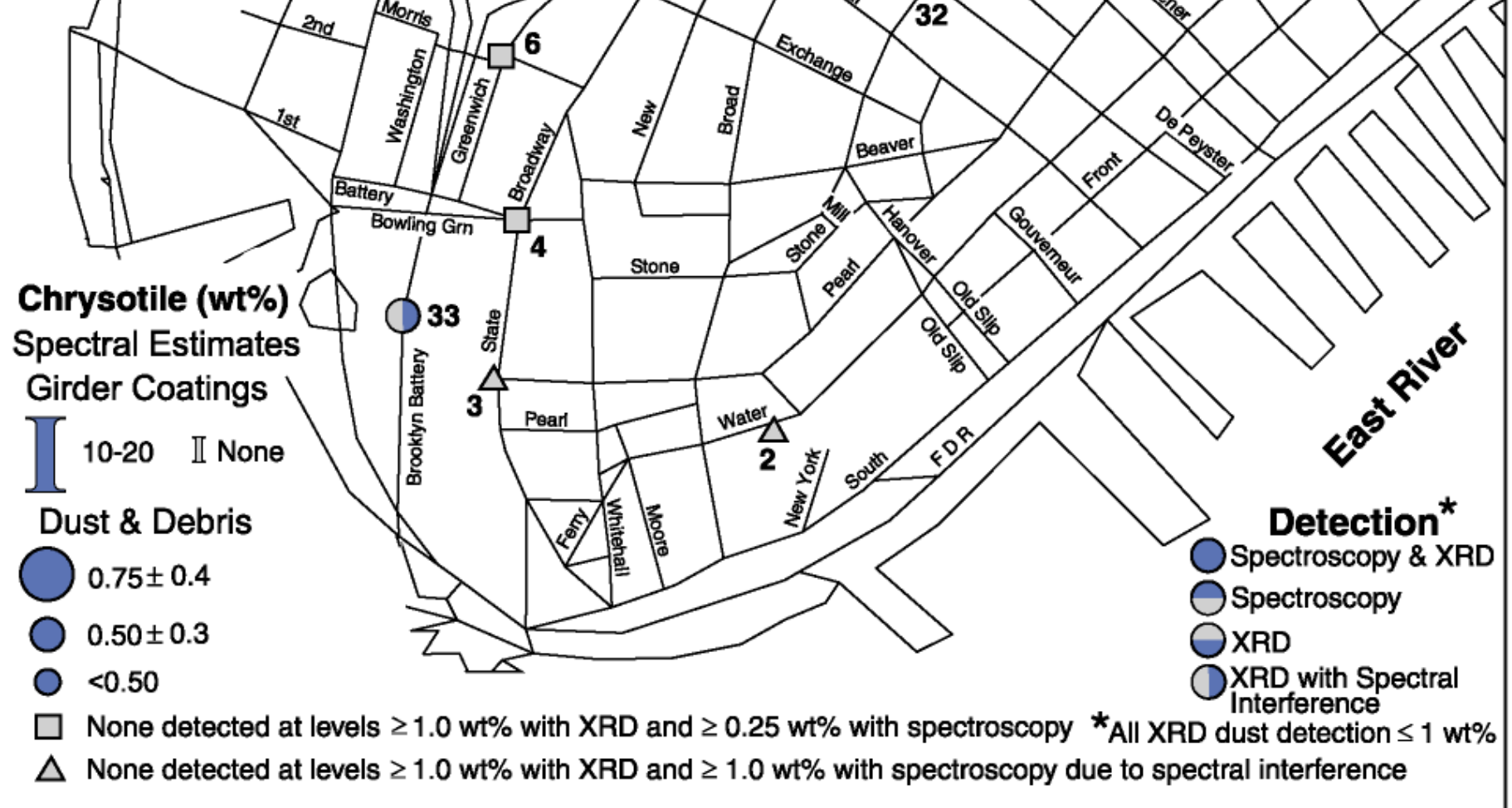
URL: <<http://pubs.usgs.gov/of/2001/ofr-01-0429/acknowledgements.html>>

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Page Last Modified: Mon Aug 22 17:57 EDT 2005







0 0.1 0.2 0.3 0.4
Kilometers

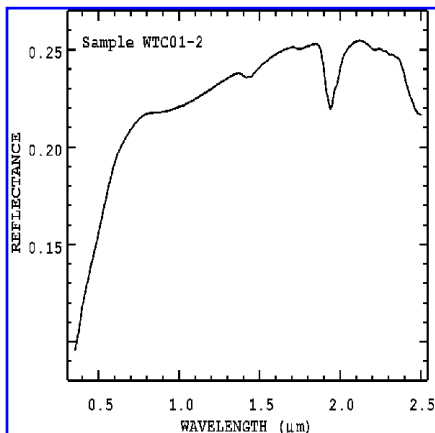
0 0.1 0.2 0.3 0.4
Miles

**Base Map Source: 2000 U.S. Census
TIGER / Line Data for New York County**

OFR 01-0429: World Trade Center USGS Lab Spectroscopy Studies

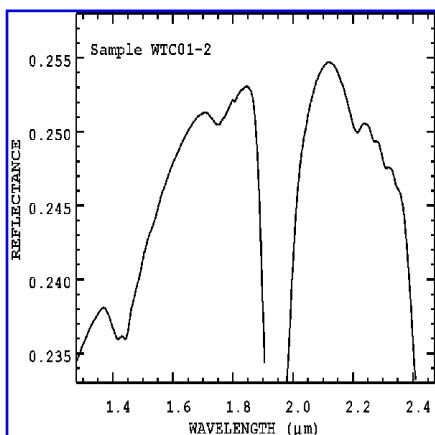
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Laboratory Spectra of WTC Sample WTC01-02



[Larger 10 KB image](#)

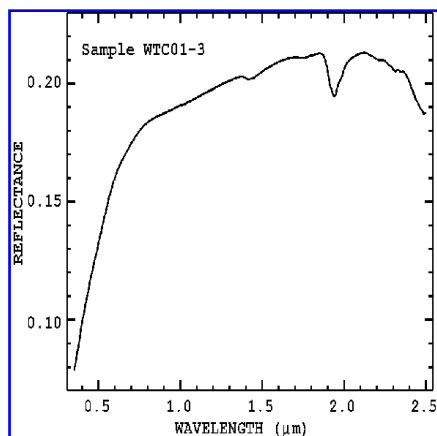
Dust sample from: Water & Vietnam Vet. Plaza 4506052N 583559E



[Larger 12 KB image](#)

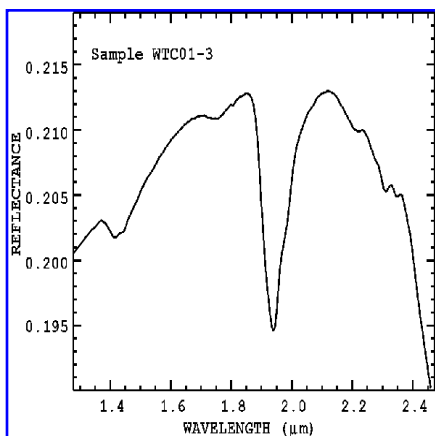
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Laboratory Spectra of WTC Sample WTC01-03



[Larger 10 KB image](#)

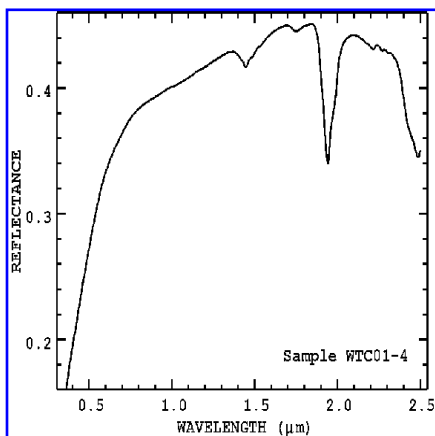
Location: Battery Park, east central 4506123N 583217E drainage disc



[Larger 12 KB image](#)

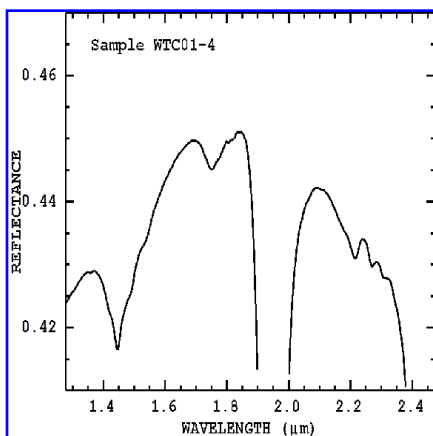
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Laboratory Spectra of WTC Sample WTC01-4



[Larger 11 KB image](#)

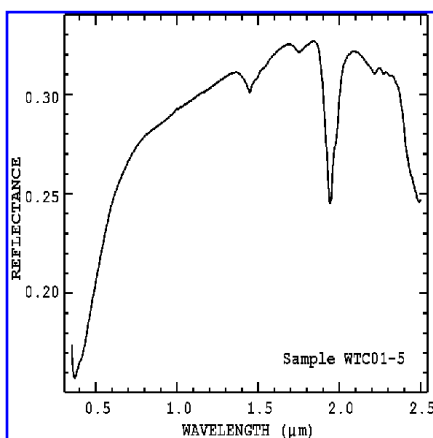
Dust sample from: Battery Park, northeast end



[Larger 11 KB image](#)

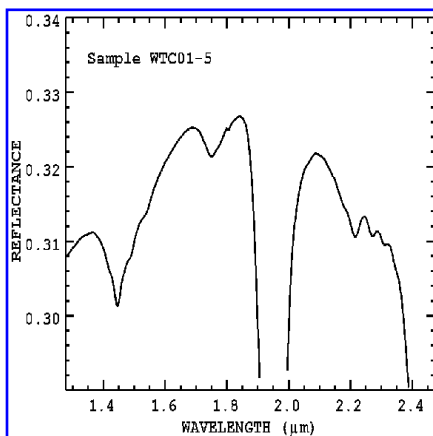
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Laboratory Spectra of WTC Sample WTC01-5



[Larger 11 KB image](#)

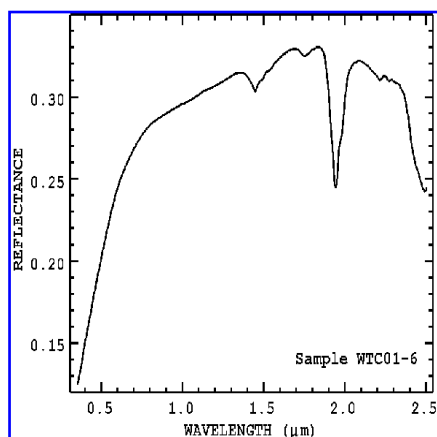
Dust sample from: Broadway and Wall St.



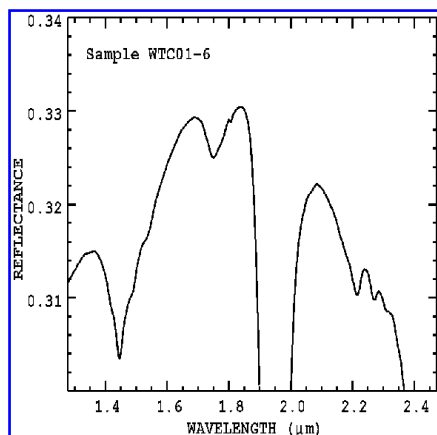
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Laboratory Spectra of WTC Sample WTC01-6



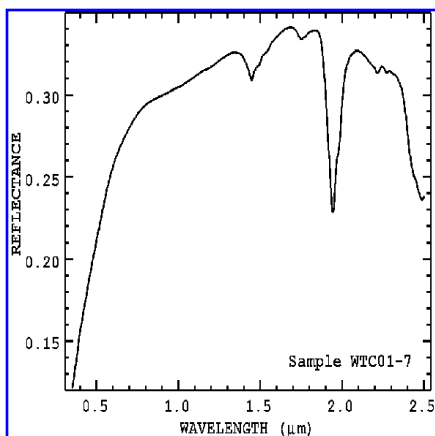
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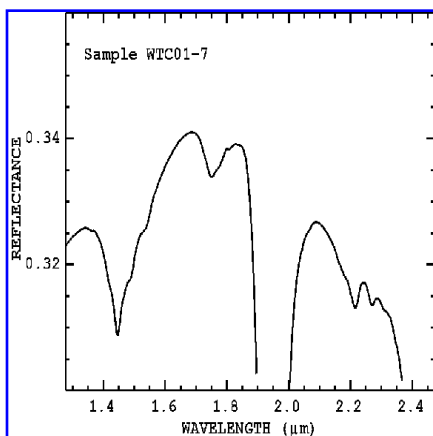
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Laboratory Spectra of WTC Sample WTC01-7



[Larger 11 KB image](#)

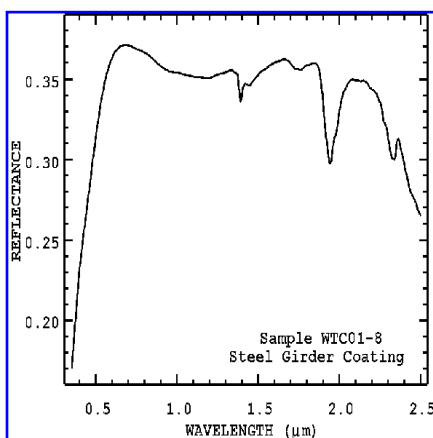
Dust sample from: Rector and Greenwich



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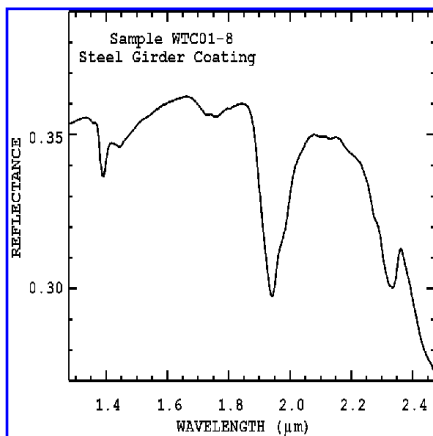
Laboratory Spectra of WTC Sample WTC01-08



[Larger 10 KB image](#)

Location: West End & Vesey, Coating on steel girder.

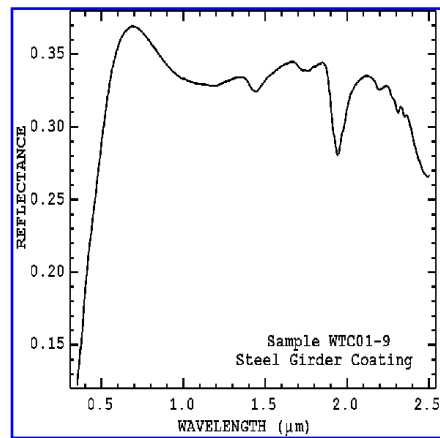
The 1.4 and 2.32-absorptions are mainly due to chrysotile.



[Larger 12 KB image](#)

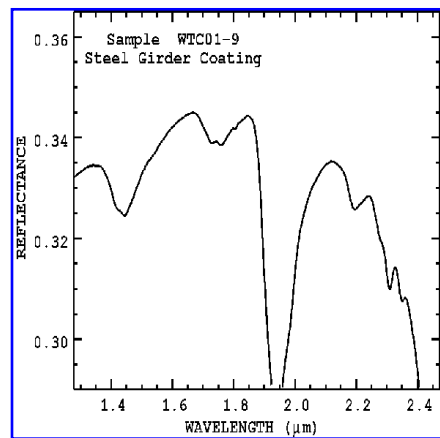
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Laboratory Spectra of WTC Sample WTC01-09



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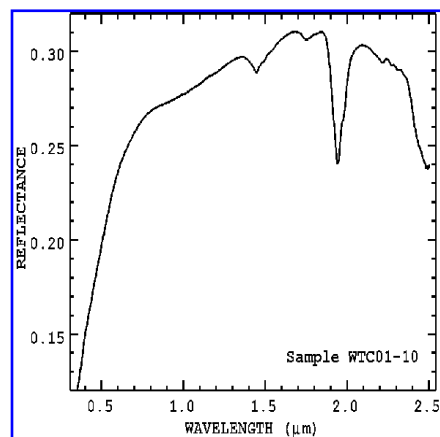
Dust sample from: West and Vesey, steel girder



[Larger 12 KB image](#)

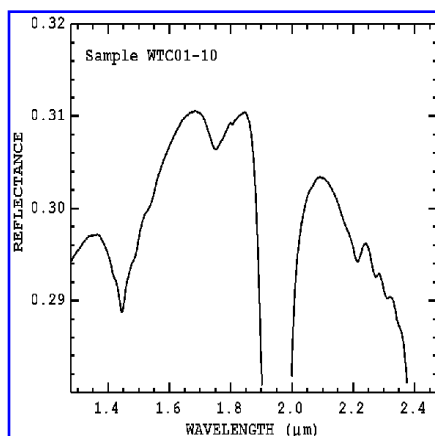
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Laboratory Spectra of WTC Sample WTC01-10



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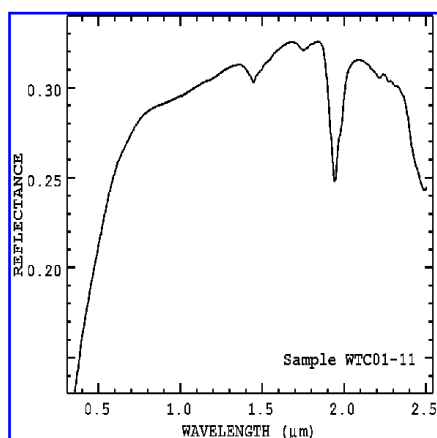
Dust sample from: West and Vesey



[Larger 12 KB image](#)

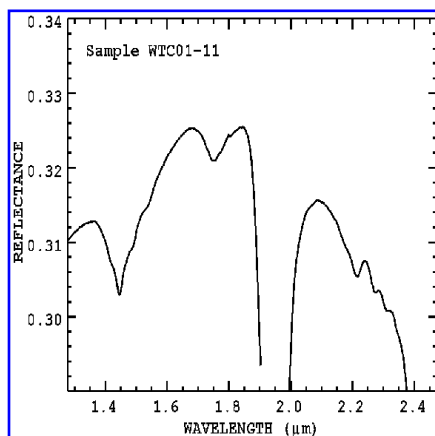
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Laboratory Spectra of WTC Sample WTC01-11



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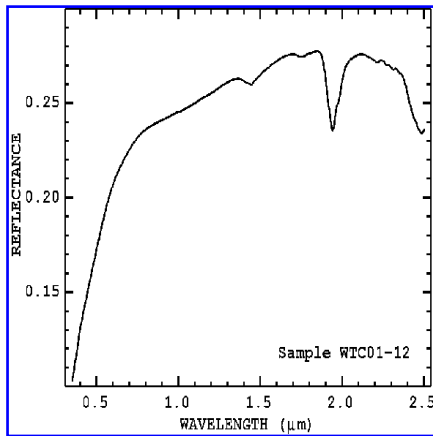
Dust sample from: West and Barclay



[Larger 12 KB image](#)

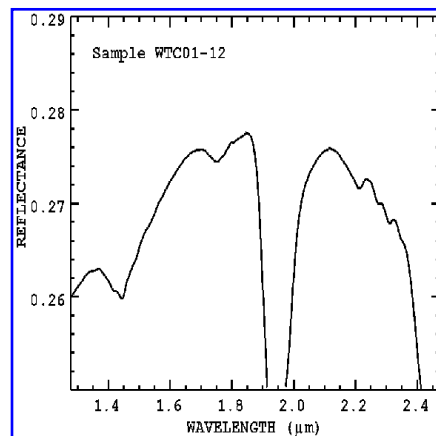
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Laboratory Spectra of WTC Sample WTC01-12



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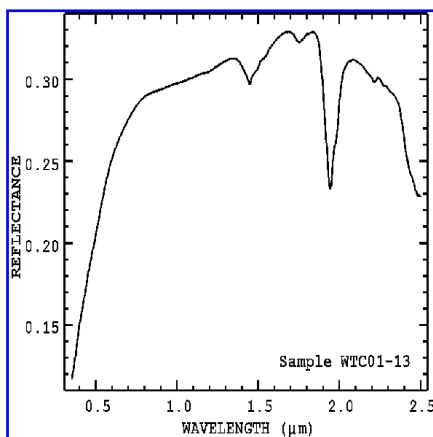
Dust sample from: West and Warren



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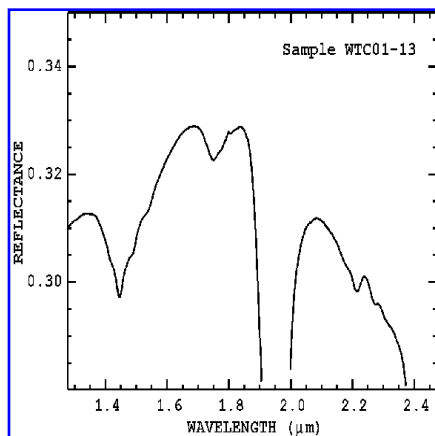
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Laboratory Spectra of WTC Sample WTC01-13



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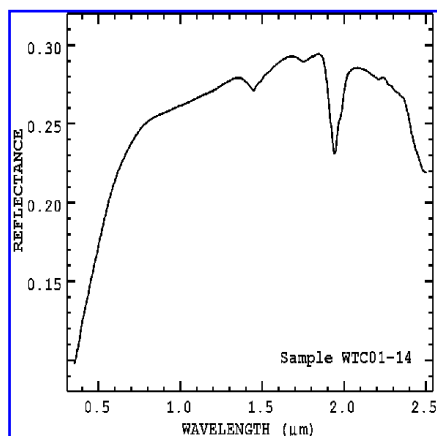
Dust sample from: Broadway and Barclay



[Larger 11 KB image](#)

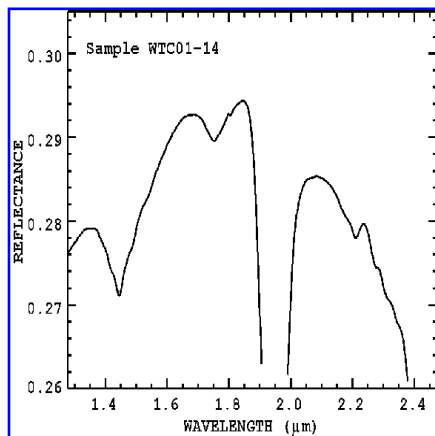
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Laboratory Spectra of WTC Sample WTC01-14



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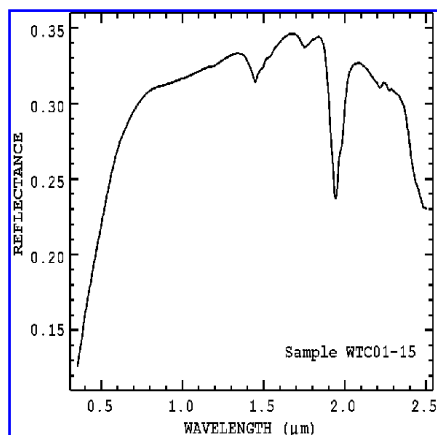
Dust sample from: Church and Barclay



[Larger 12 KB image](#)

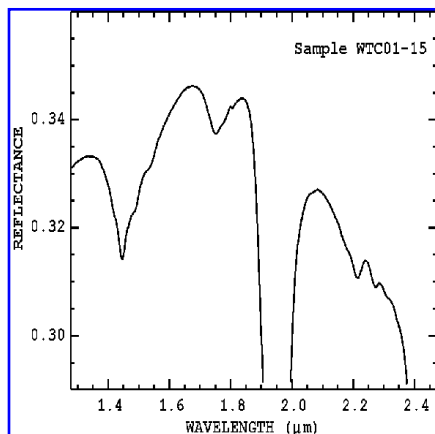
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Laboratory Spectra of WTC Sample WTC01-15



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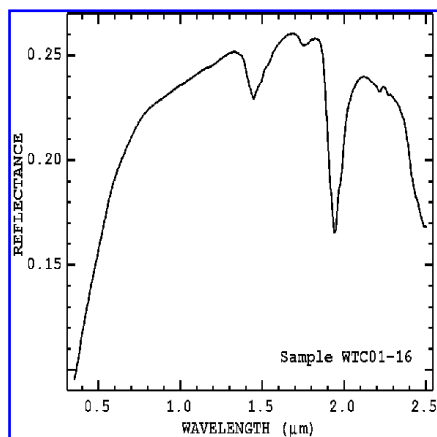
Dust sample from: Maiden Ln. and Church



[Larger 12 KB image](#)

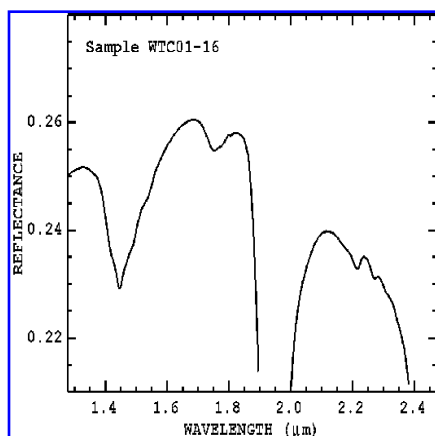
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Laboratory Spectra of WTC Sample WTC01-16



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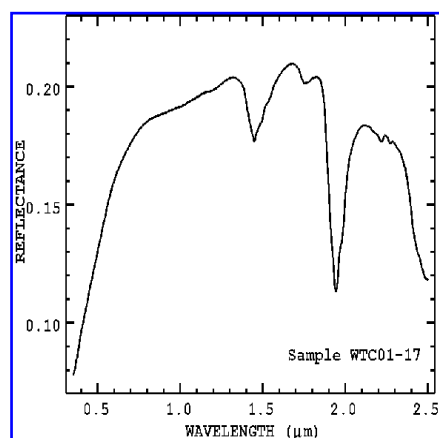
Dust sample from: Broadway and Dey



[Larger 11 KB image](#)

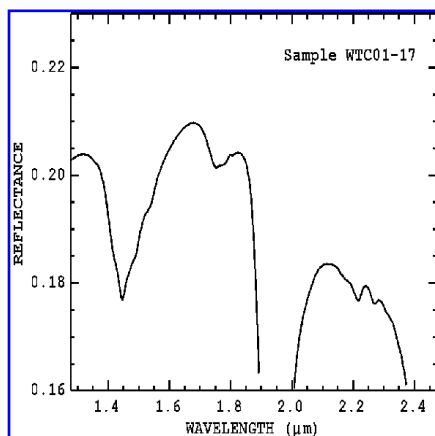
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Laboratory Spectra of WTC Sample WTC01-17



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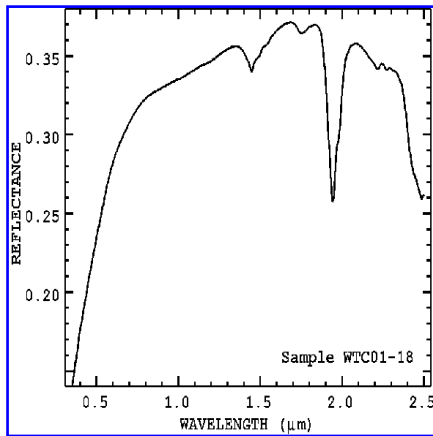
Dust sample from: Greenwich and Albany



[Larger 11 KB image](#)

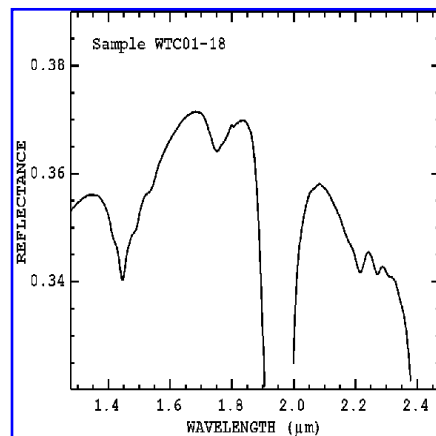
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Laboratory Spectra of WTC Sample WTC01-18



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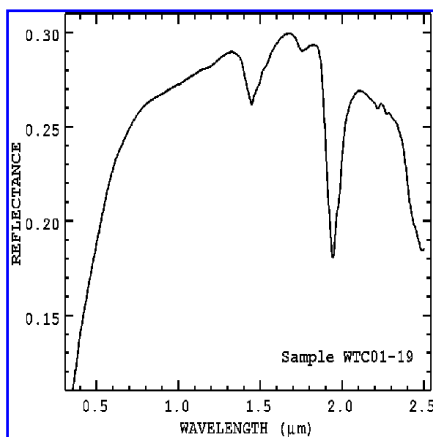
Dust sample from: Washington and Albany



[Larger 12 KB image](#)

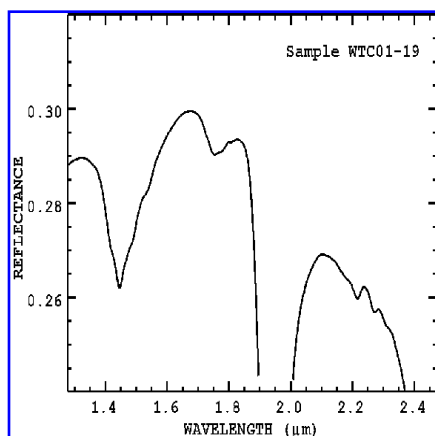
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Laboratory Spectra of WTC Sample WTC01-19



[Larger 11 KB image](#)

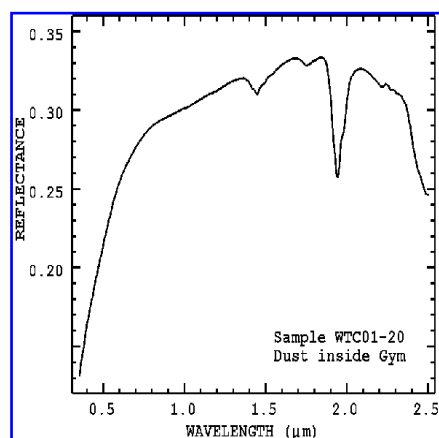
Dust sample from: South End and Cedar



[Larger 11 KB image](#)

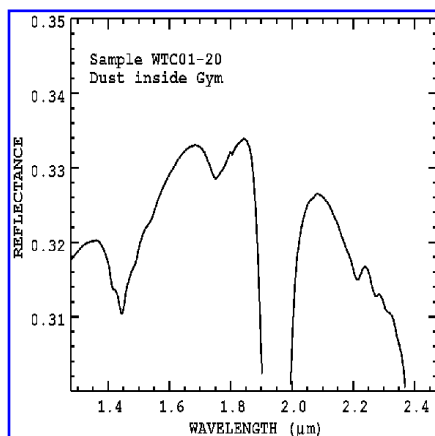
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Laboratory Spectra of WTC Sample WTC01-20



[Larger 11 KB image](#)

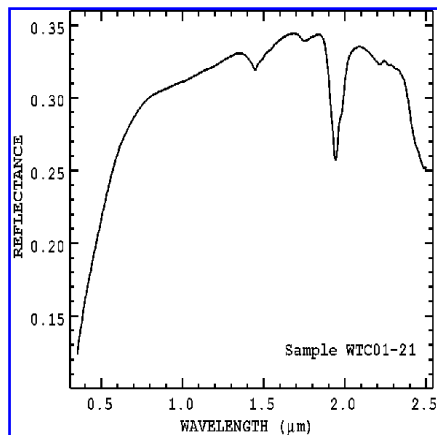
Dust sample from: Liberty and South End



[Larger 12 KB image](#)

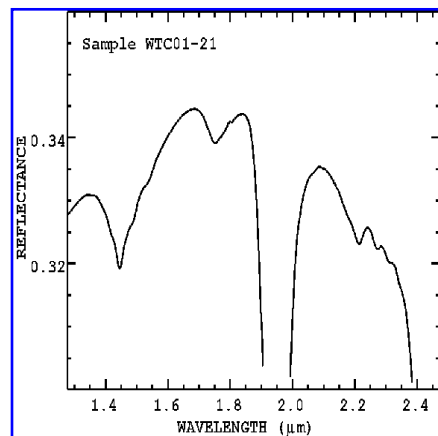
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Laboratory Spectra of WTC Sample WTC01-21



[Larger 11 KB image](#)

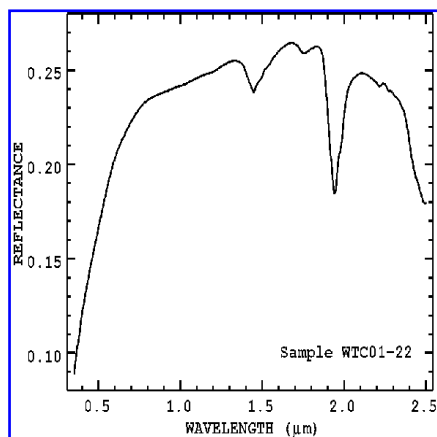
Dust sample from: Directly west of the WTC at ferry dock on pedestrian mall



[Larger 11 KB image](#)

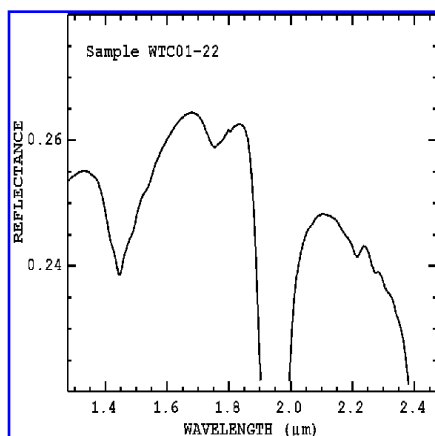
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Laboratory Spectra of WTC Sample WTC01-22



[Larger 11 KB image](#)

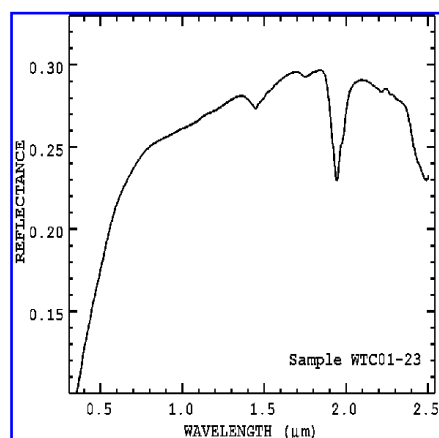
Dust sample from: half way between WTC and ferry dock along pedestrian mall



[Larger 11 KB image](#)

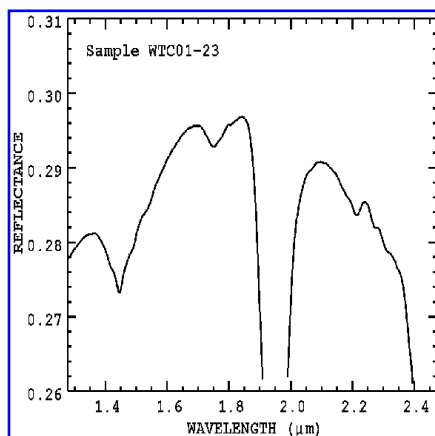
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Laboratory Spectra of WTC Sample WTC01-23



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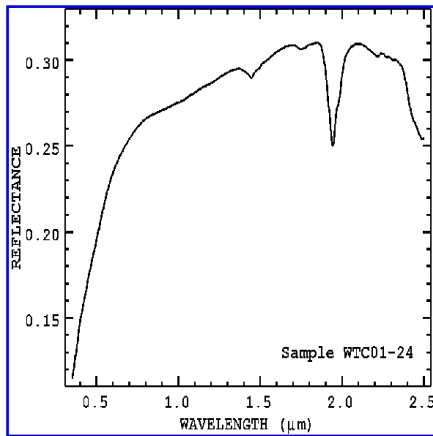
Dust sample from: Broadway and Murray



[Larger 12 KB image](#)

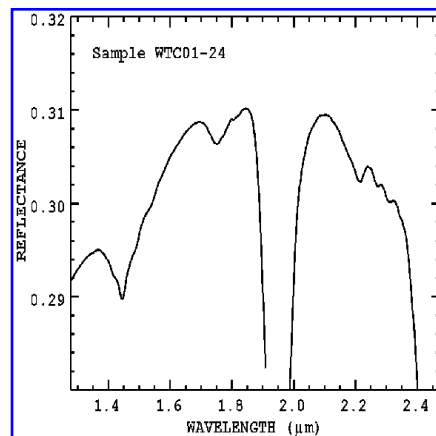
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-24



[Larger 11 KB image](#)

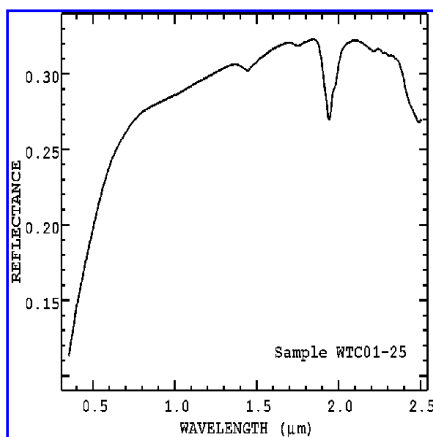
Dust sample from: Broadway and Chambers



[Larger 12 KB image](#)

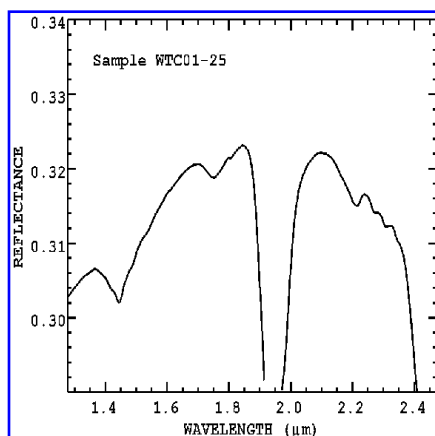
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Laboratory Spectra of WTC Sample WTC01-25



[Larger 10 KB image](#)

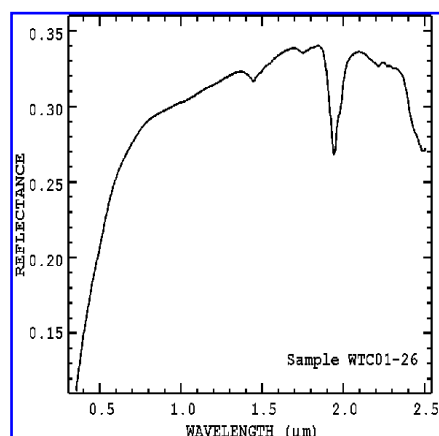
Dust sample from: Church and Warren



[Larger 12 KB image](#)

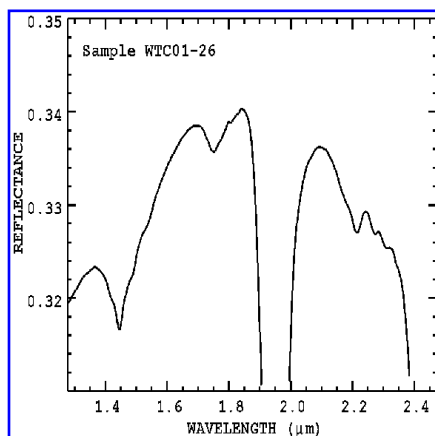
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-26



[Larger 11 KB image](#)

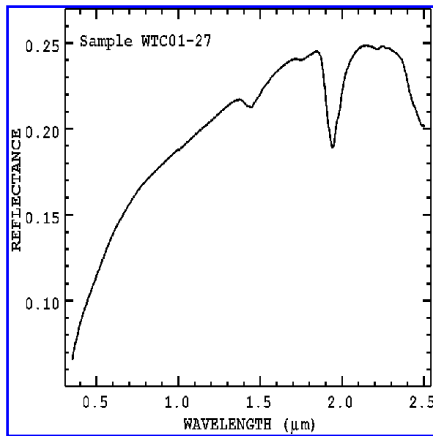
Dust sample from: one half way between Broadway and Church on Park



[Larger 12 KB image](#)

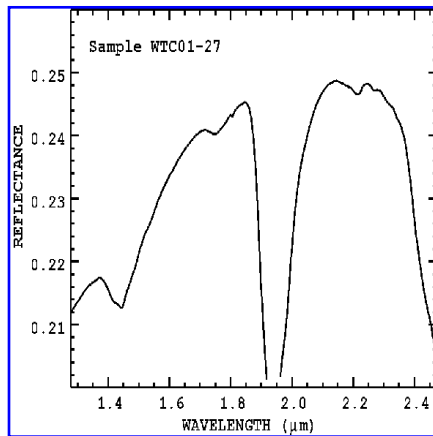
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-27



[Larger 11 KB image](#)

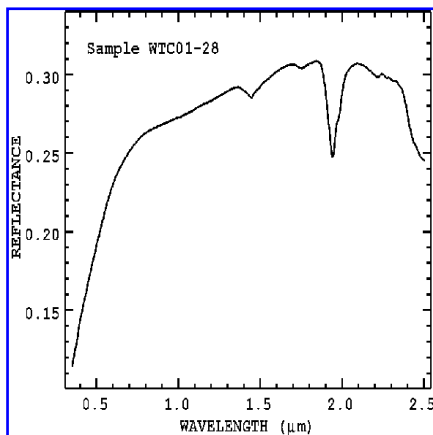
Dust sample from: Broadway and Vessey



[Larger 12 KB image](#)

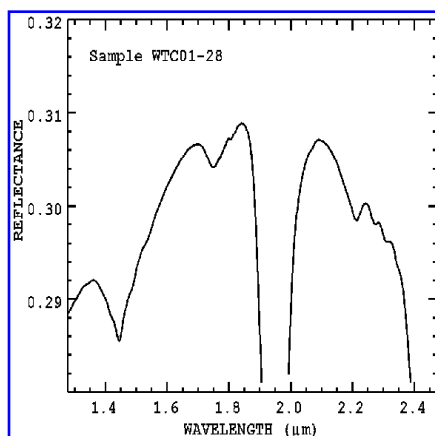
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-28



[Larger 10 KB image](#)

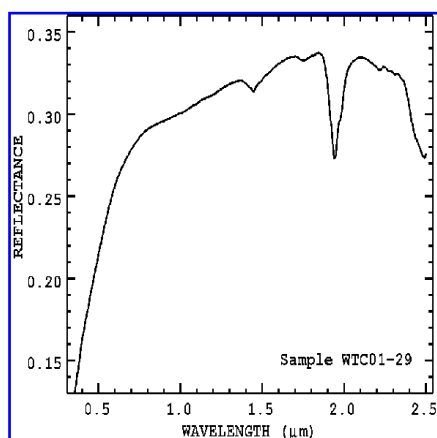
Dust sample from: Ann and Nassau



[Larger 12 KB image](#)

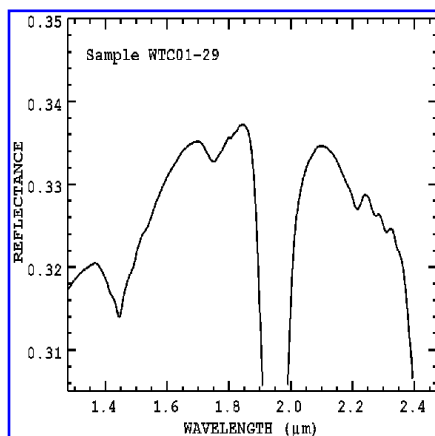
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-29



[Larger 11 KB image](#)

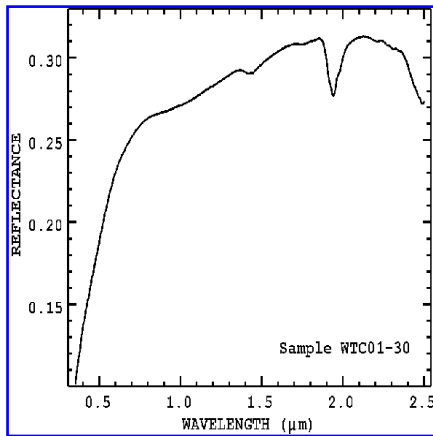
Dust sample from: William and Fulton



[Larger 12 KB image](#)

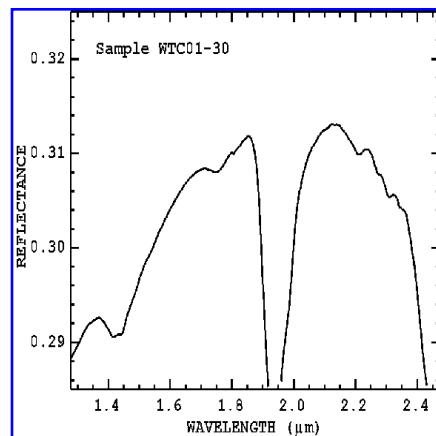
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-30



[Larger 10 KB image](#)

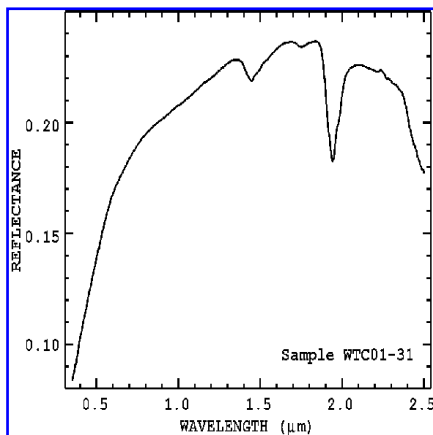
Dust sample from: Fulton and Cliff St.



[Larger 12 KB image](#)

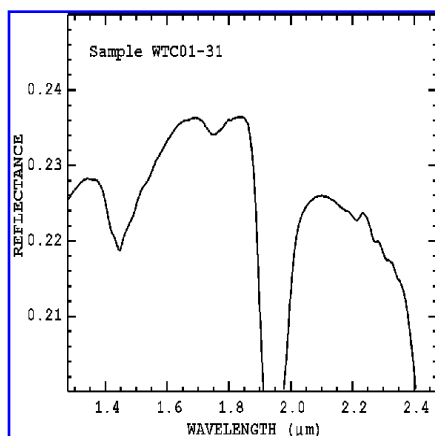
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-31



[Larger 11 KB image](#)

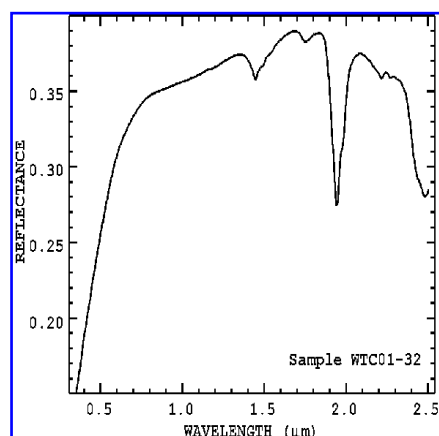
Dust sample from: William and Platt



[Larger 12 KB image](#)

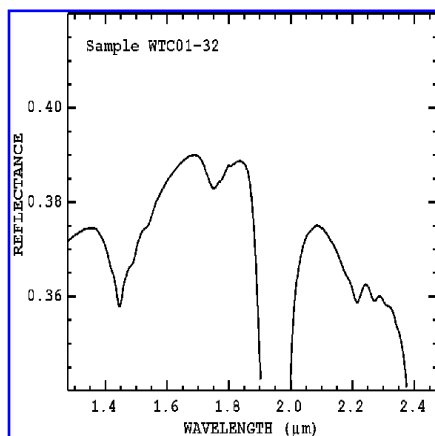
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-32



[Larger 11 KB image](#)

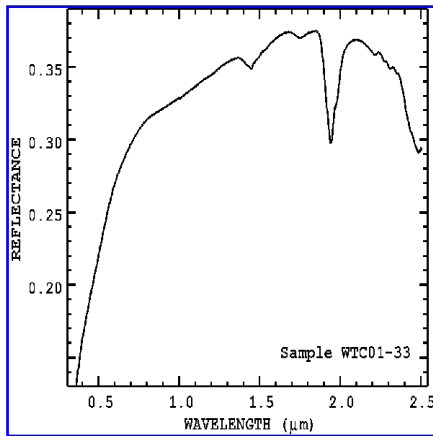
Dust sample from: William and Pine



[Larger 11 KB image](#)

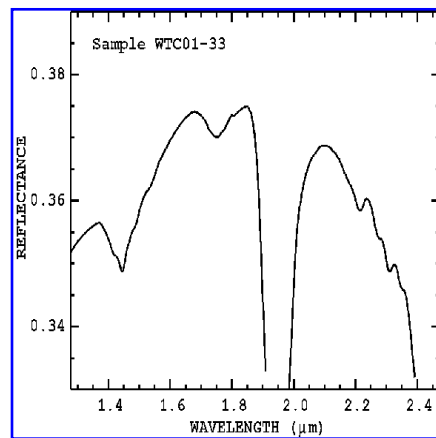
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-33



[Larger 11 KB image](#)

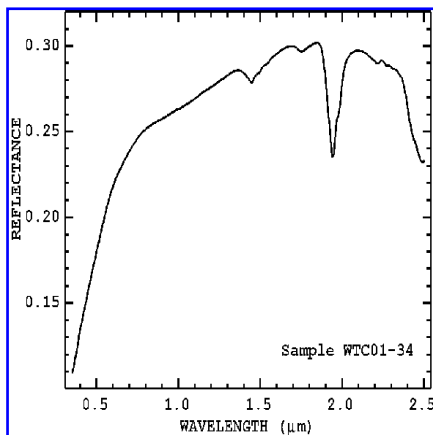
Dust sample from: middle of Battery Park



[Larger 12 KB image](#)

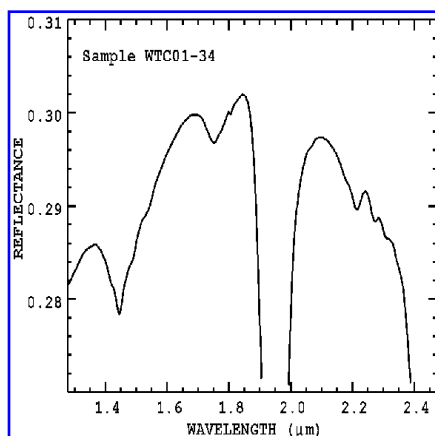
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-34



[Larger 11 KB image](#)

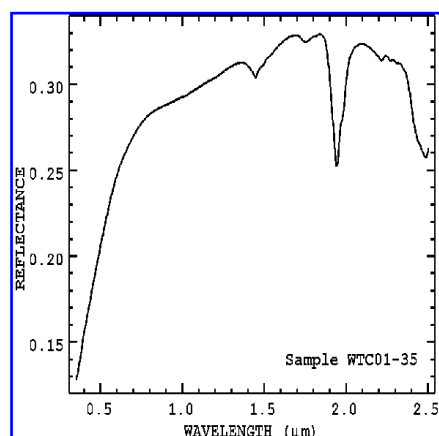
Dust sample from: South End and Thames



[Larger 12 KB image](#)

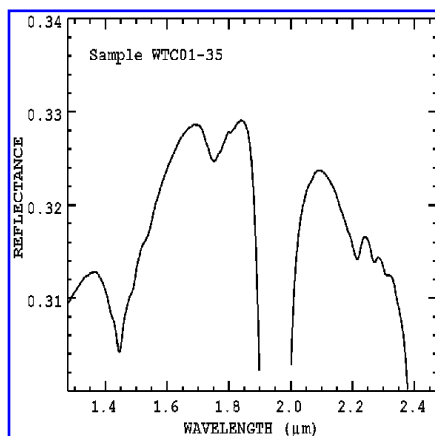
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-35



[Larger 11 KB image](#)

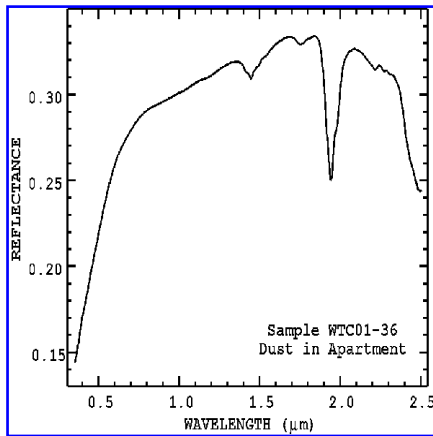
Dust sample from: Albany and Hudson River



[Larger 12 KB image](#)

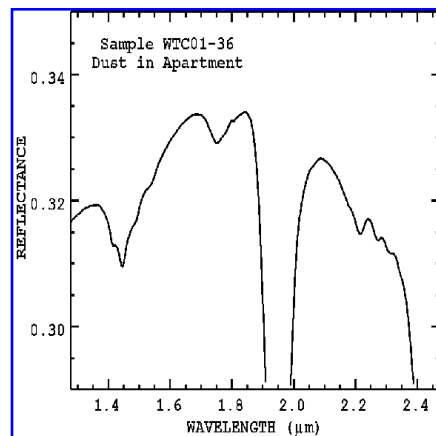
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-36



[Larger 11 KB image](#)

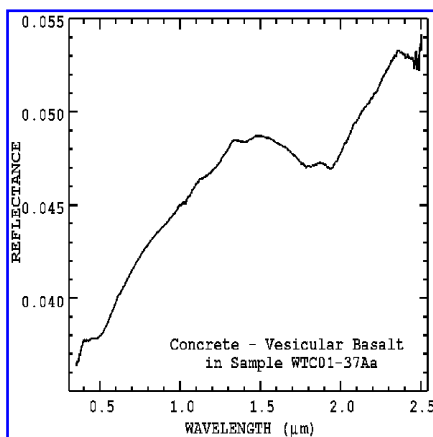
Dust sample from: South End and Albany (inside apartment)



[Larger 12 KB image](#)

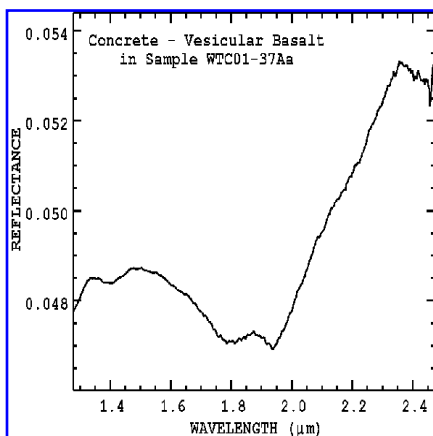
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-37Aa



[Larger 11 KB image](#)

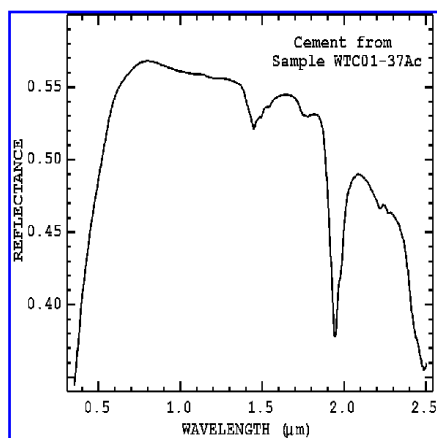
Dust sample from:



[Larger 12 KB image](#)

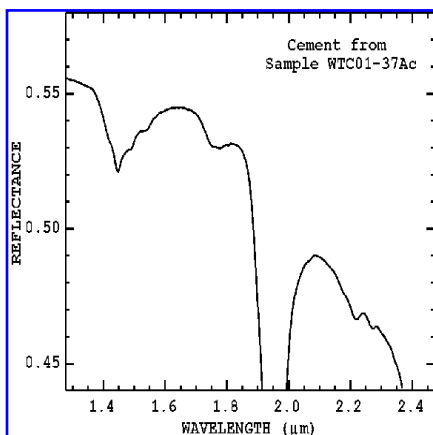
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-37Ac



[Larger 12 KB image](#)

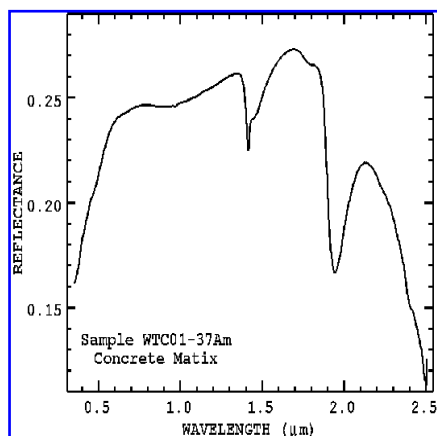
Dust sample from:



[Larger 11 KB image](#)

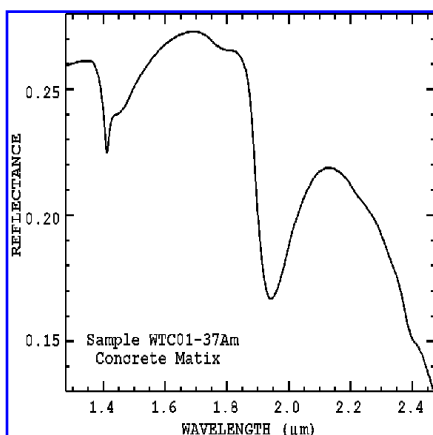
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-37Am



[Larger 12 KB image](#)

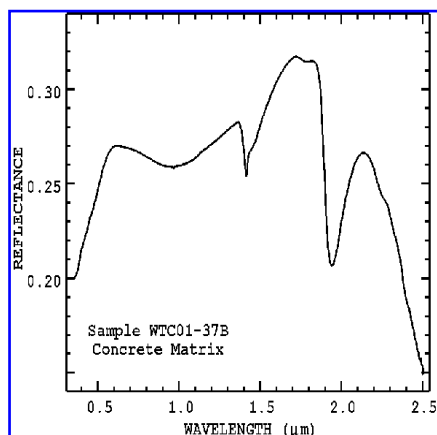
Dust sample from:



[Larger 12 KB image](#)

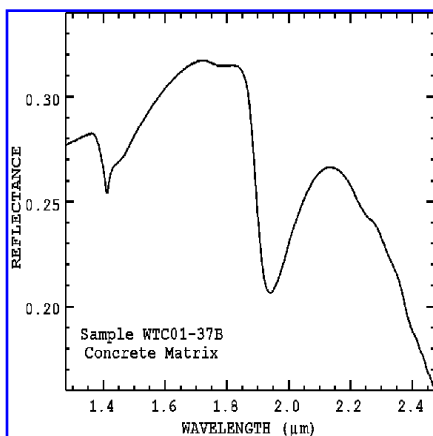
[Click here to get ascii data.](#)

Laboratory Spectra of WTC Sample WTC01-37B



[Larger 12 KB image](#)

Dust sample from:



[Larger 11 KB image](#)

[Click here to get ascii data.](#)

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[Back to document Table of Contents](#)

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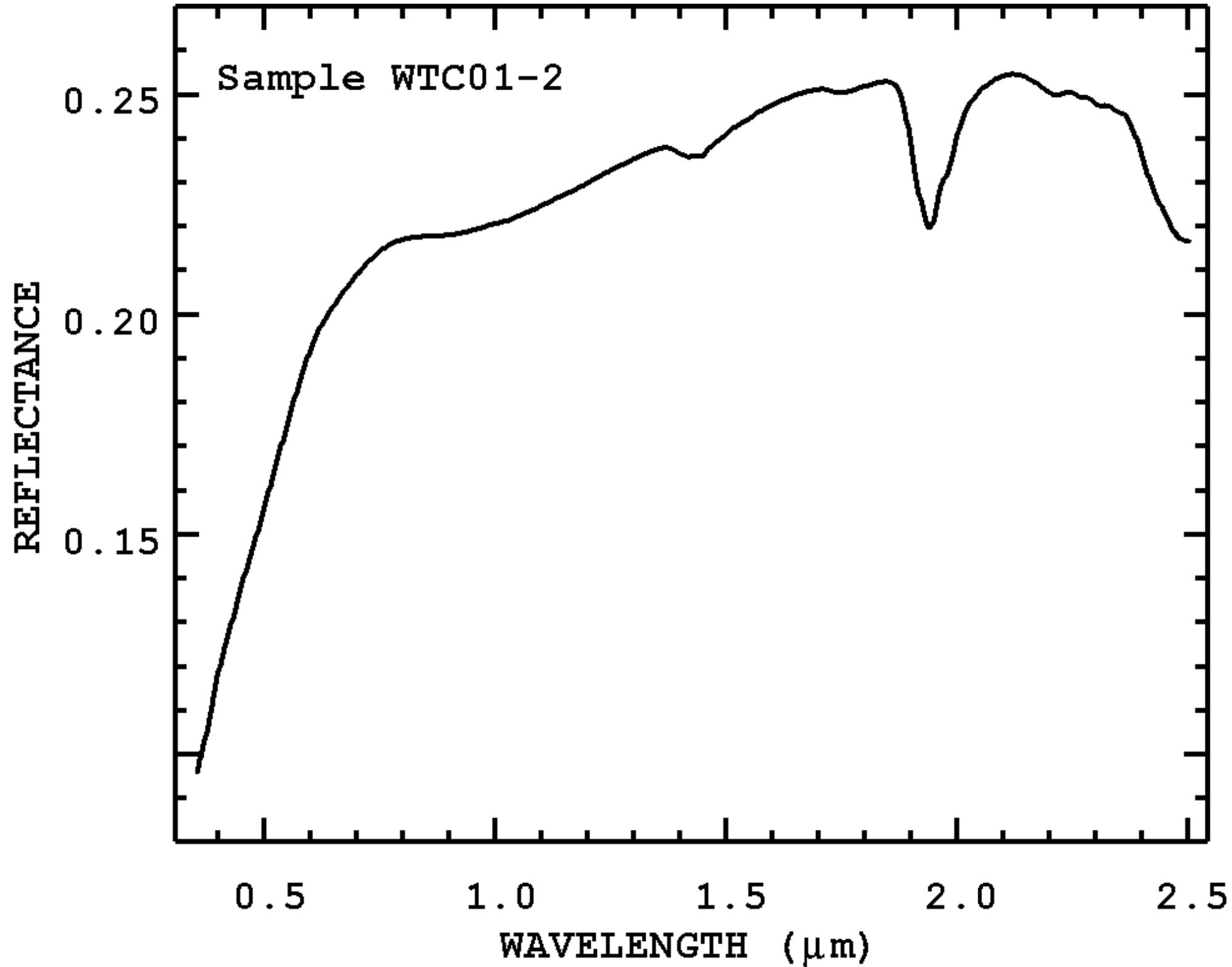
[U.S. Department of the Interior](#) | [U.S. Geological Survey](#)

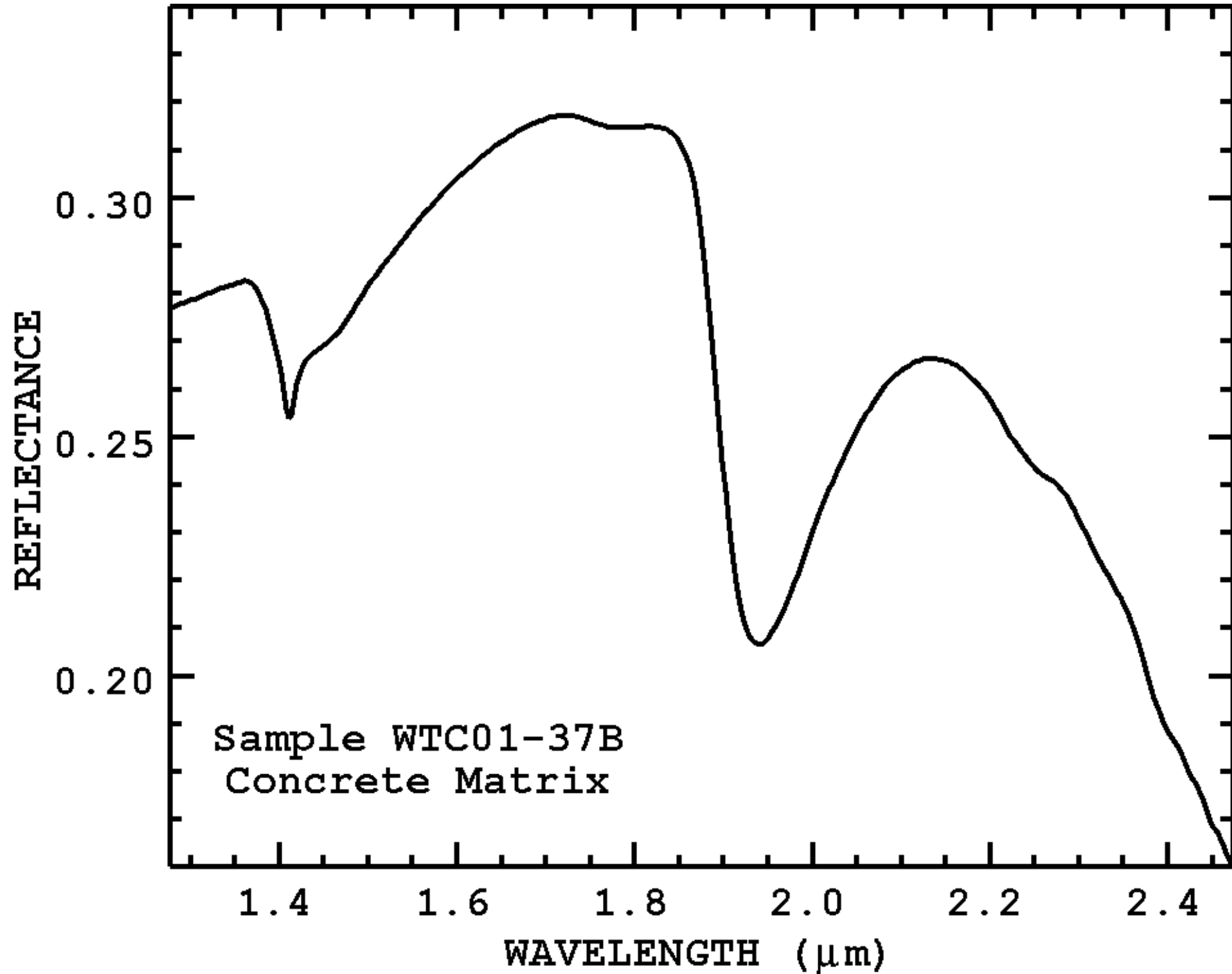
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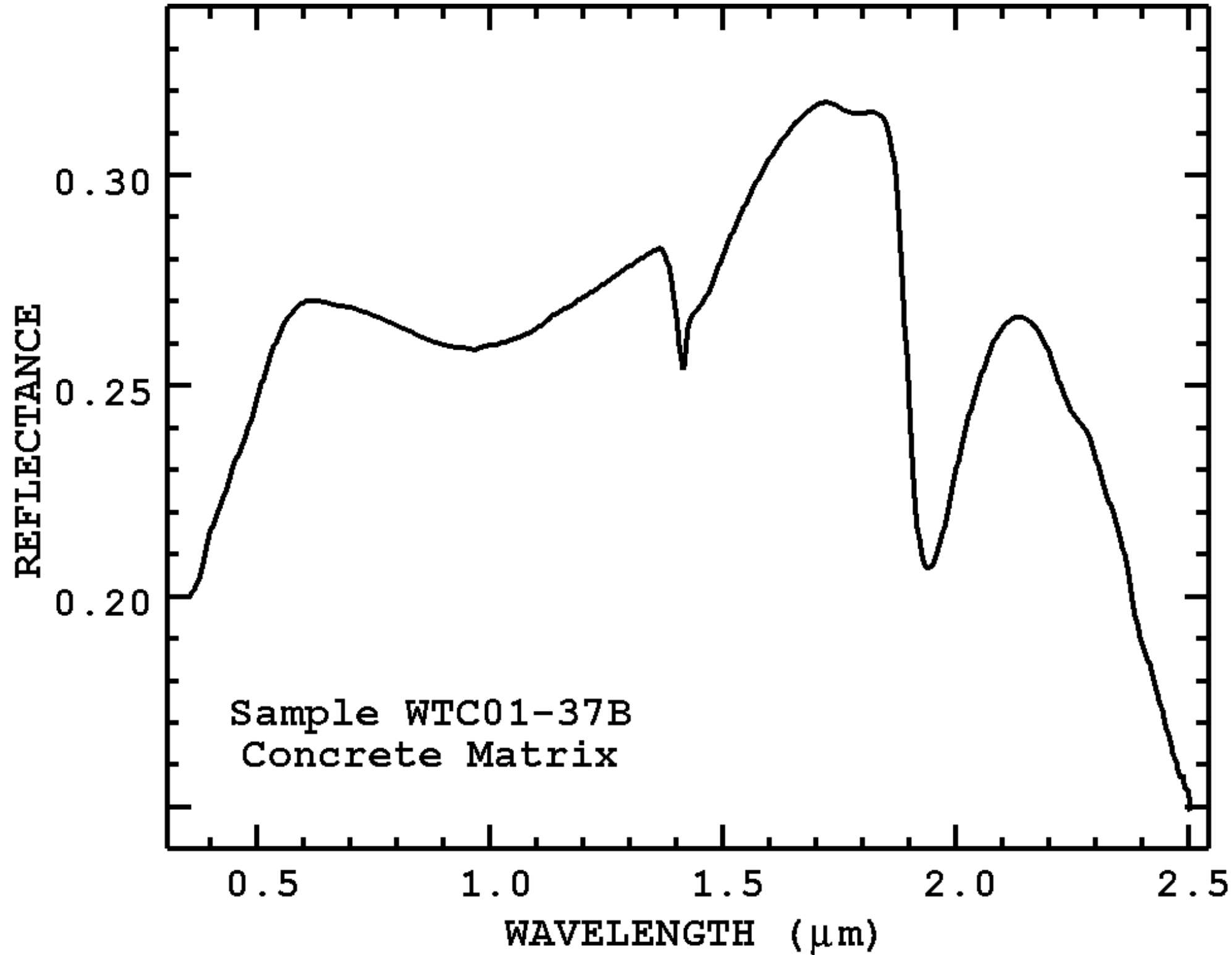
Questions or Assistance: [Contact USGS](#)

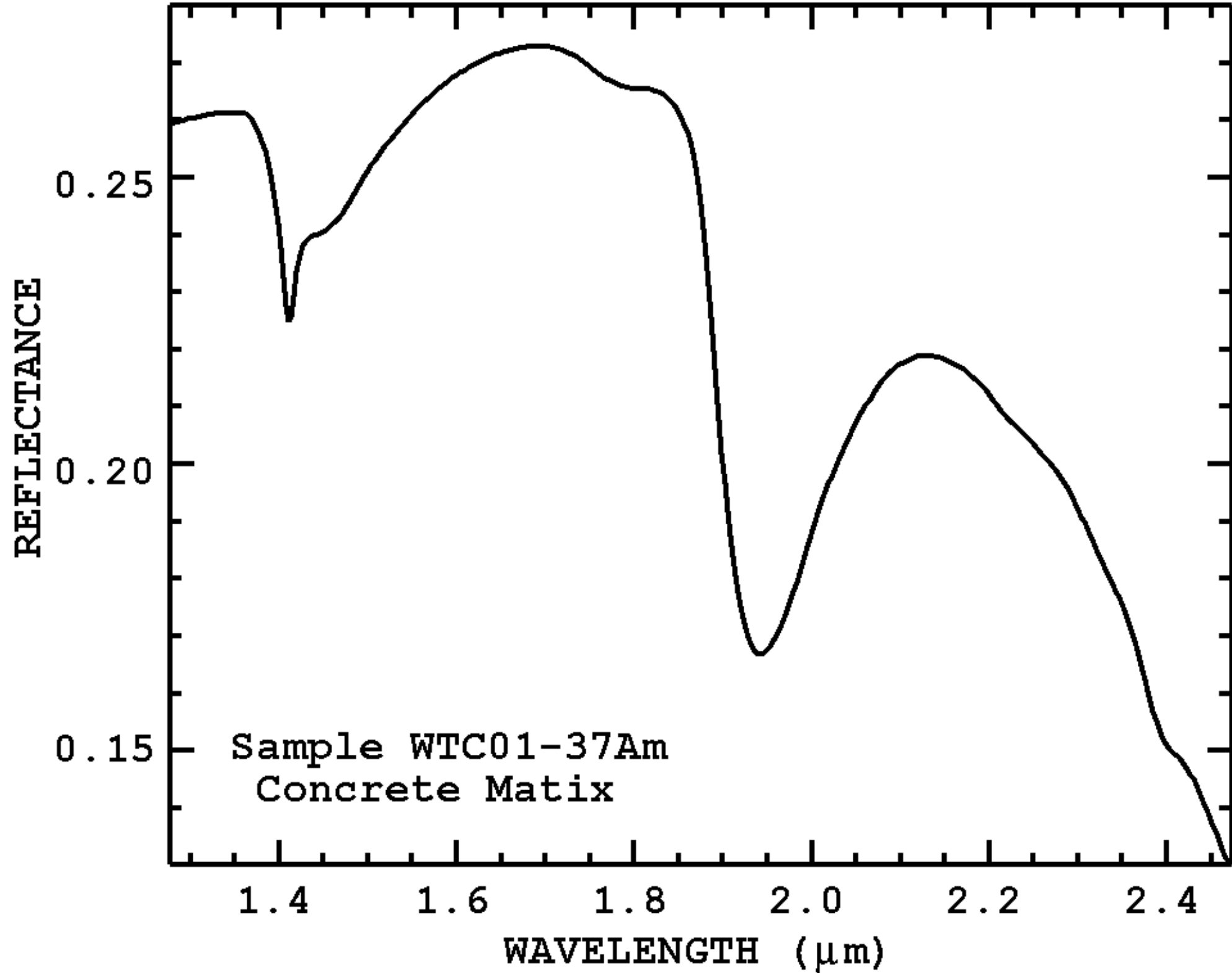
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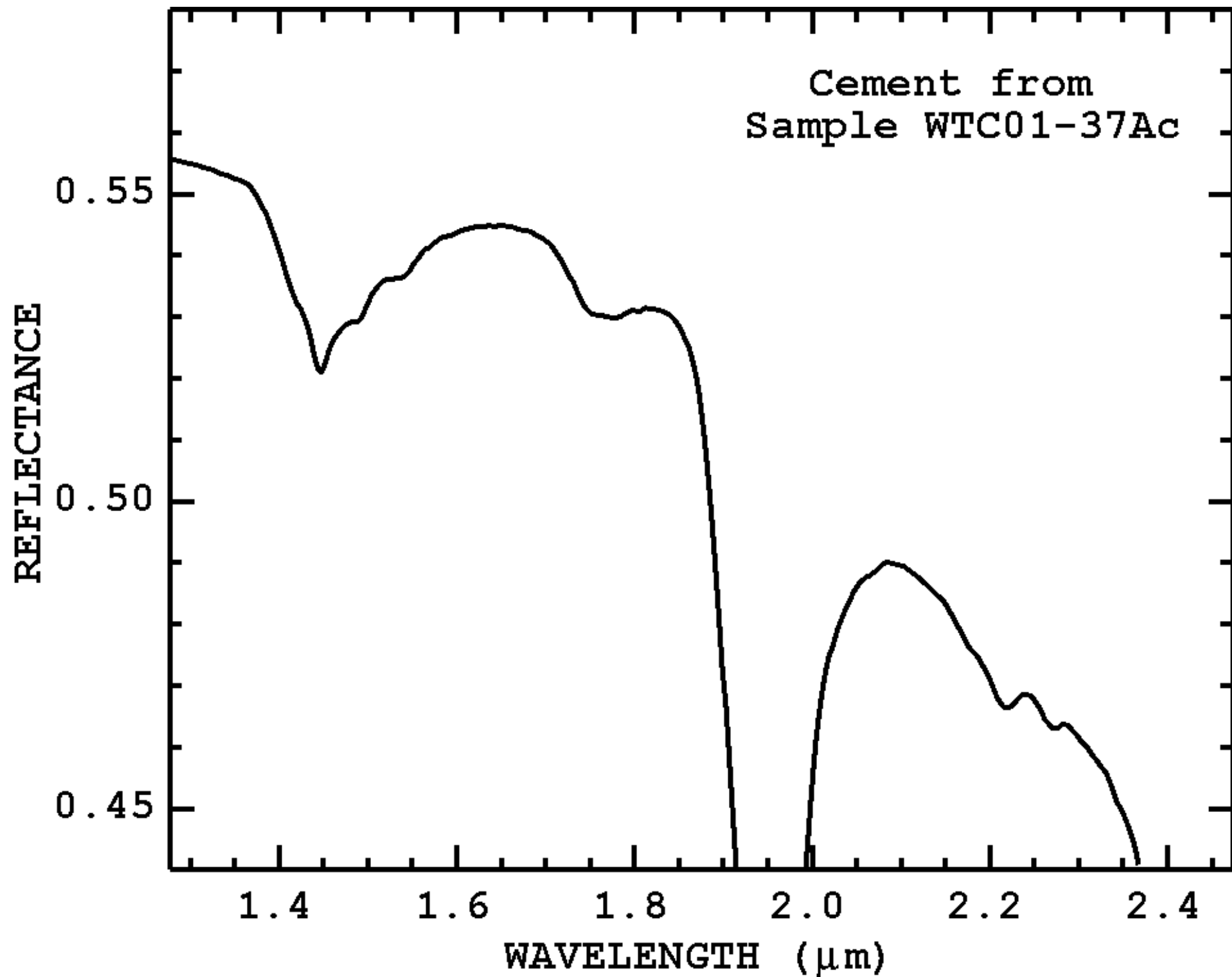


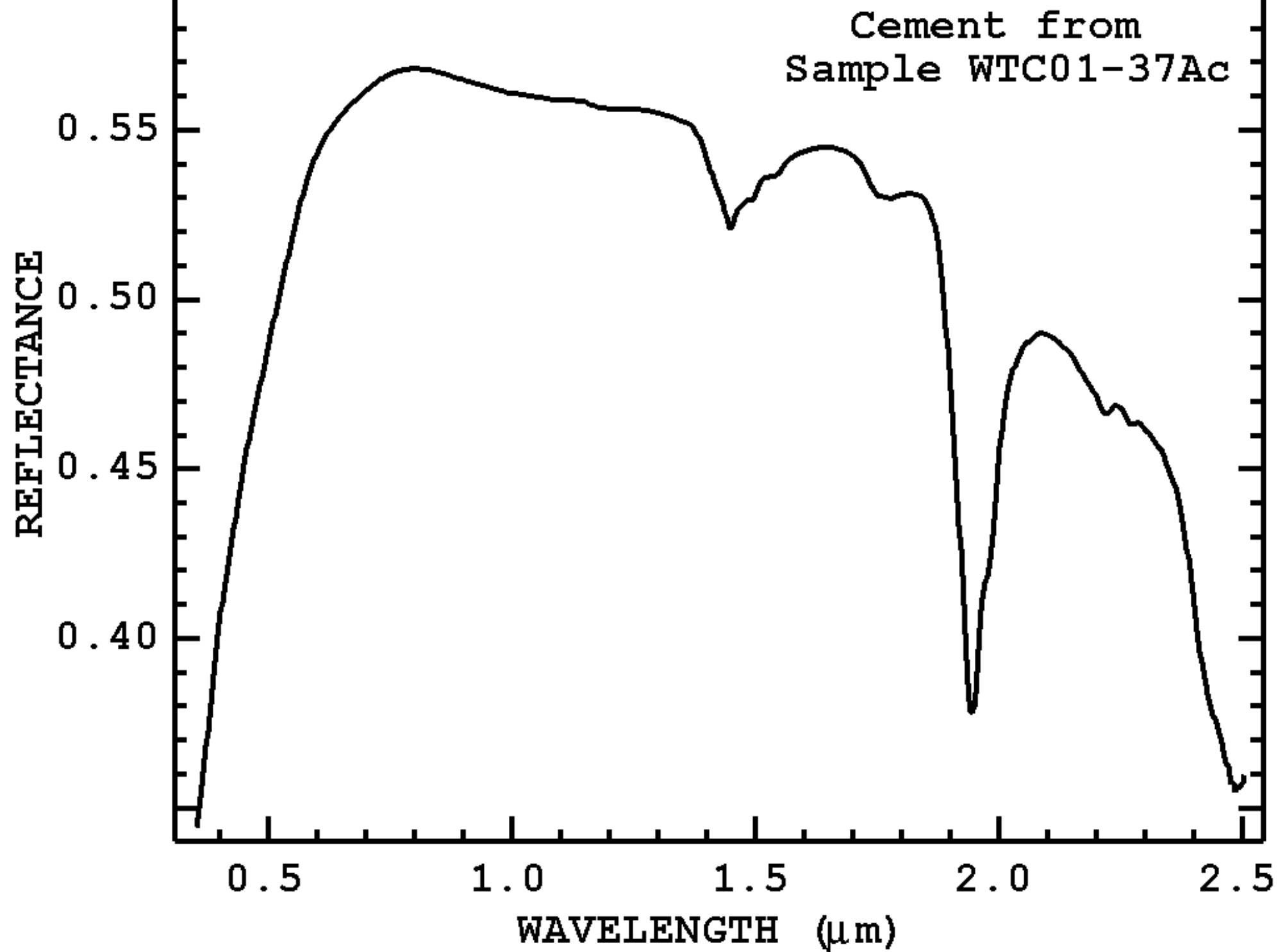


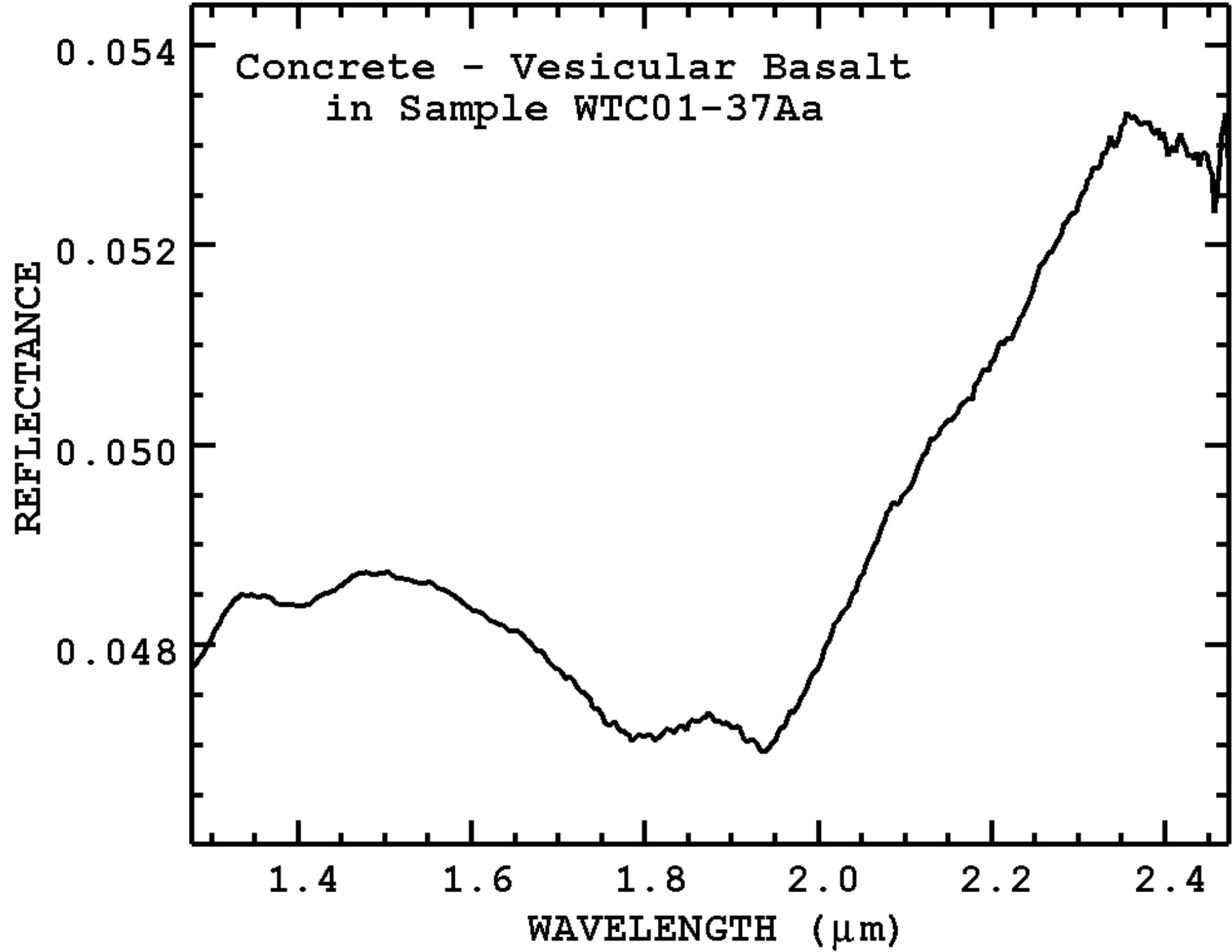


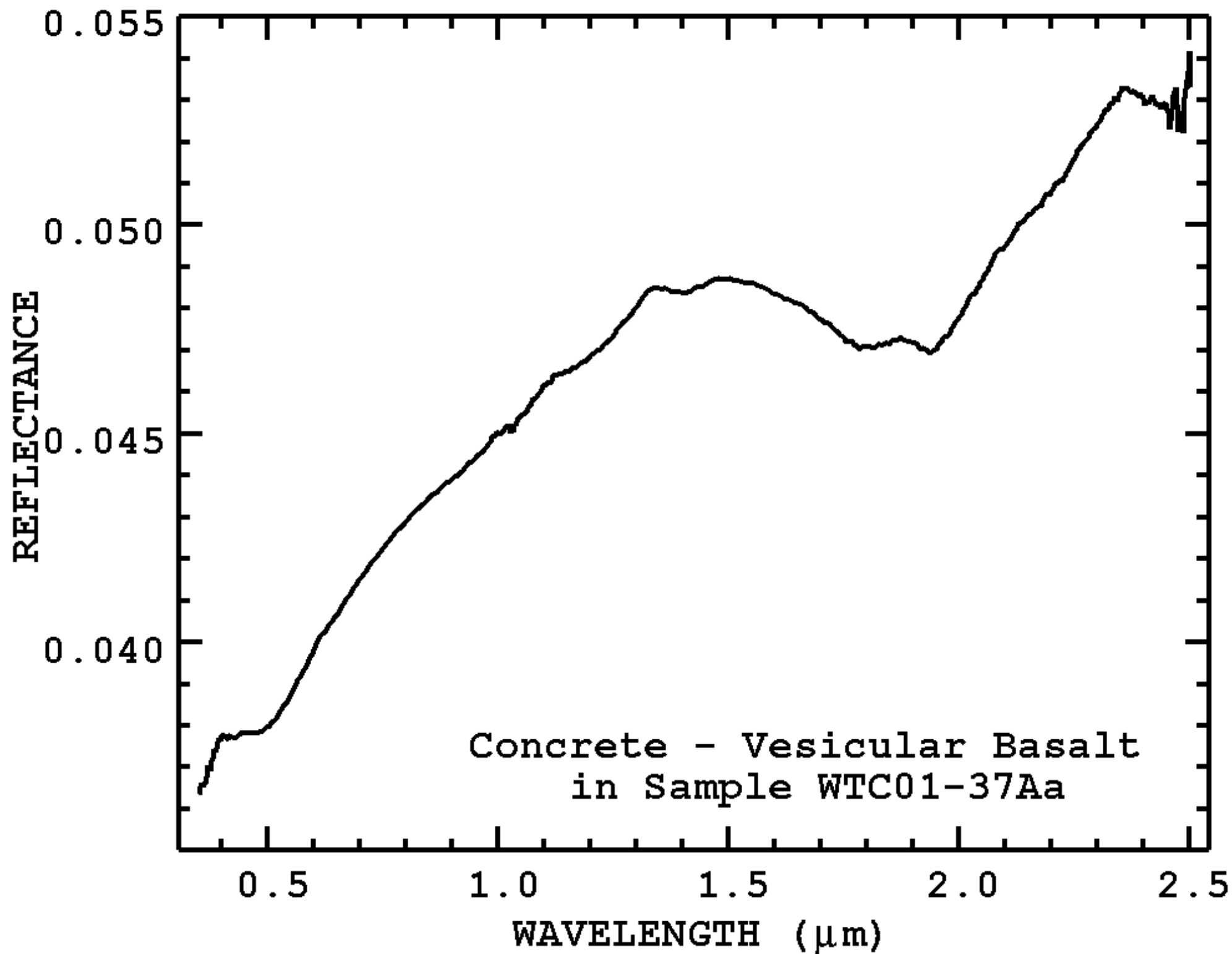


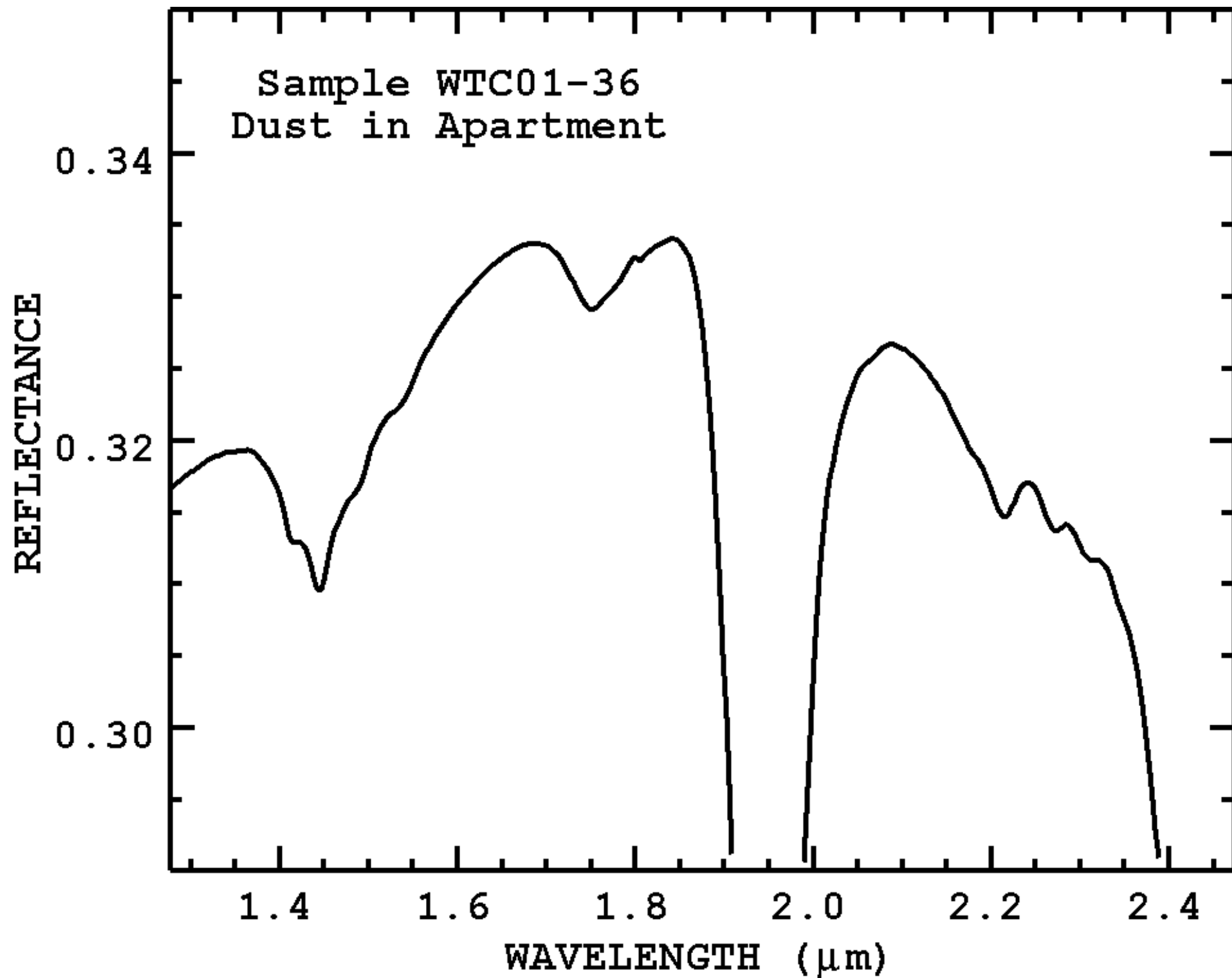


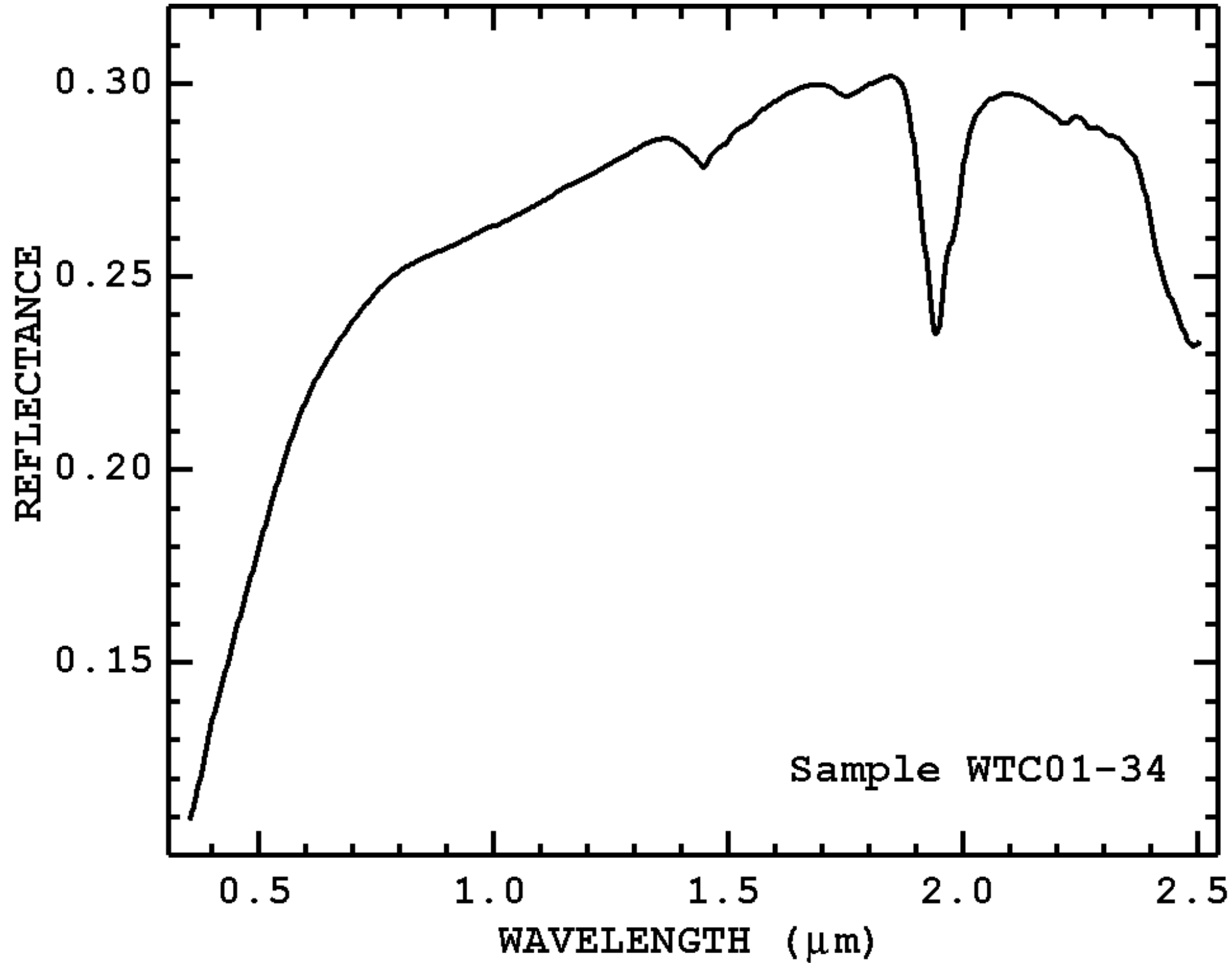


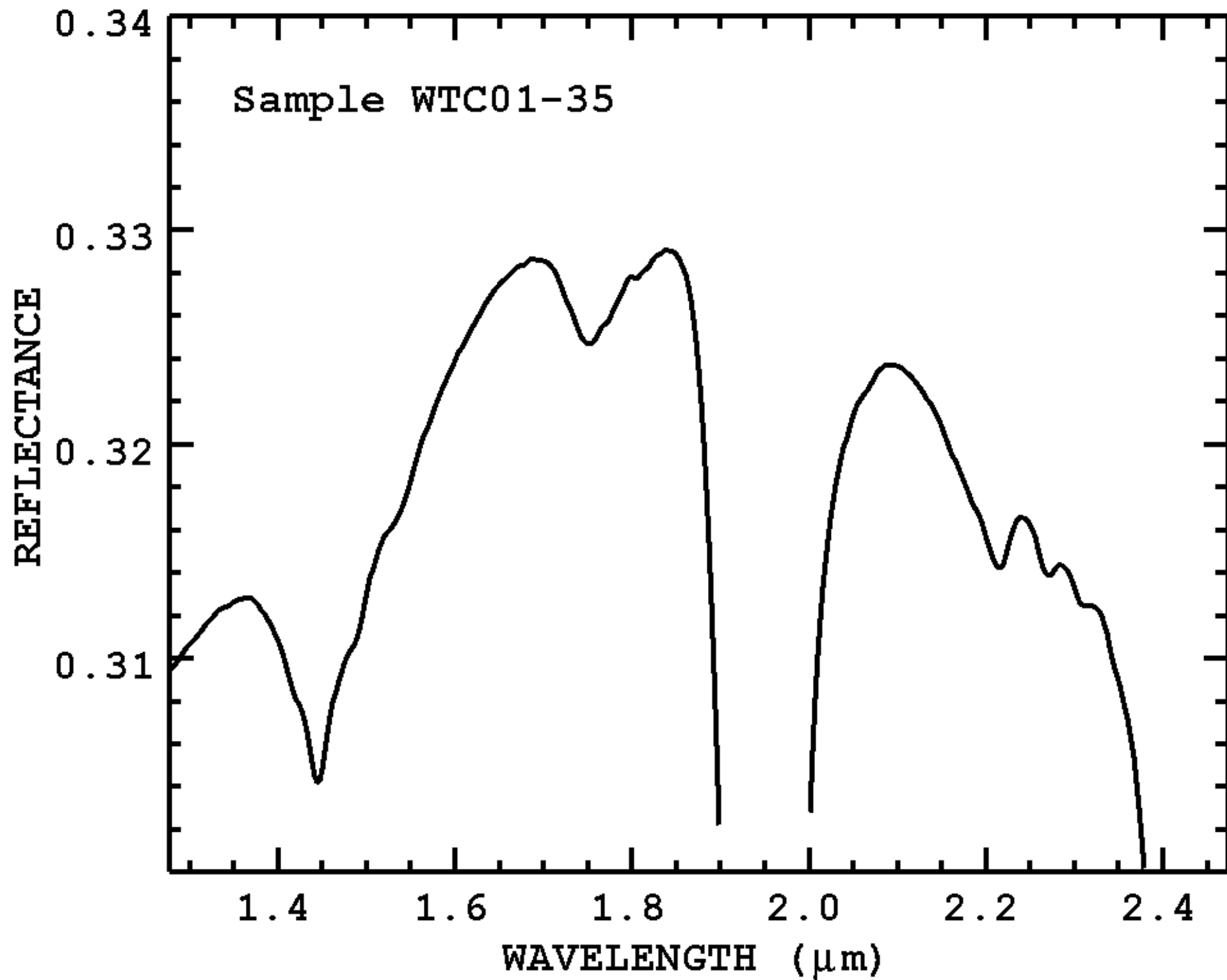


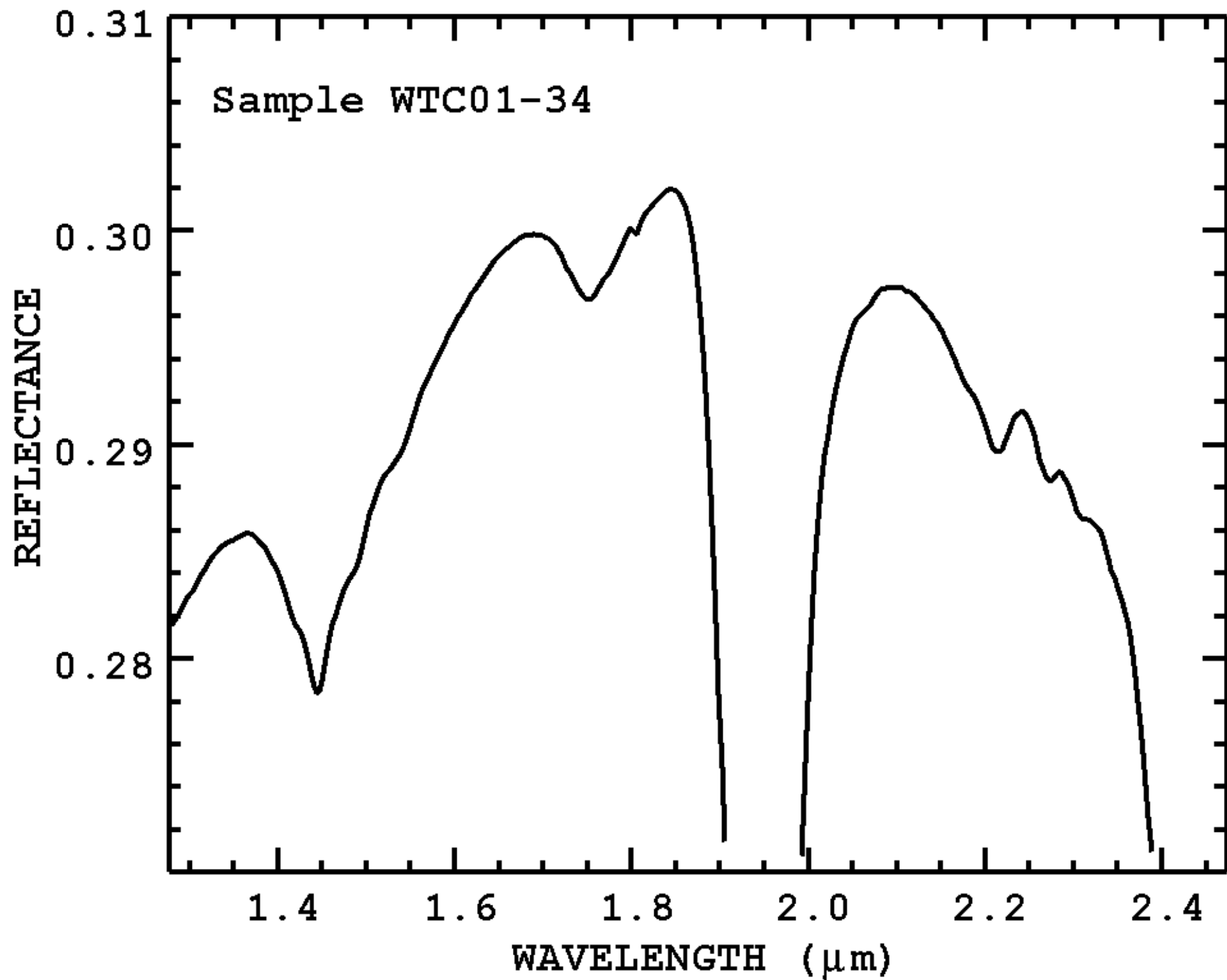


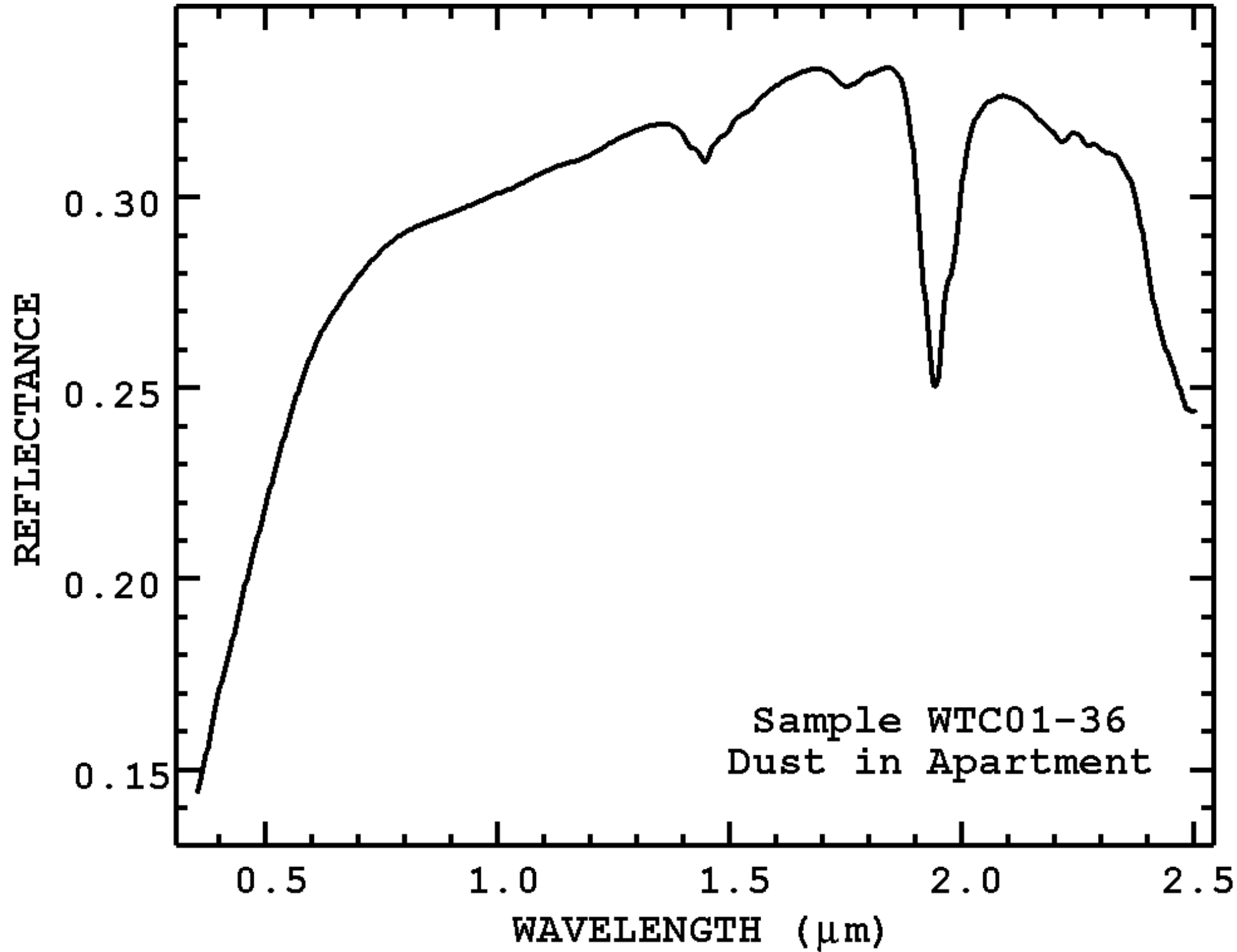


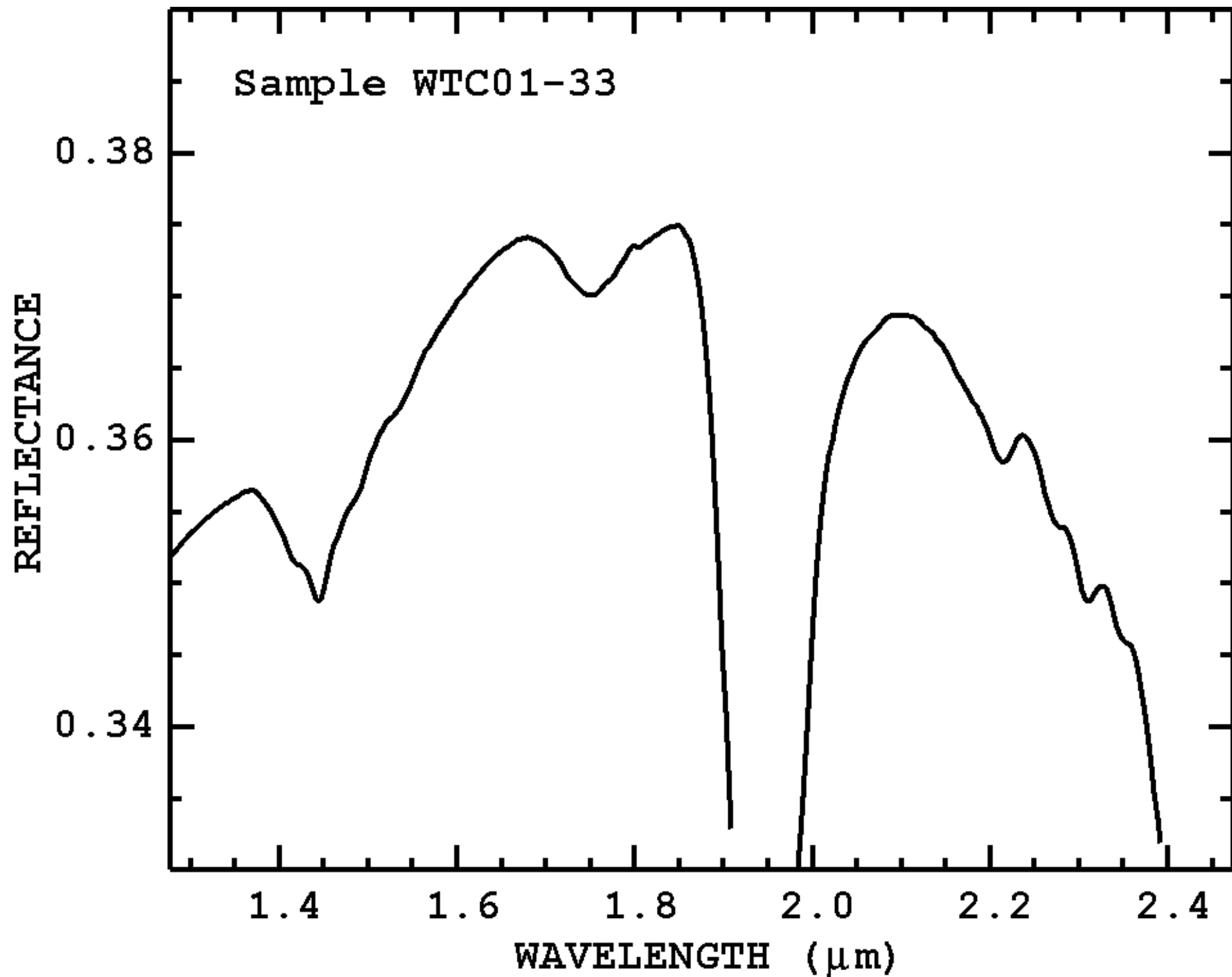


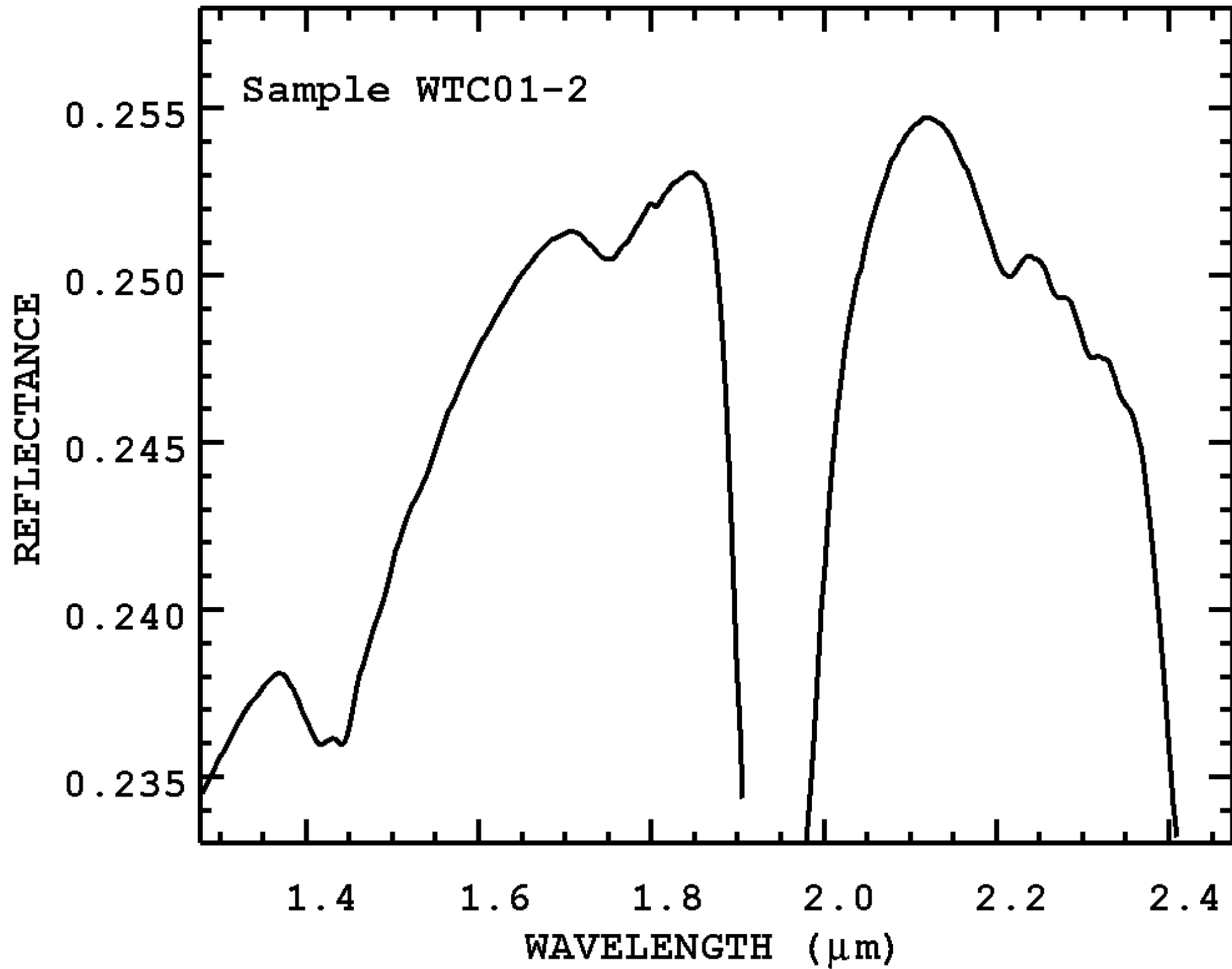


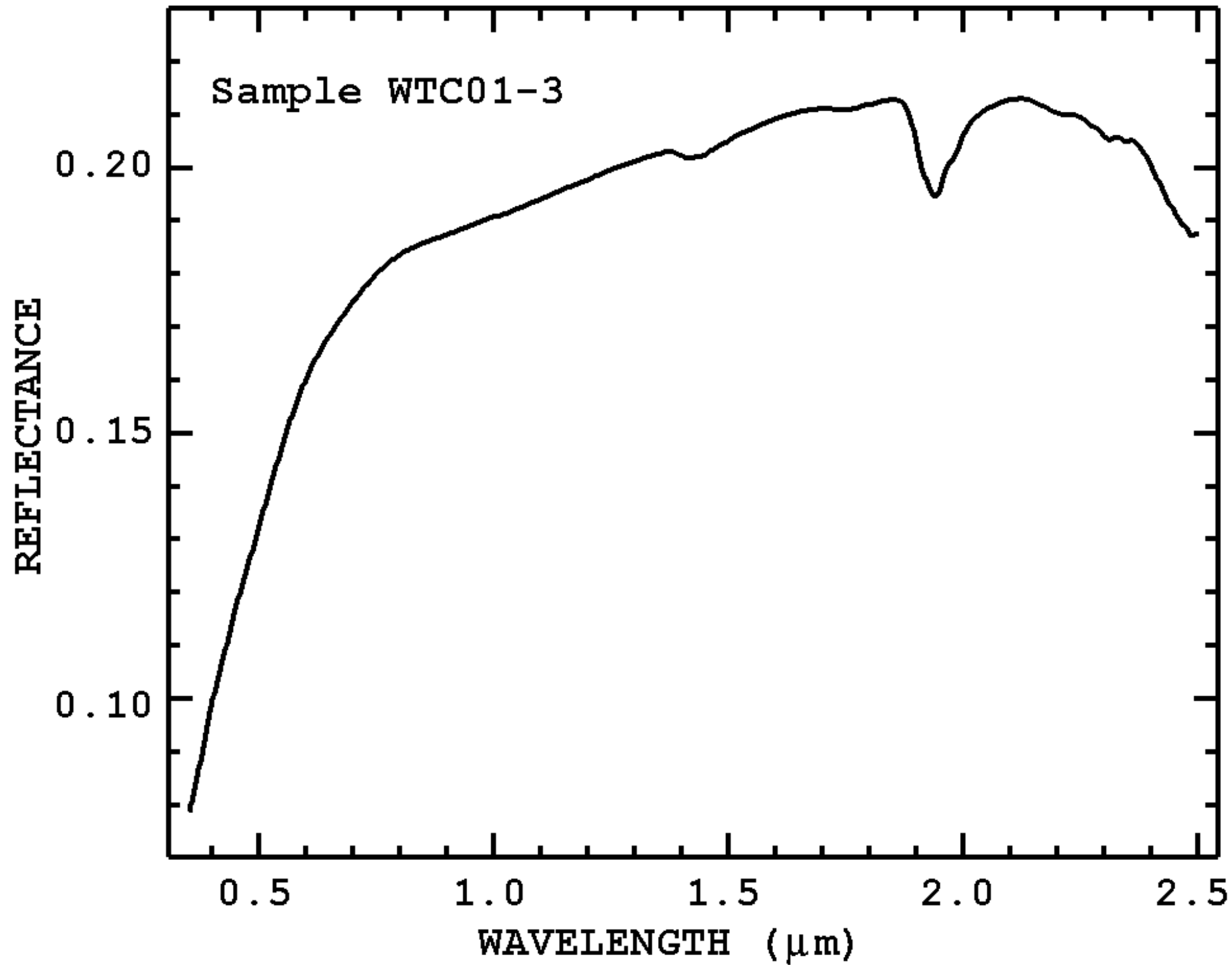


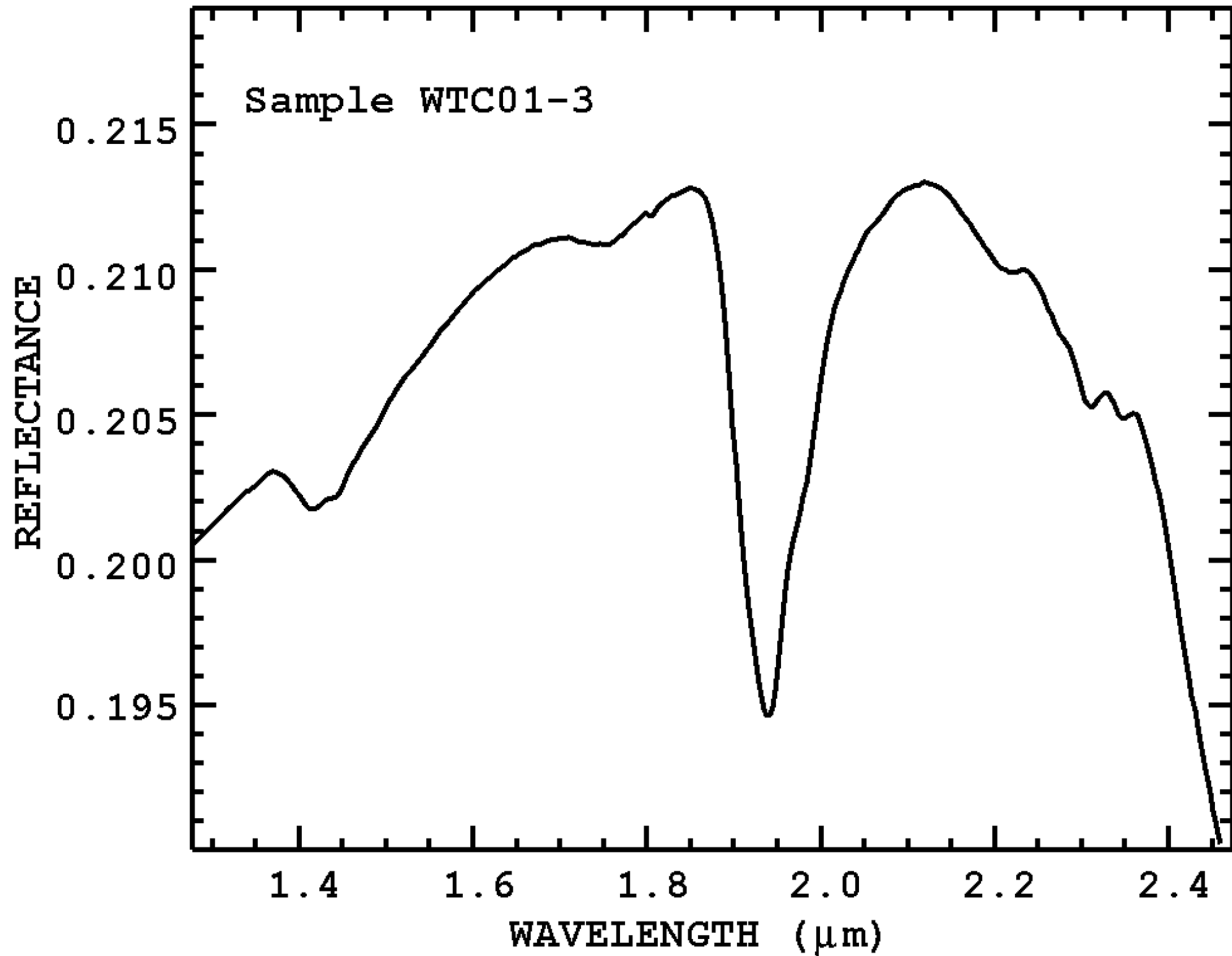


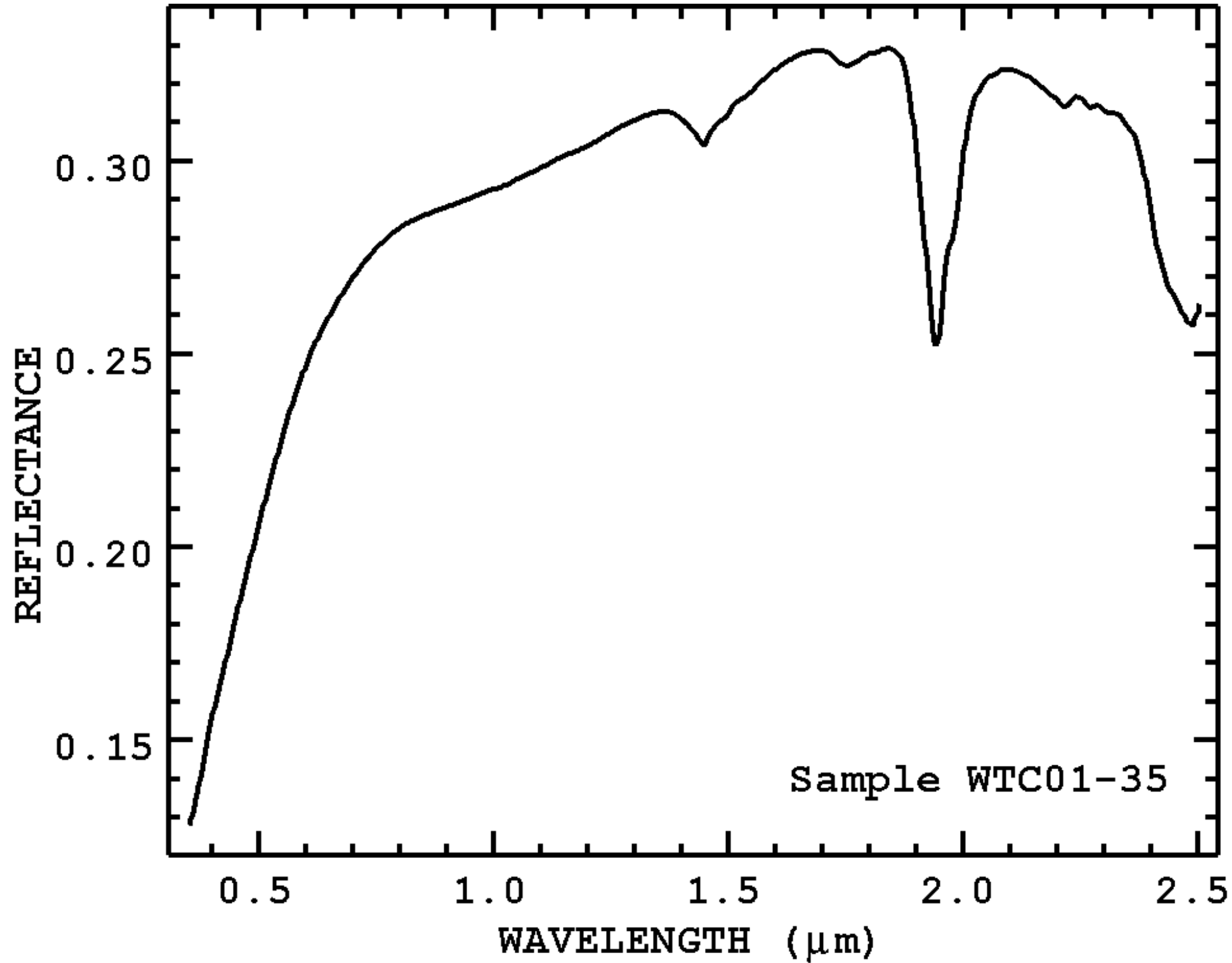


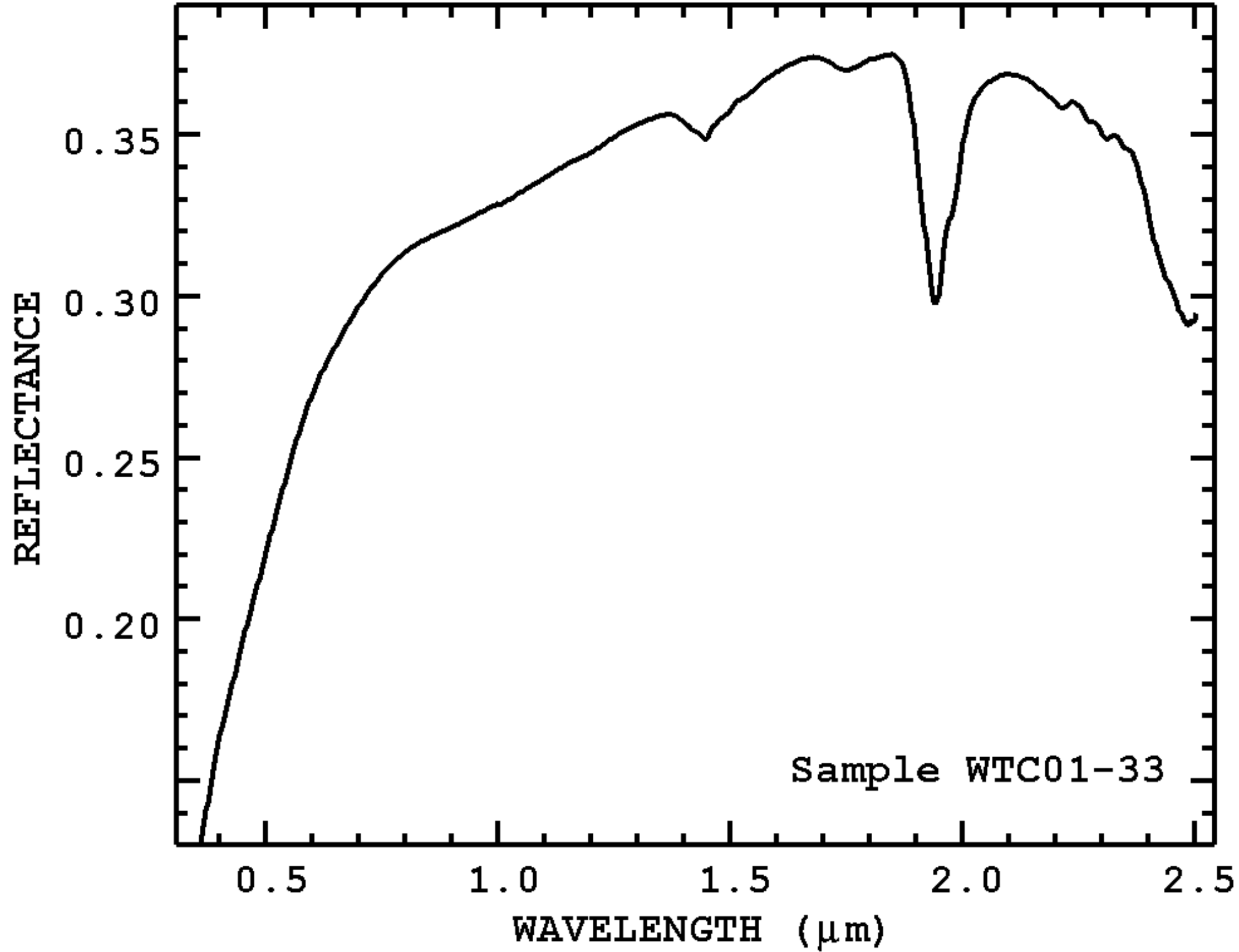


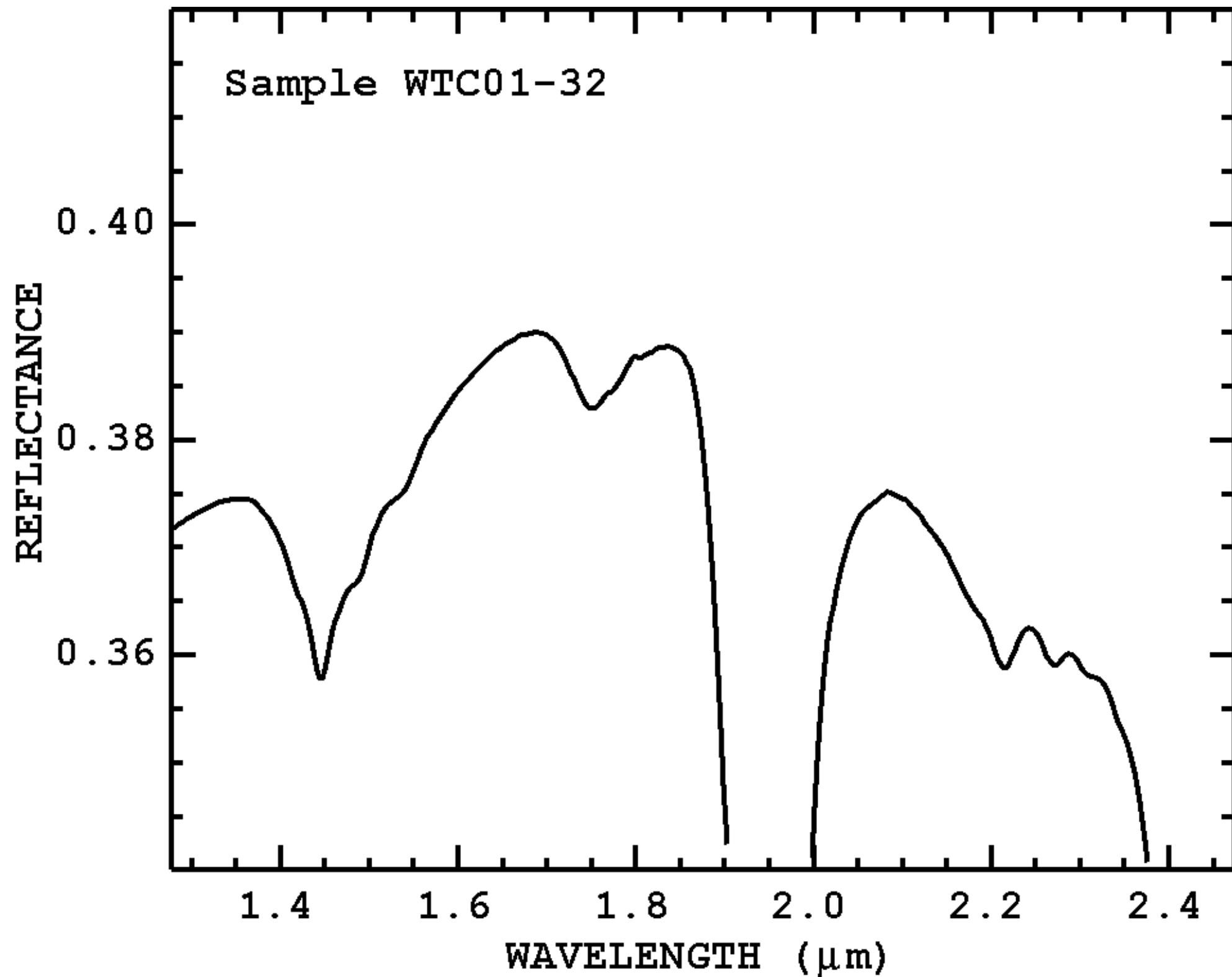


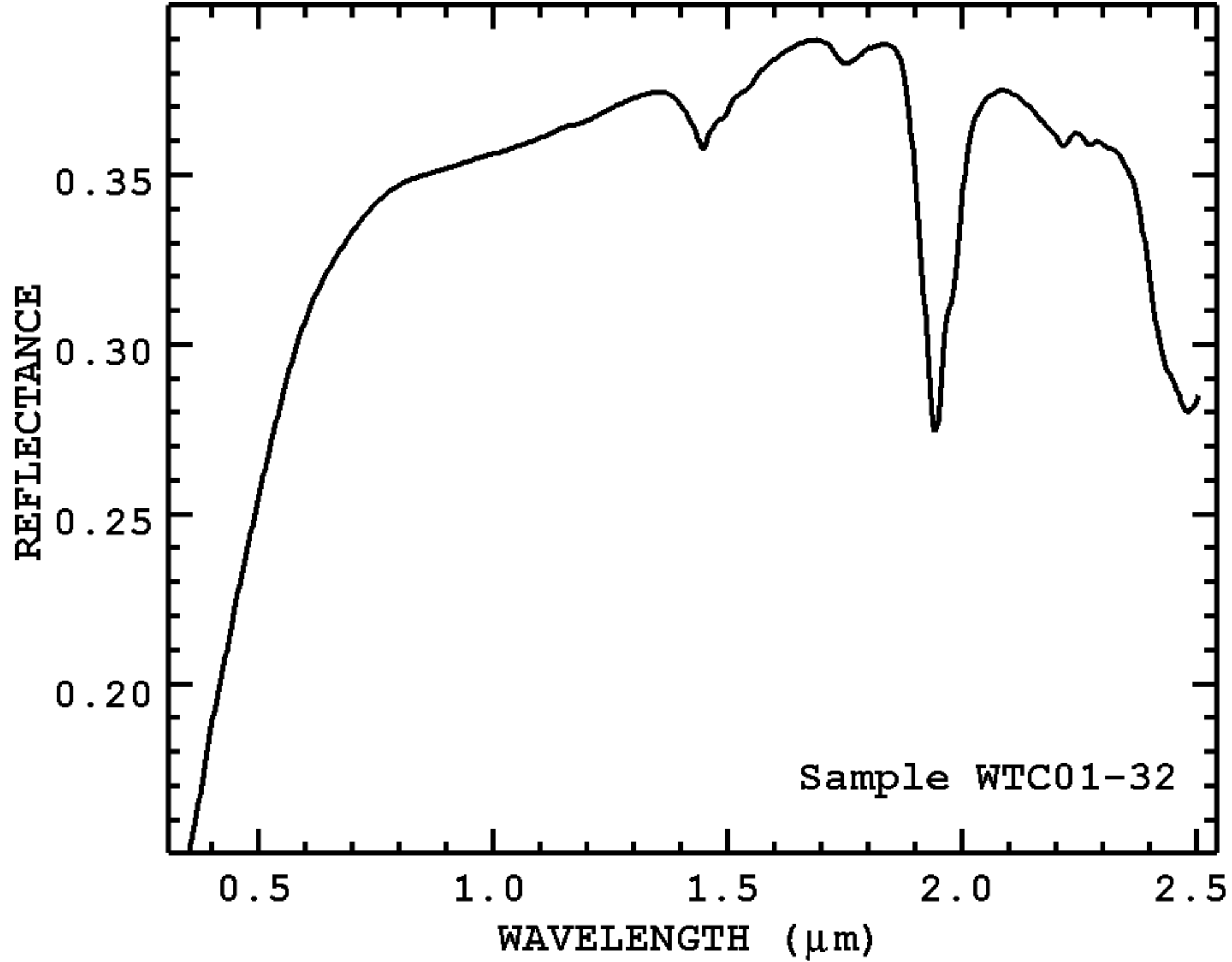


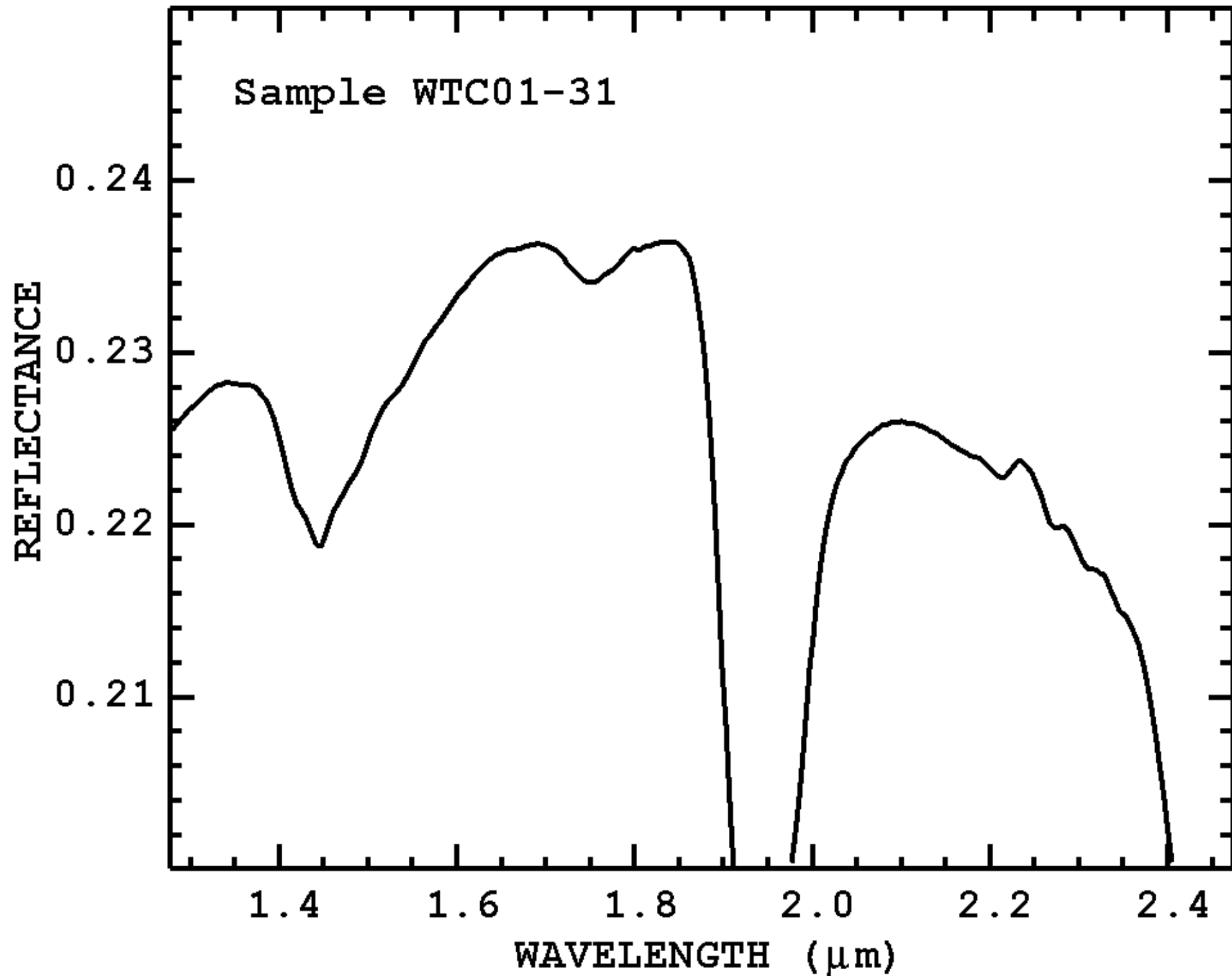


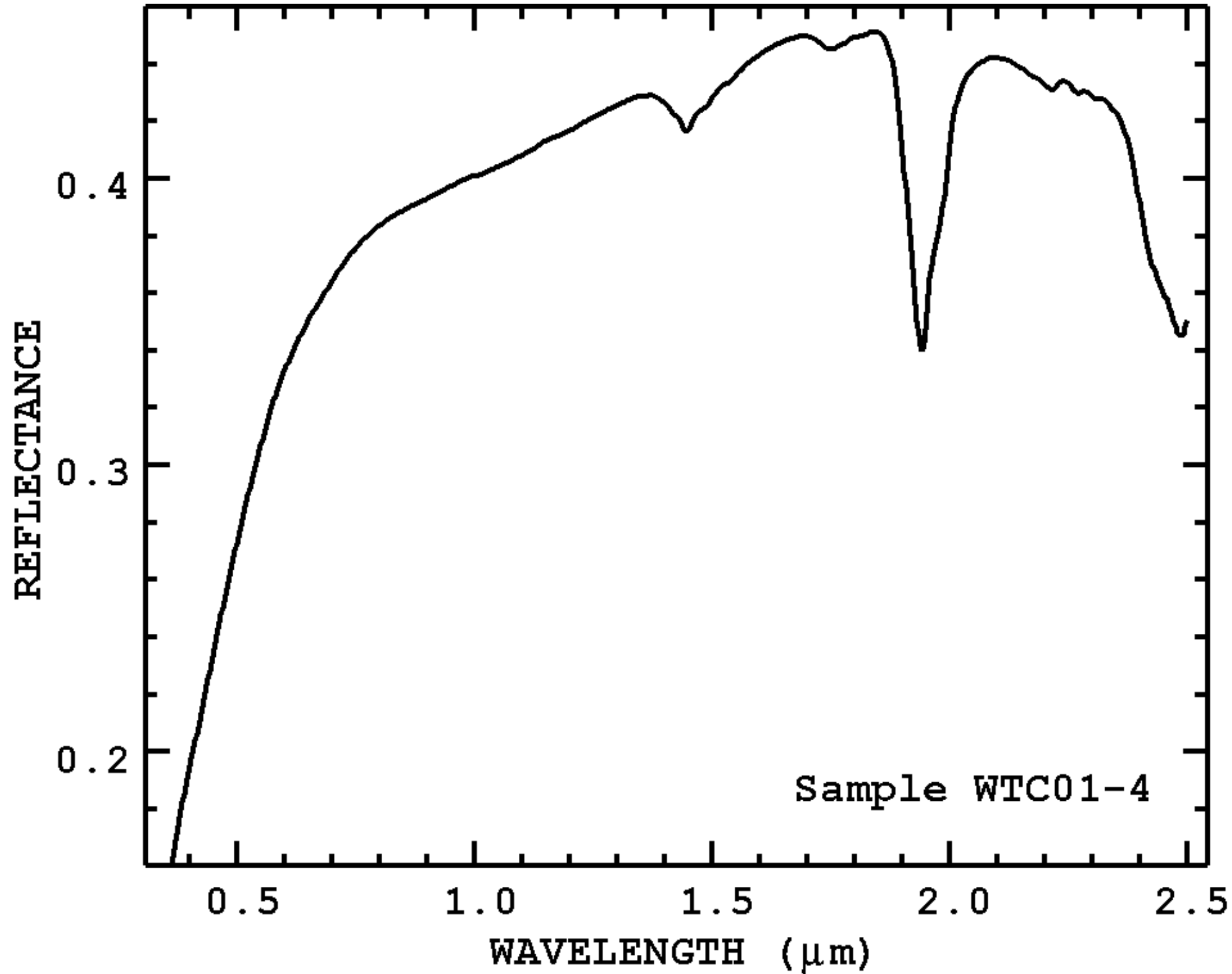












Sample WTC01-4

REFLECTANCE

0.46

0.44

0.42

1.4

1.6

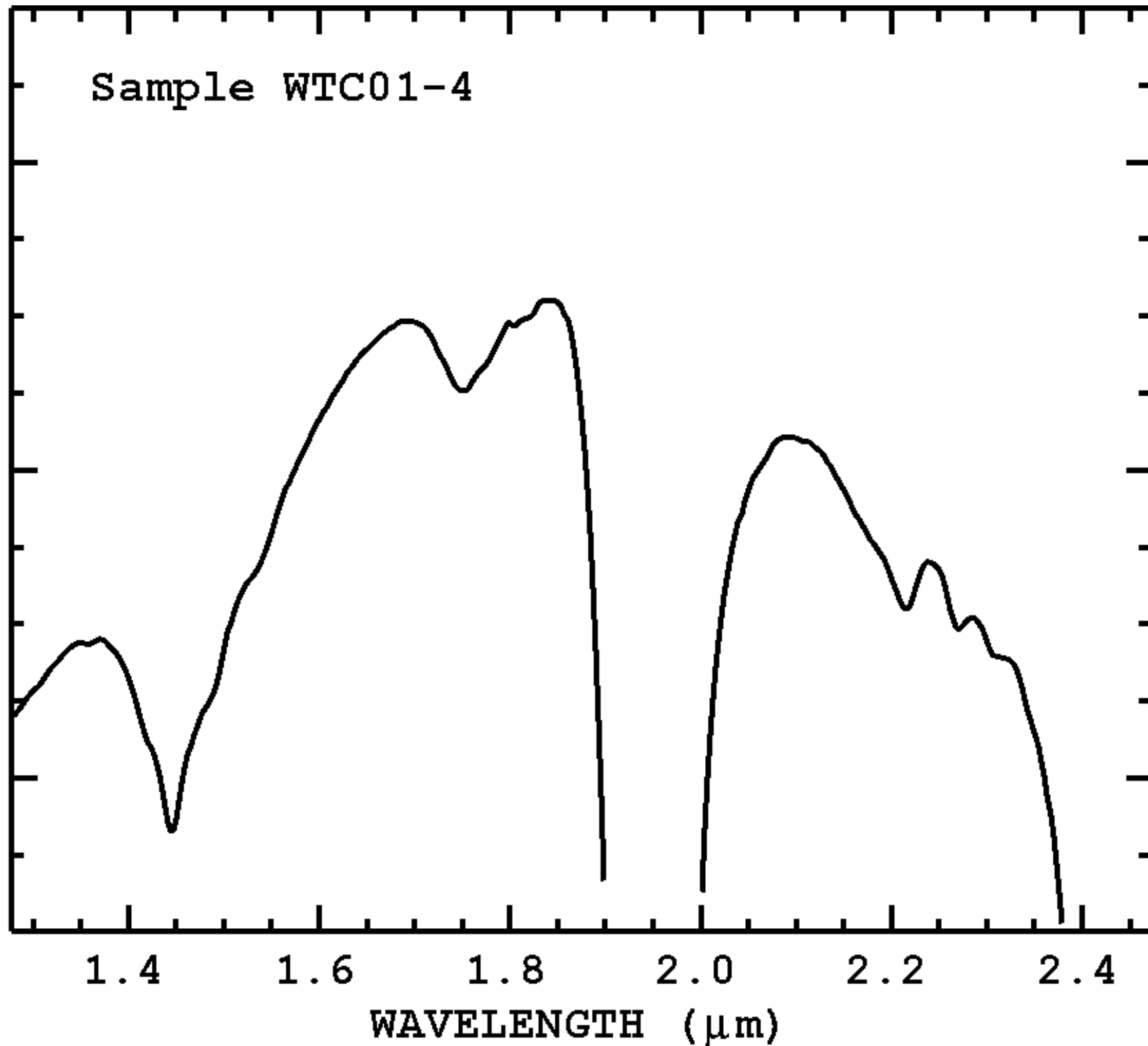
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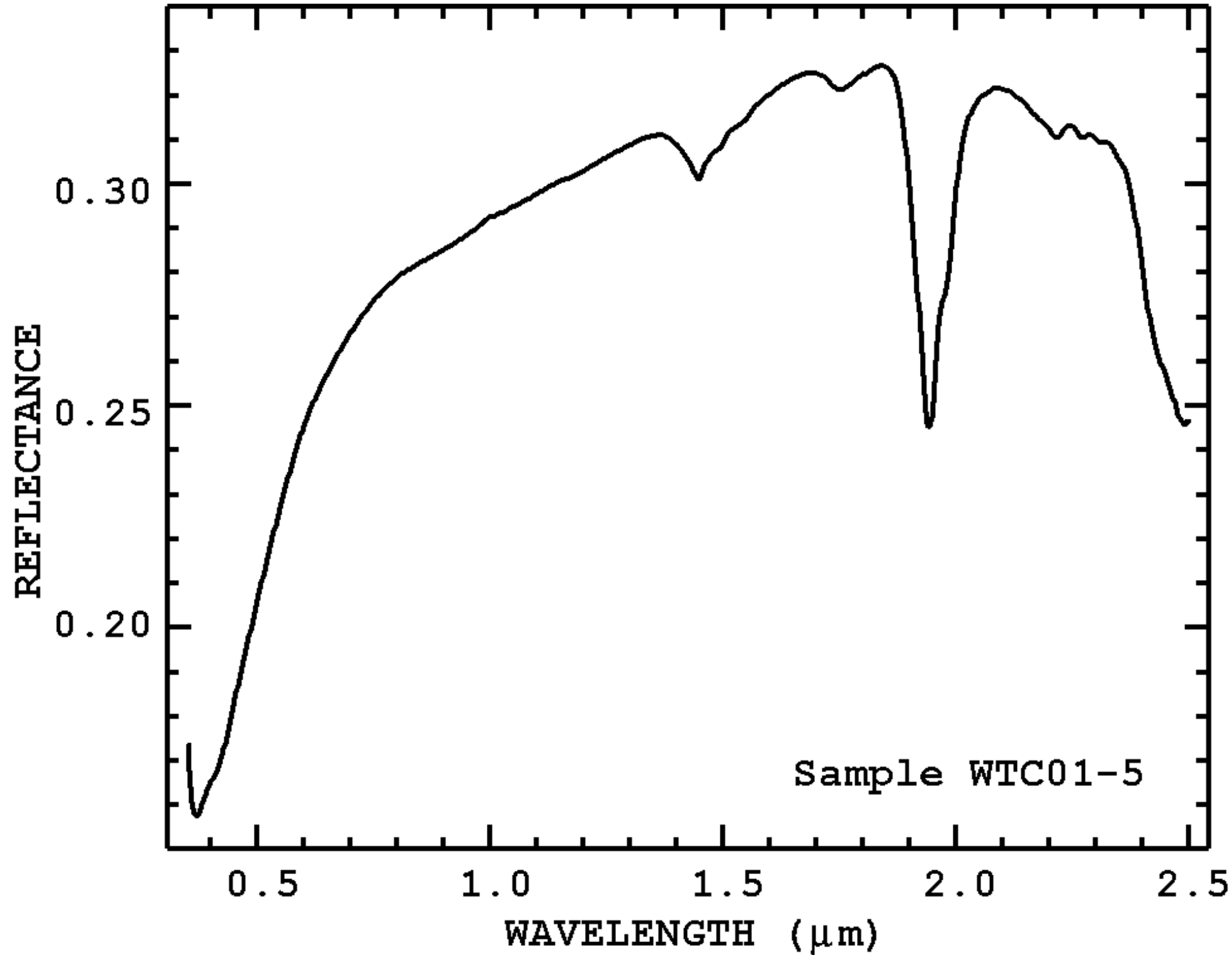
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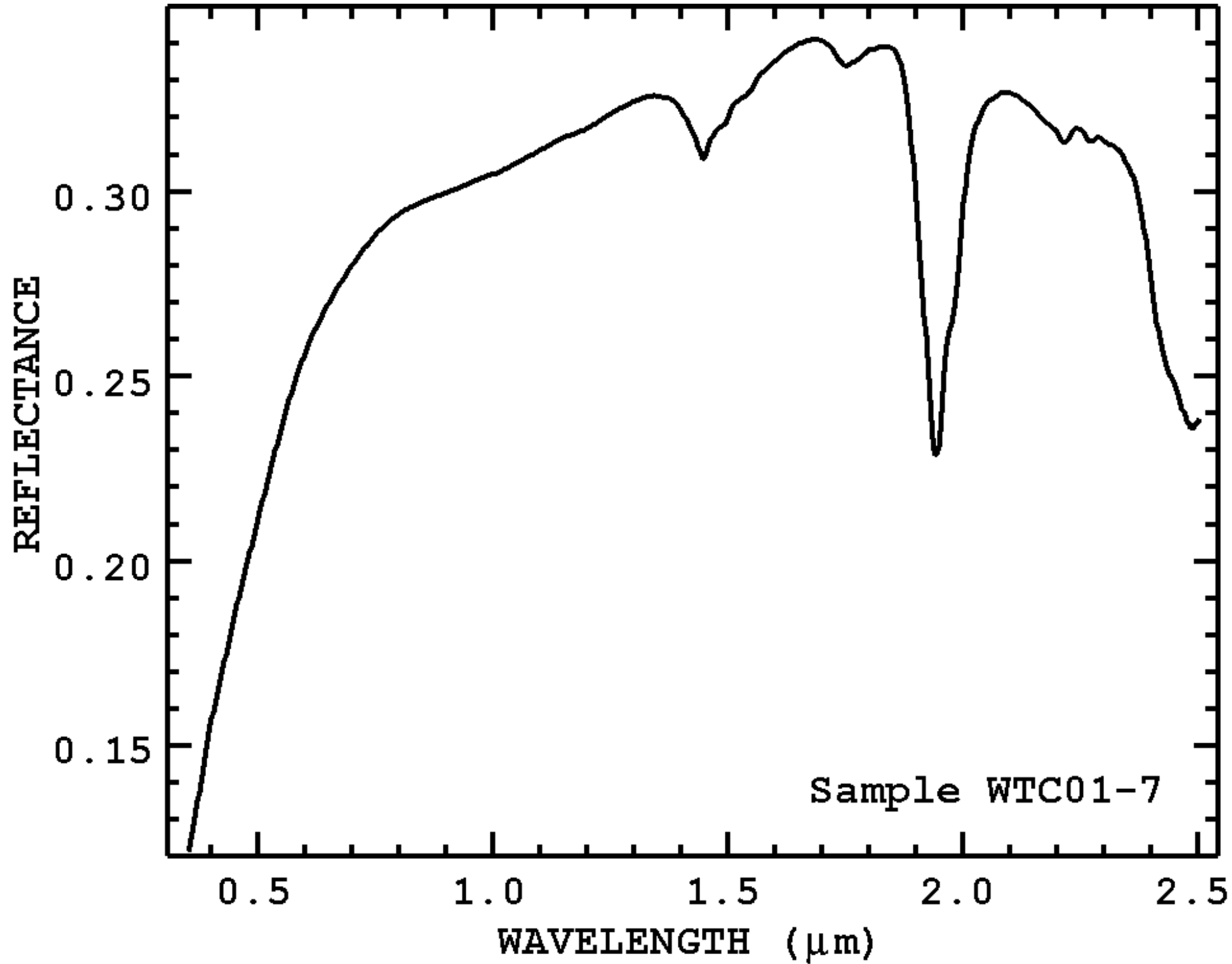
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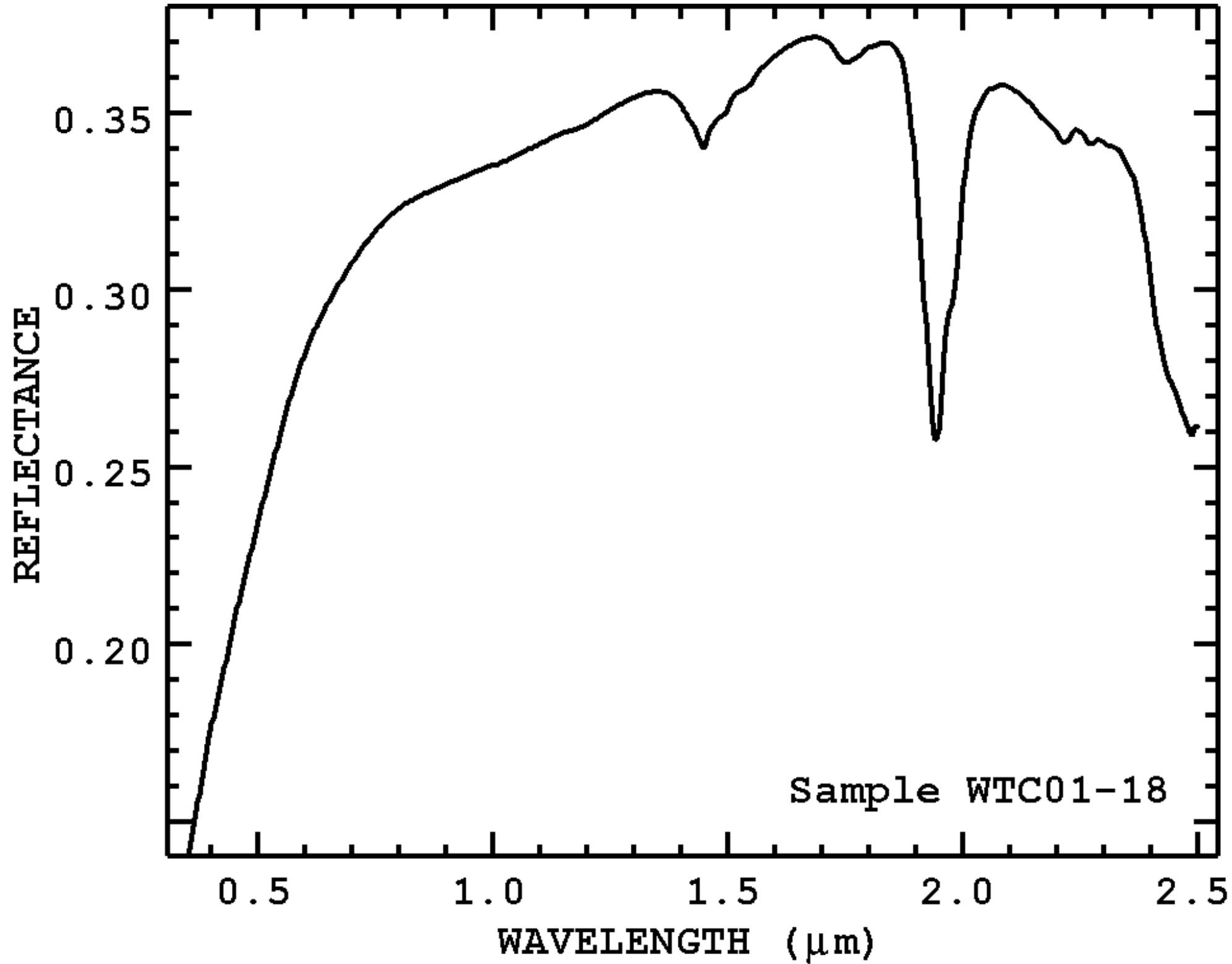
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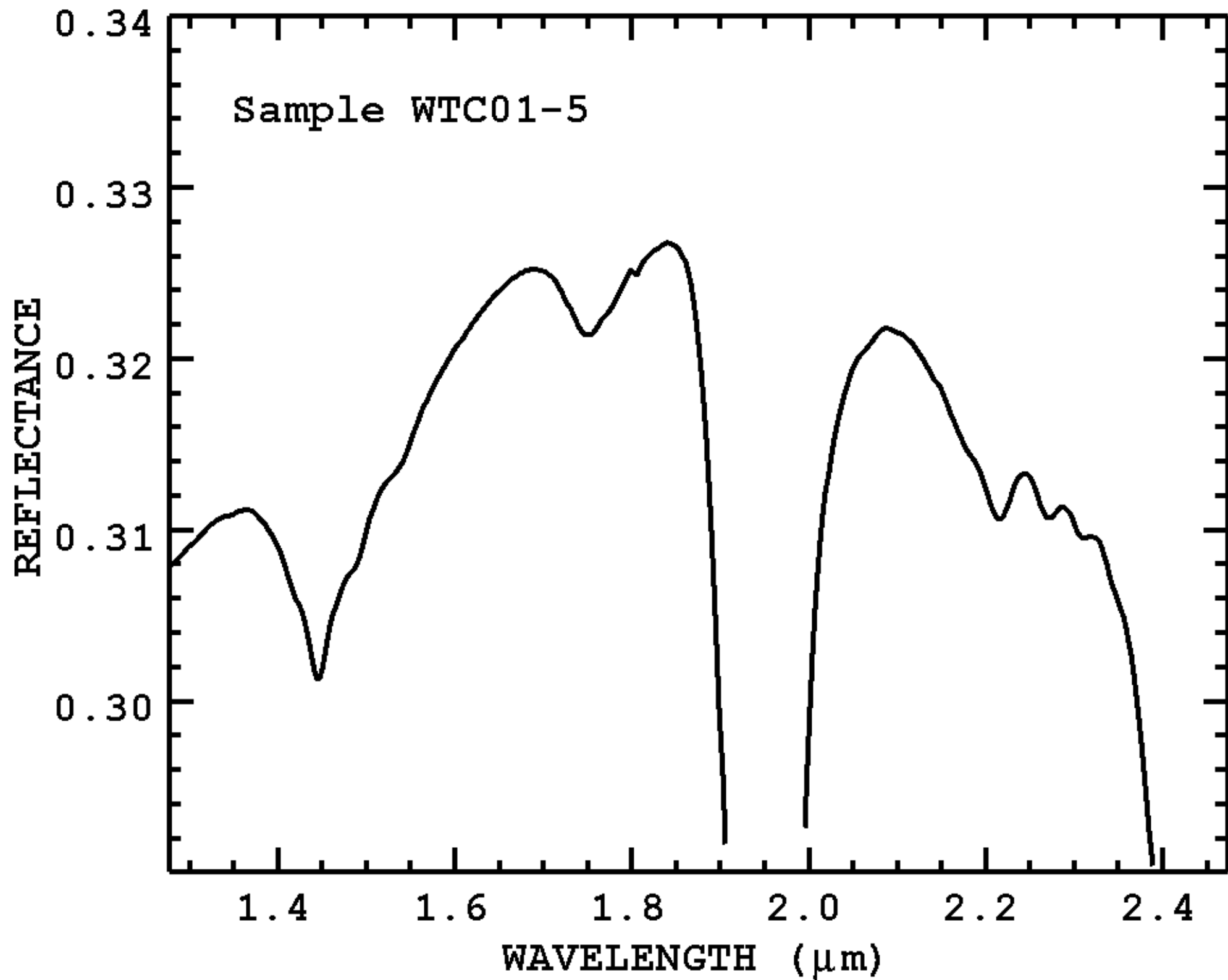
WAVELENGTH (μm)

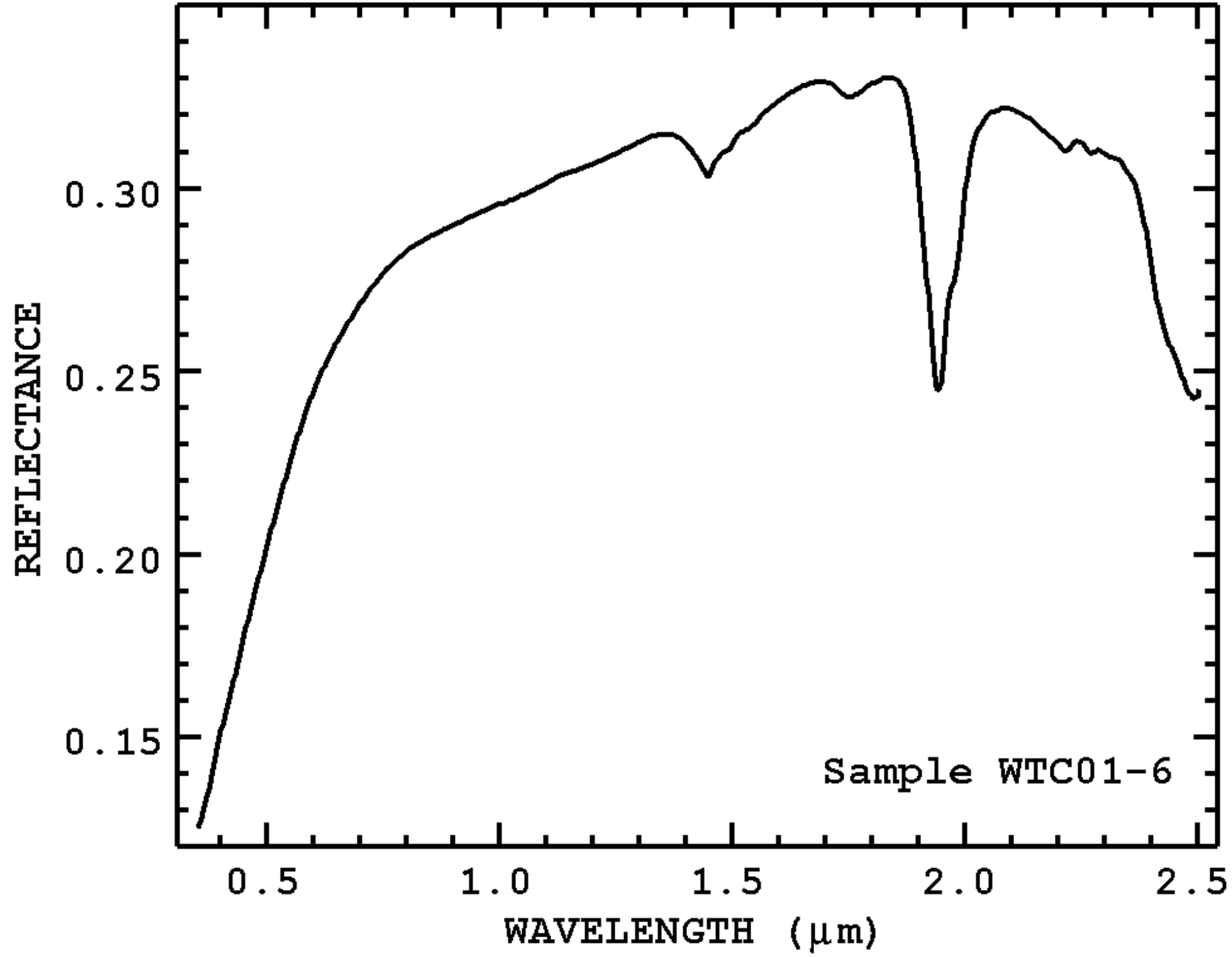


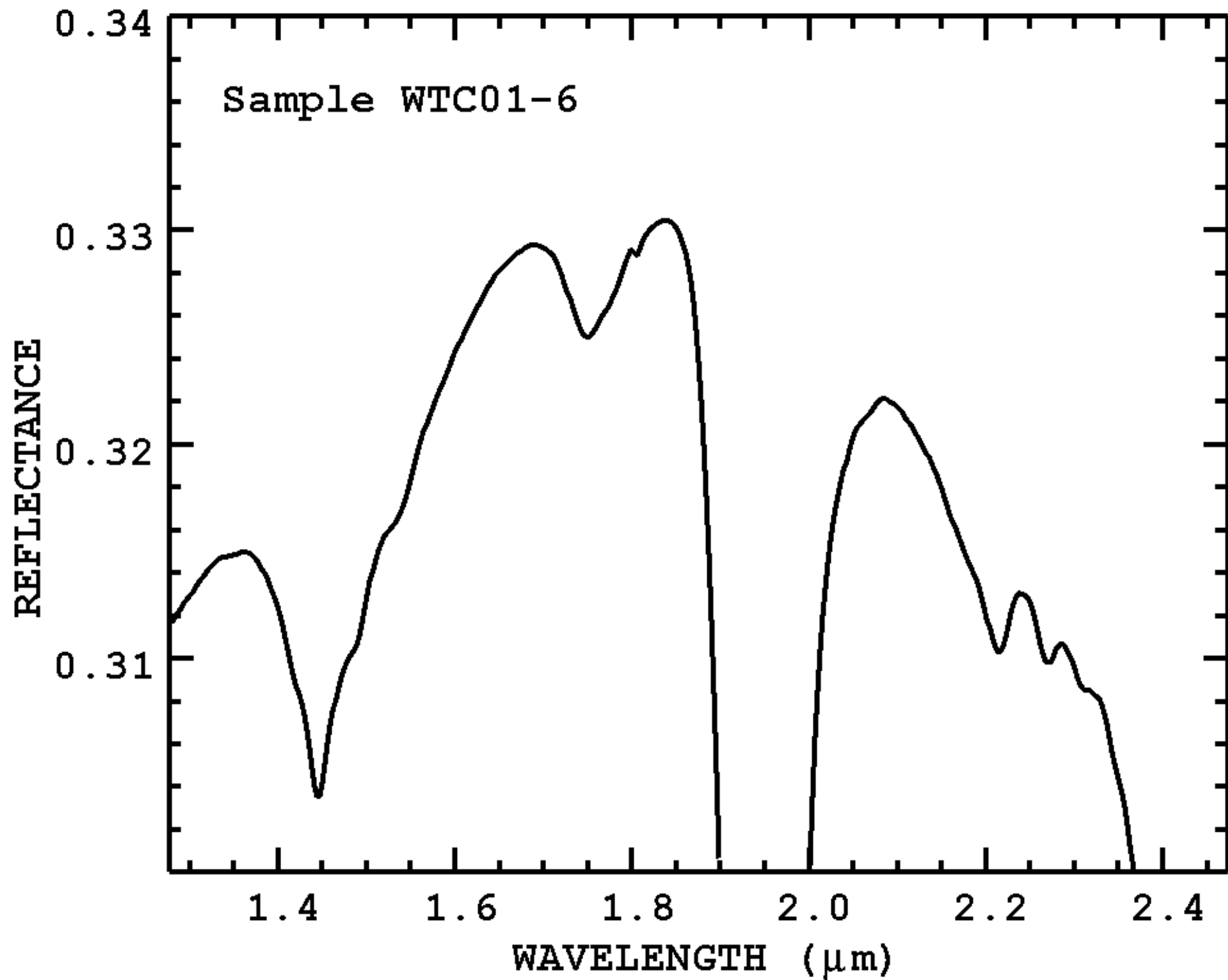












Sample WTC01-7

REFLECTANCE

0.34

0.32

1.4

1.6

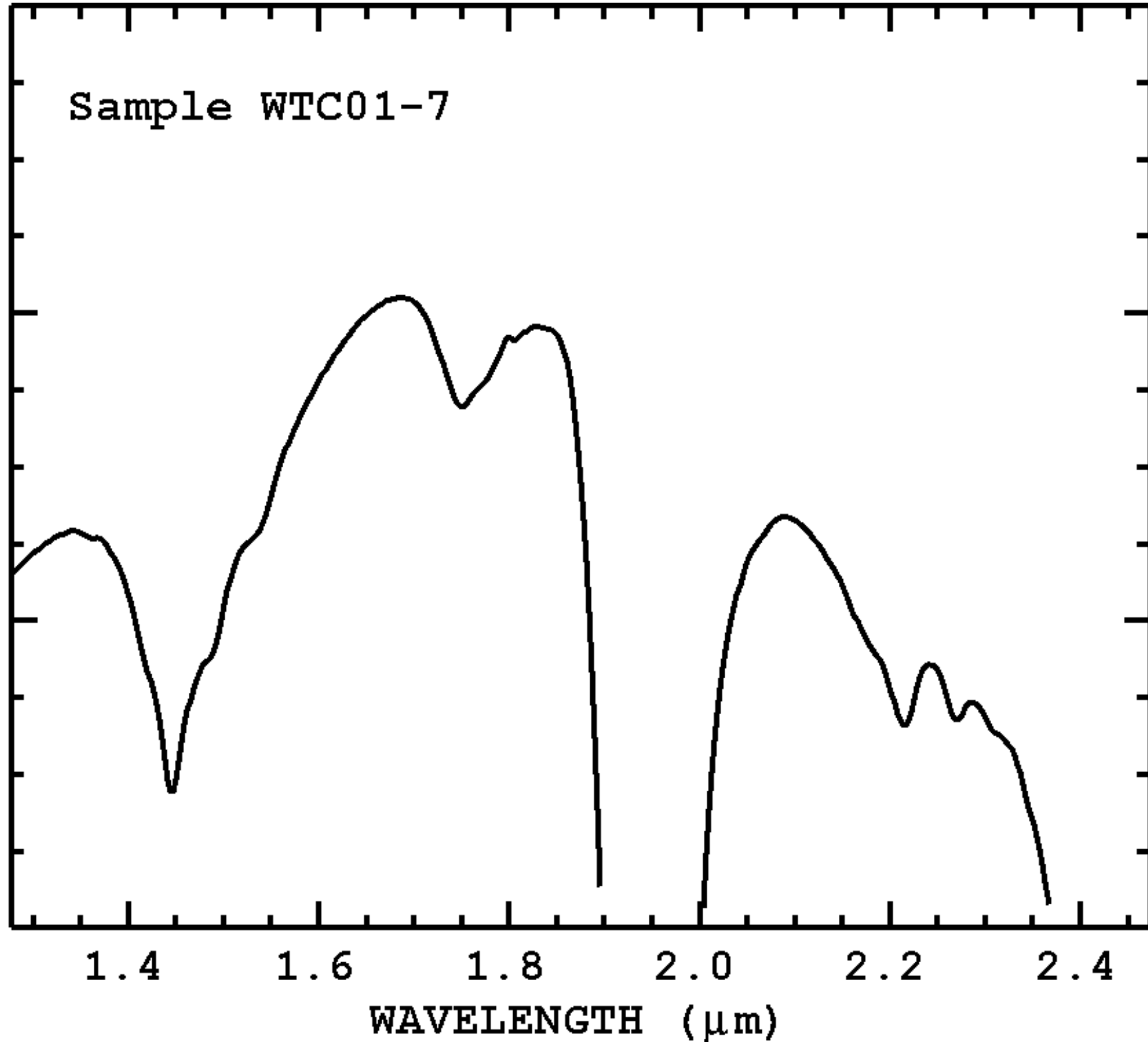
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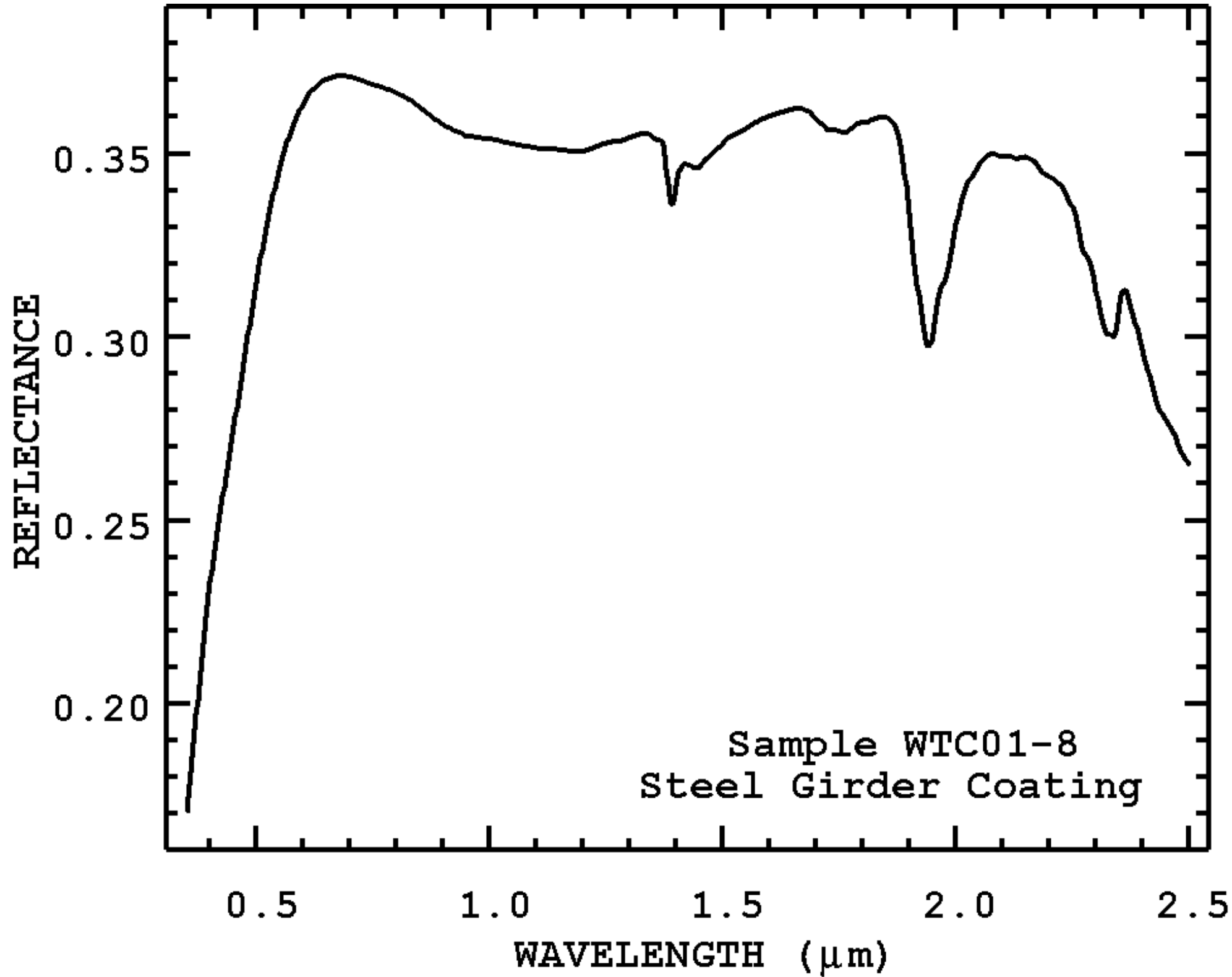
2.0

2.2

2.4

WAVELENGTH (μm)





Sample WTC01-8
Steel Girder Coating

REFLECTANCE

0.35

0.30

1.4

1.6

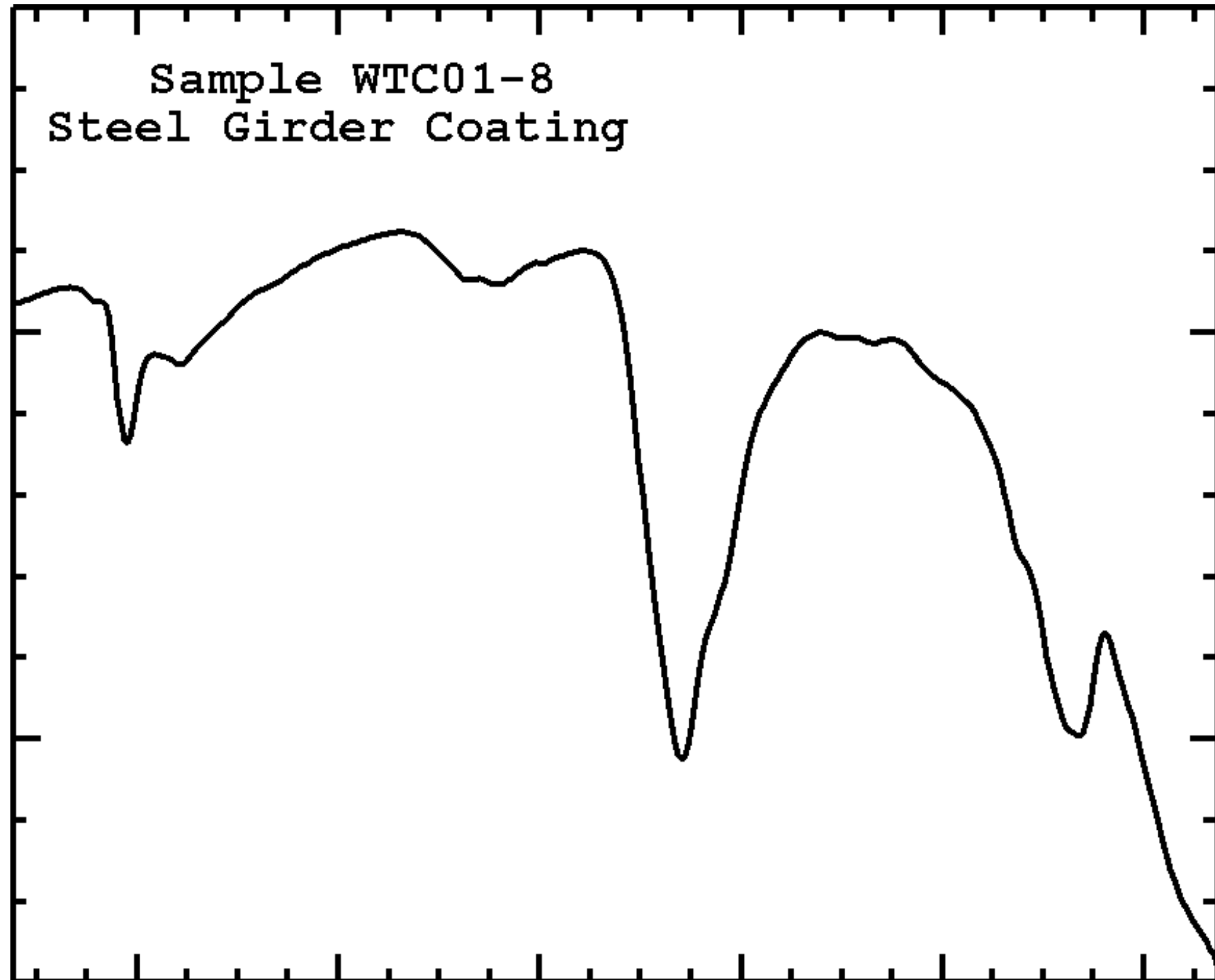
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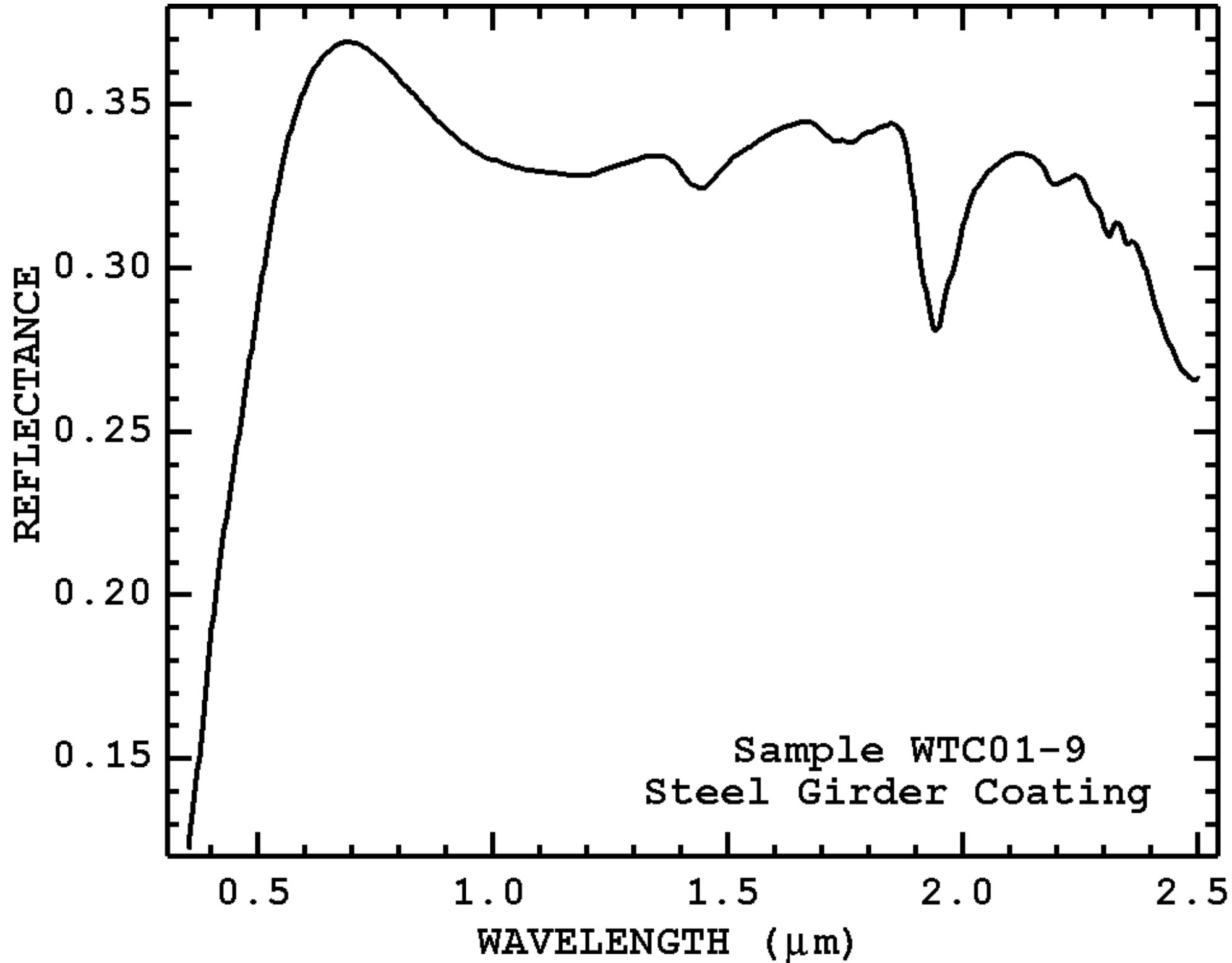
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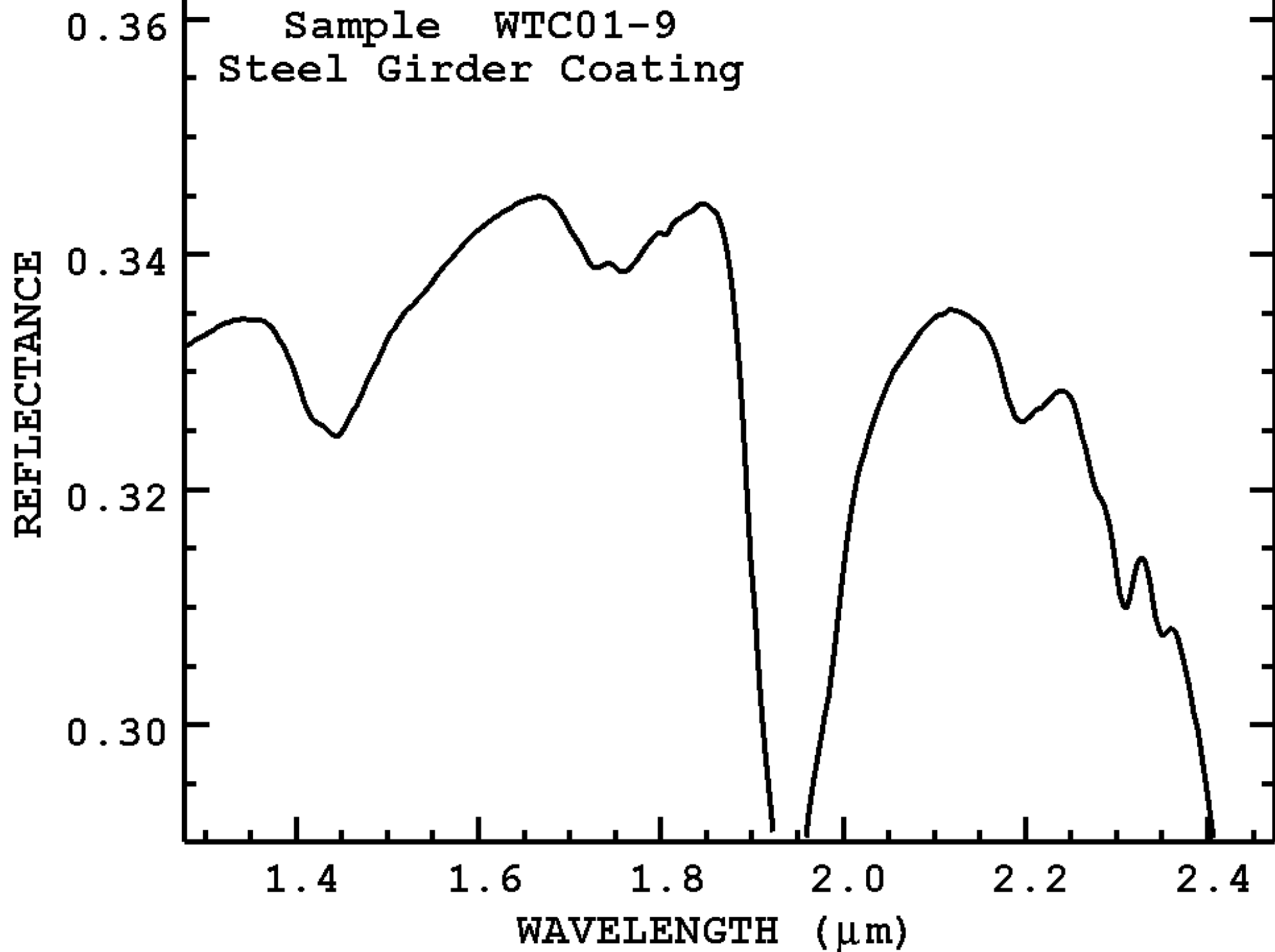
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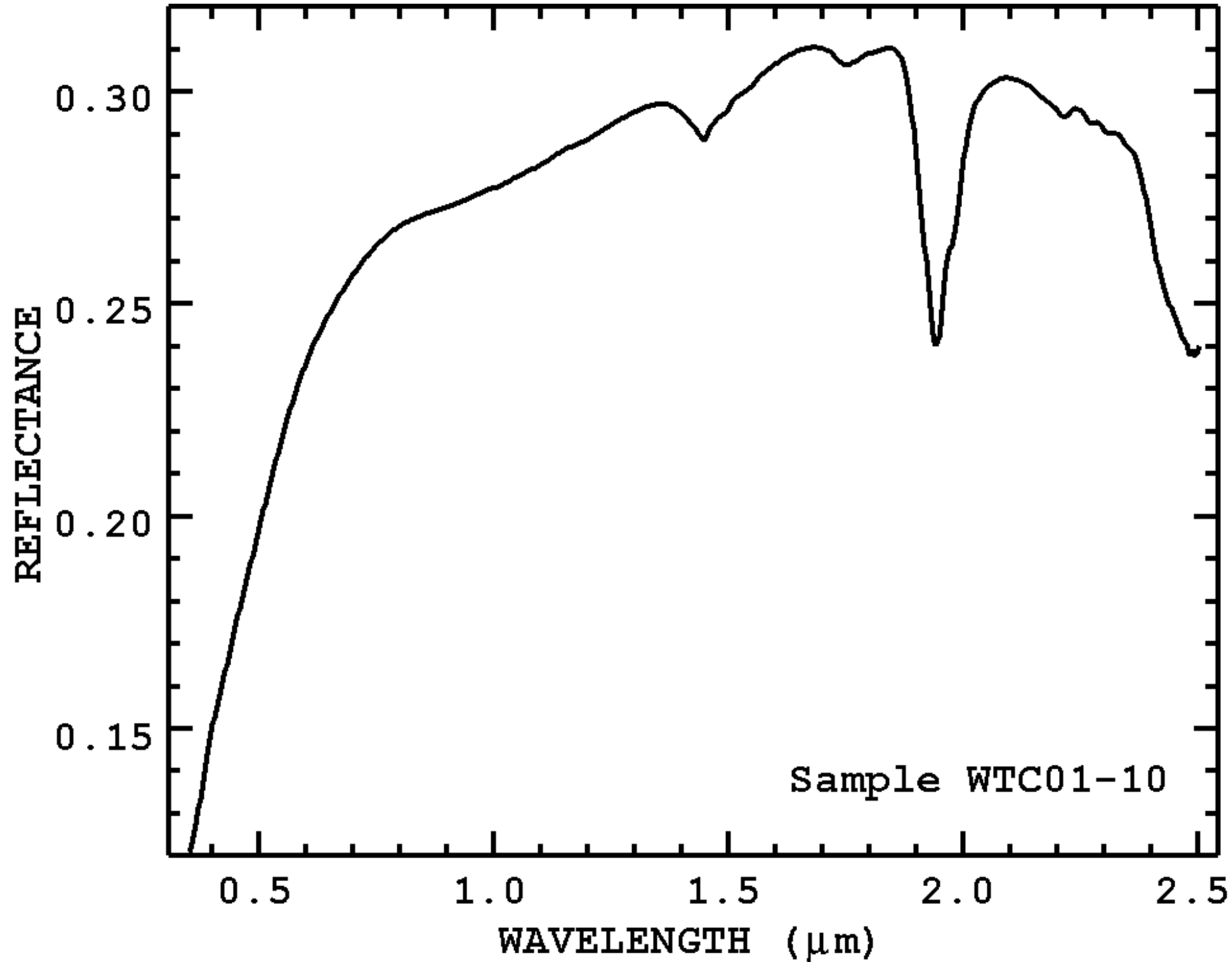
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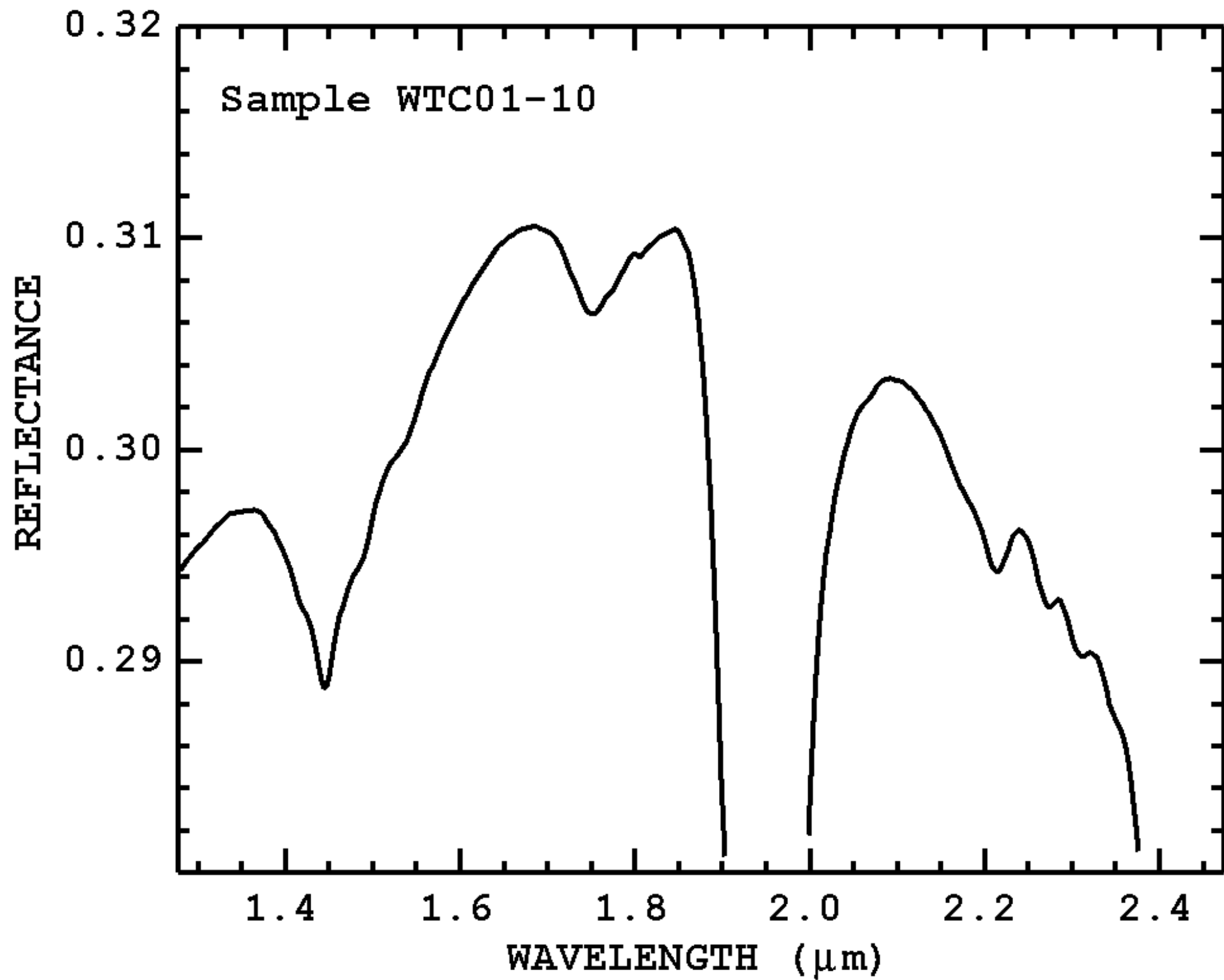
WAVELENGTH (μm)

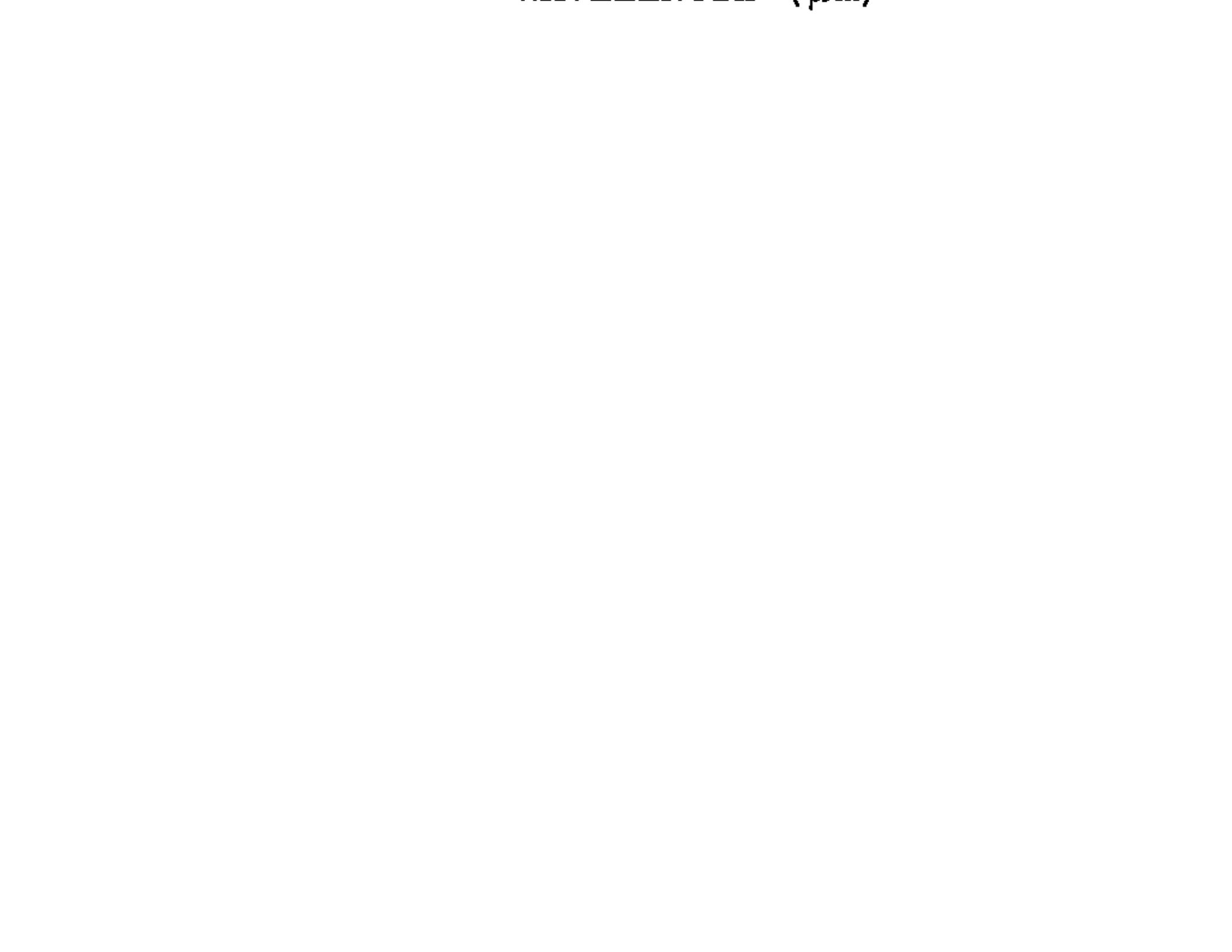


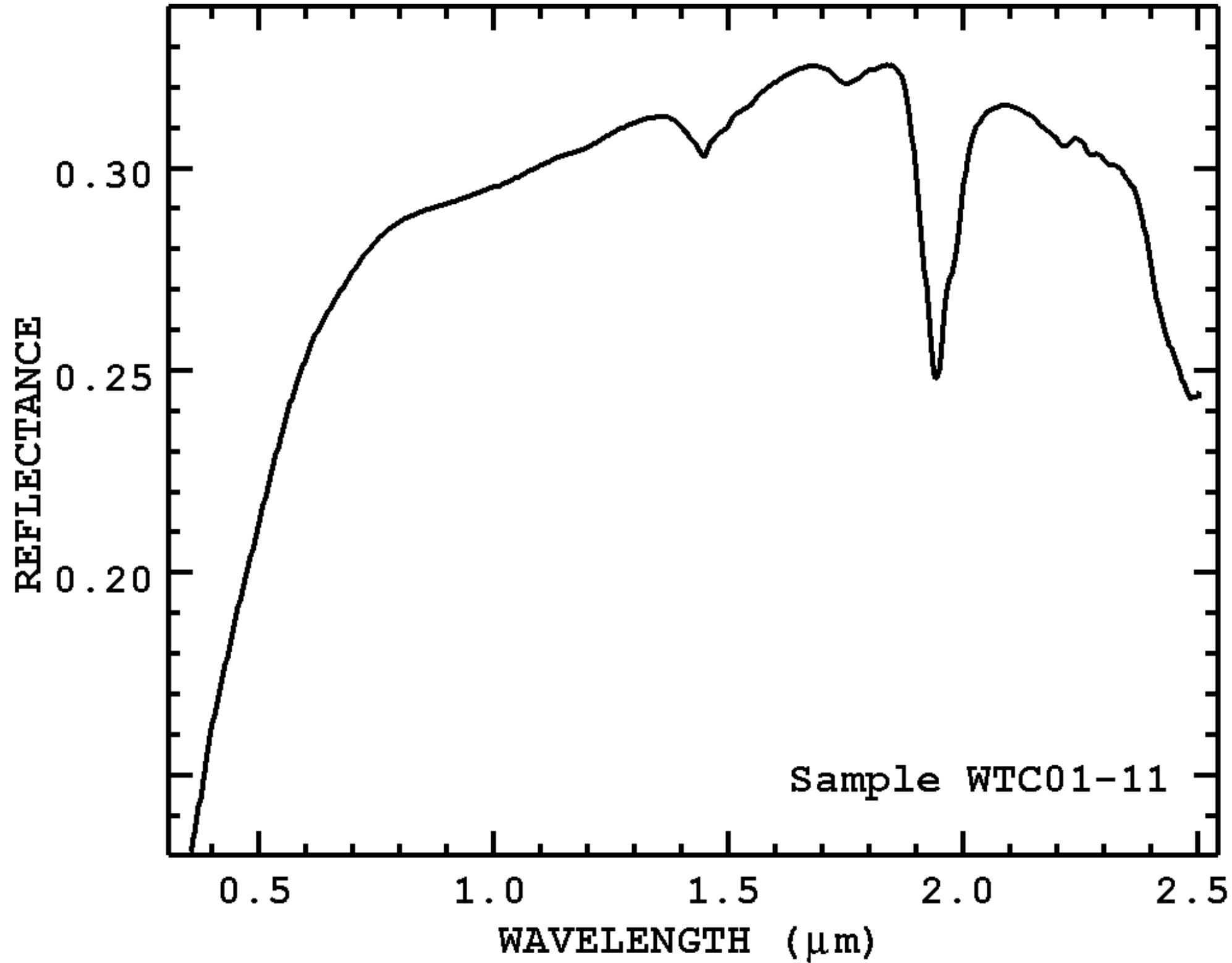


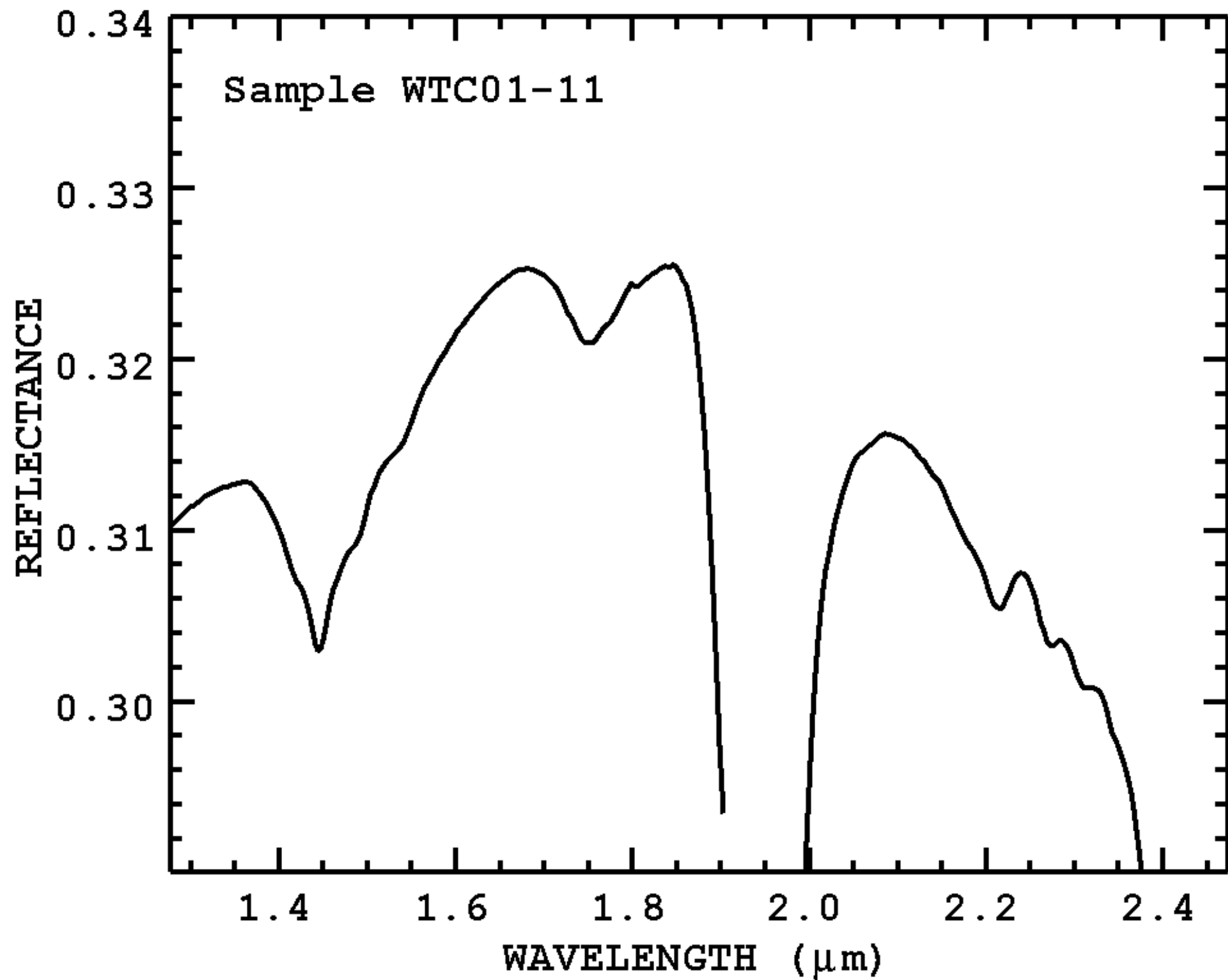


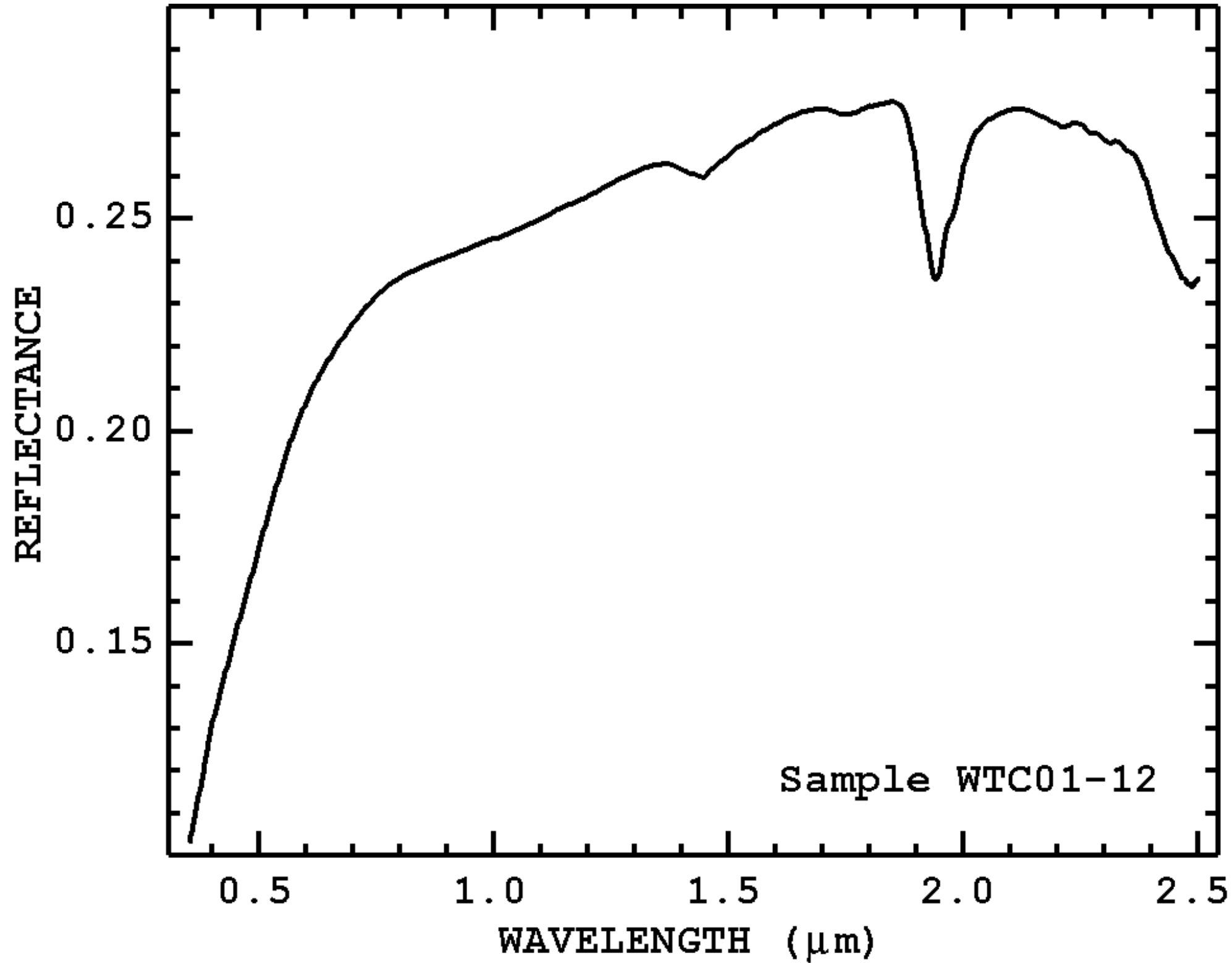


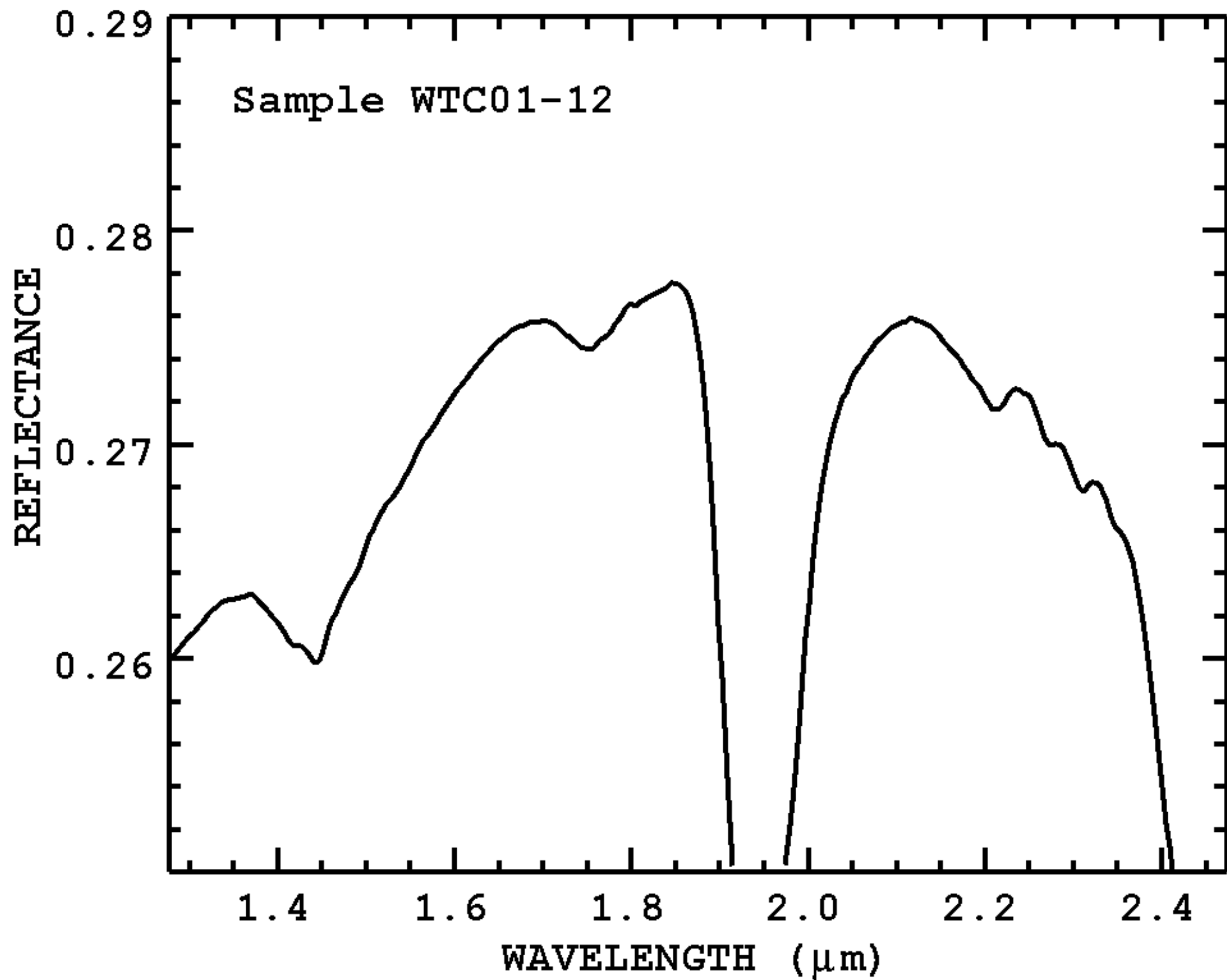


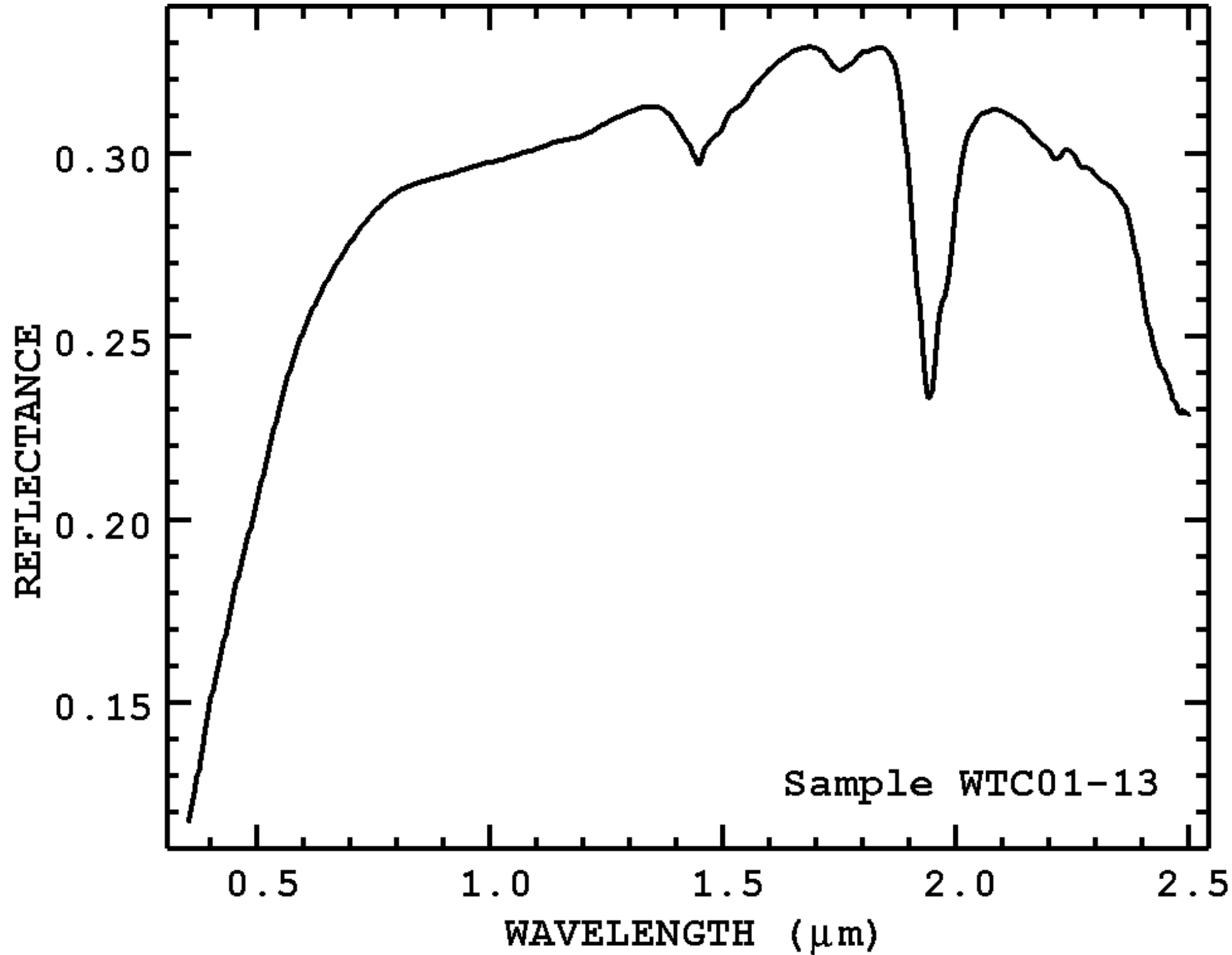


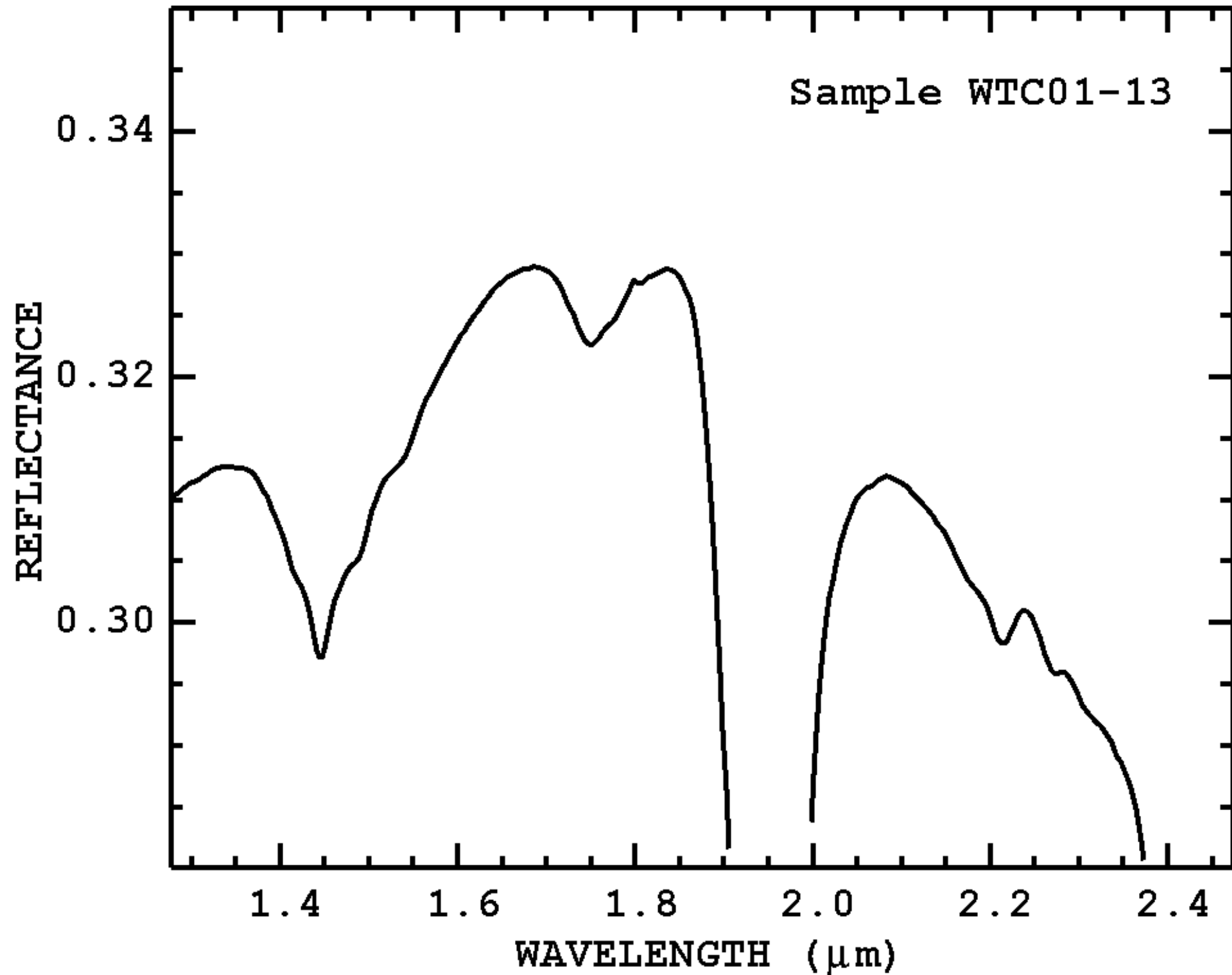


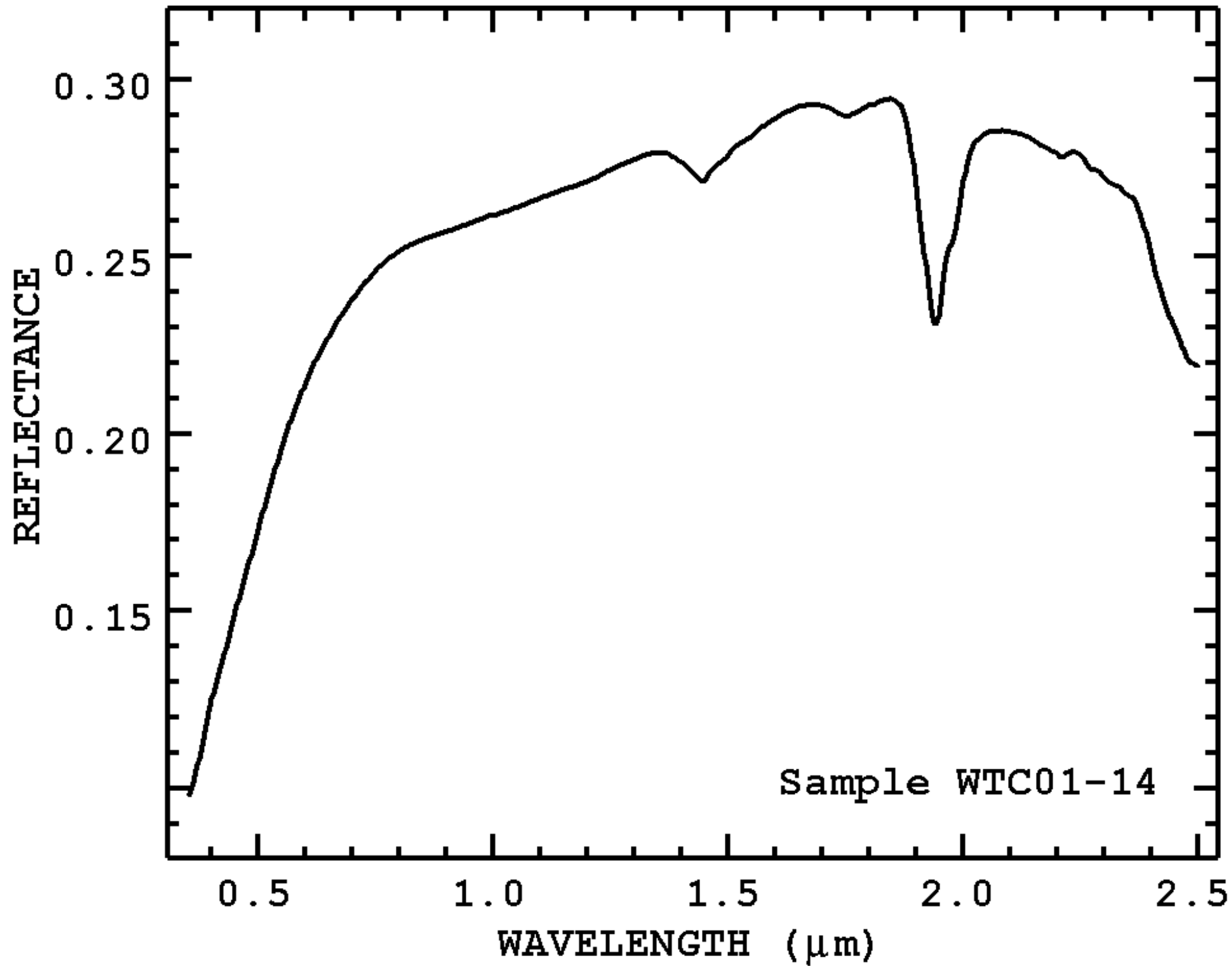


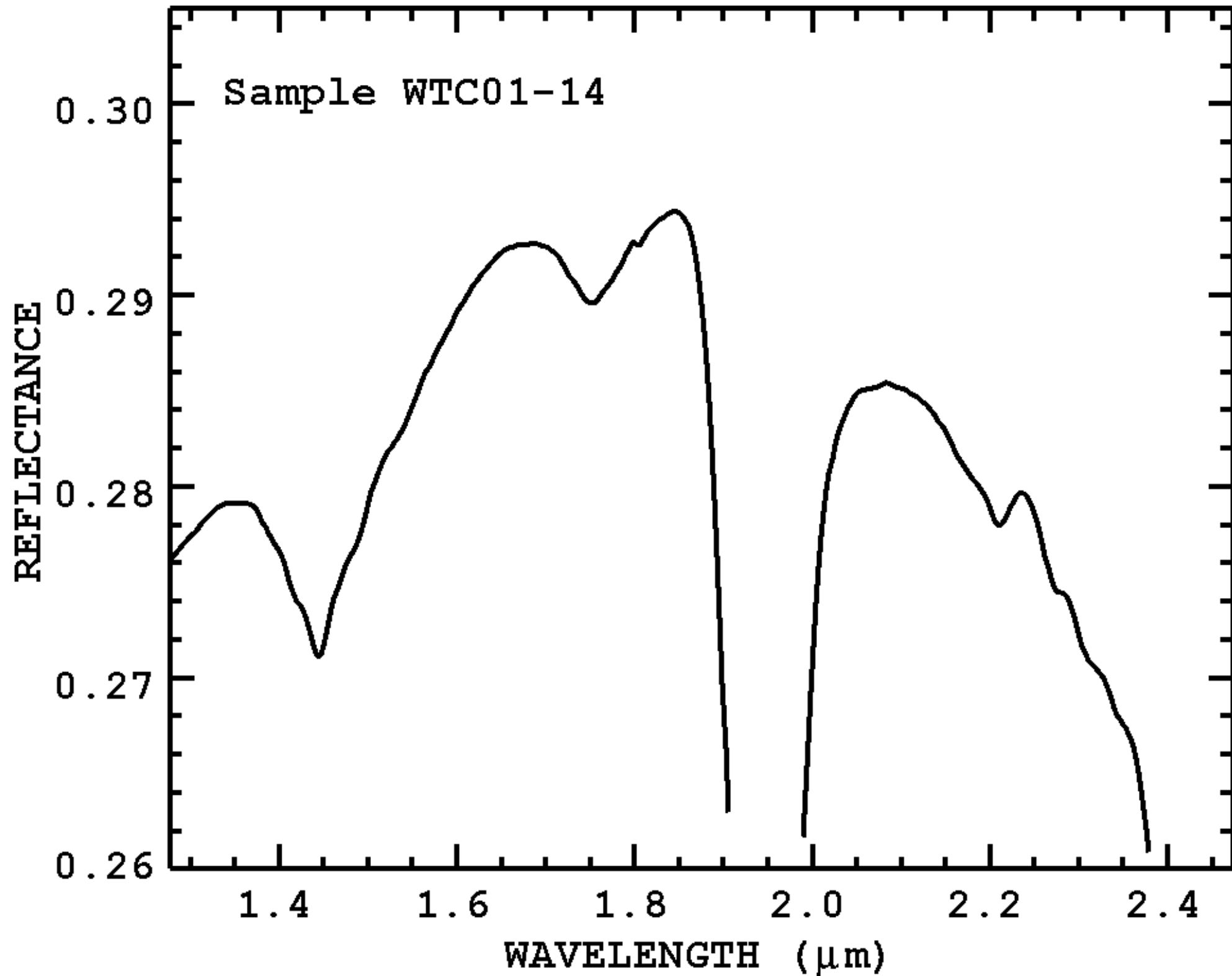


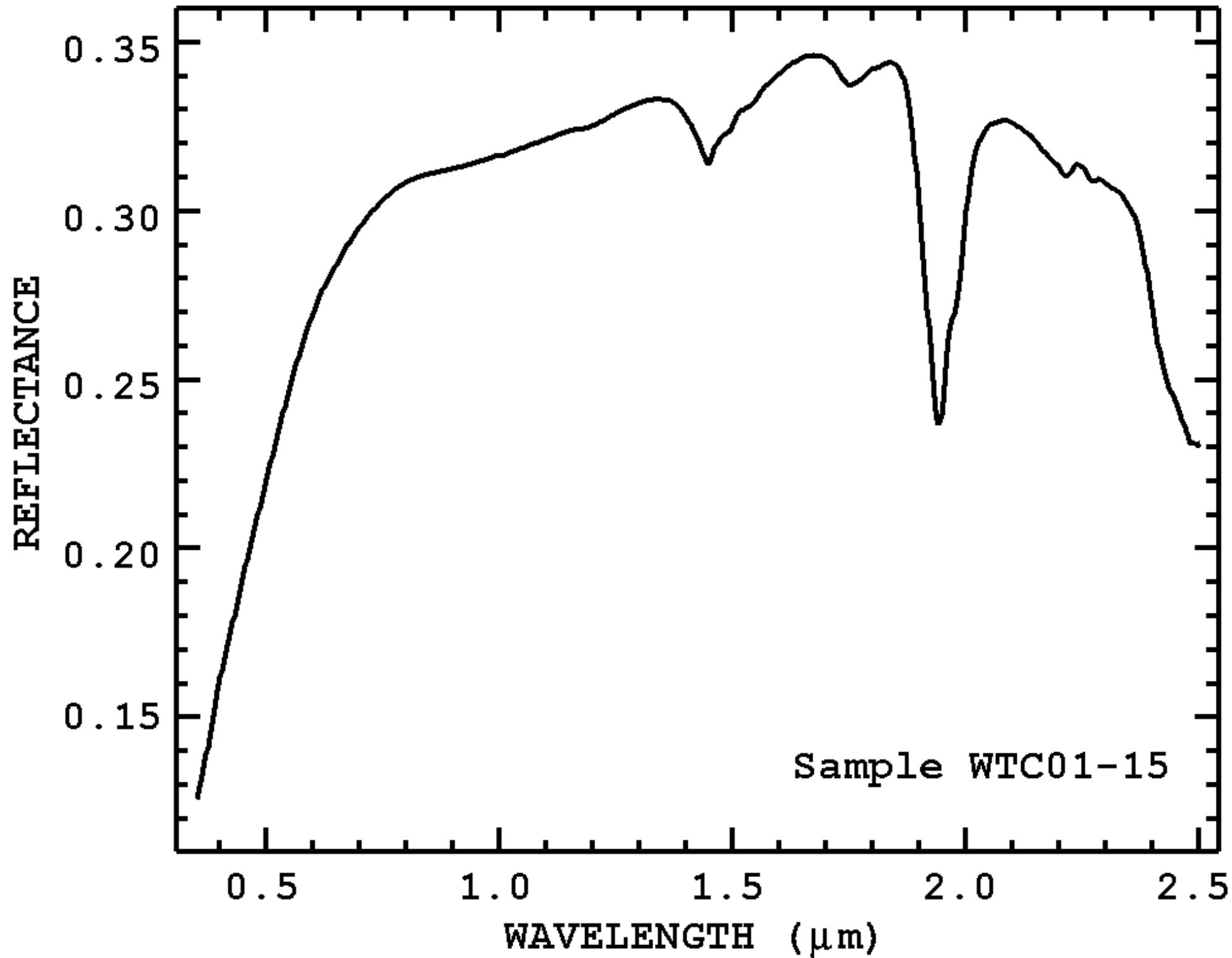












REFLECTANCE

Sample WTC01-15

0.34

0.32

0.30

1.4

1.6

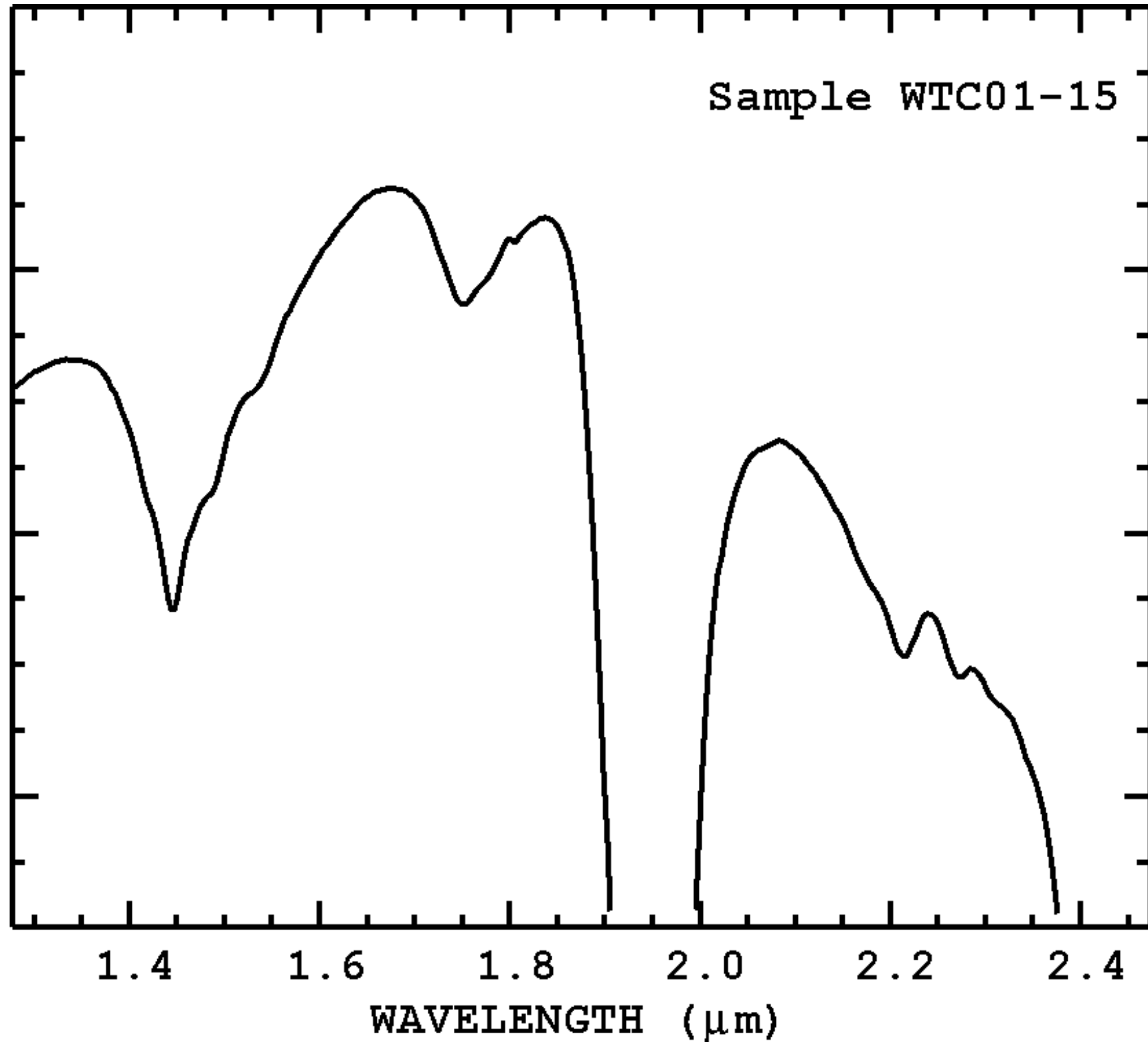
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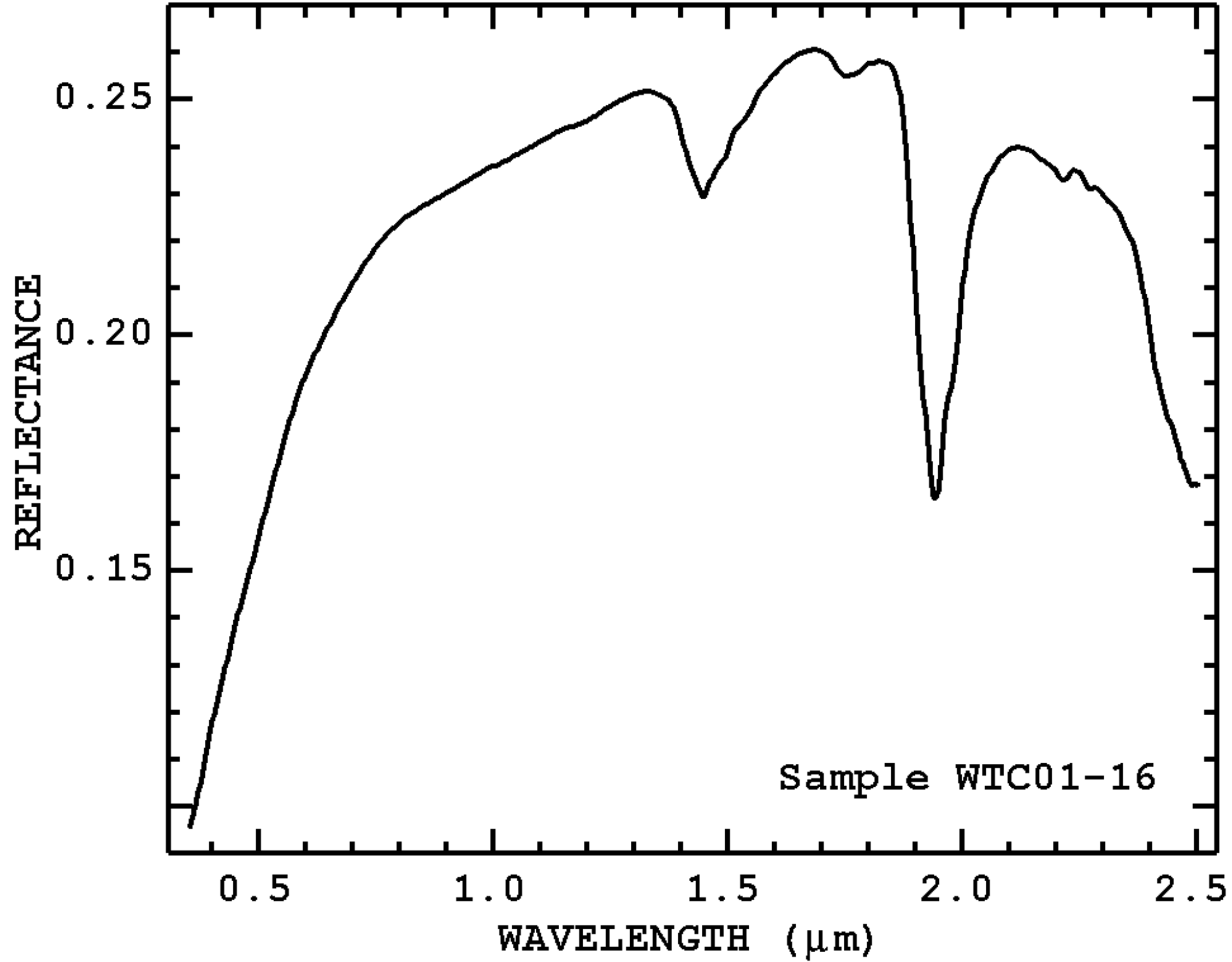
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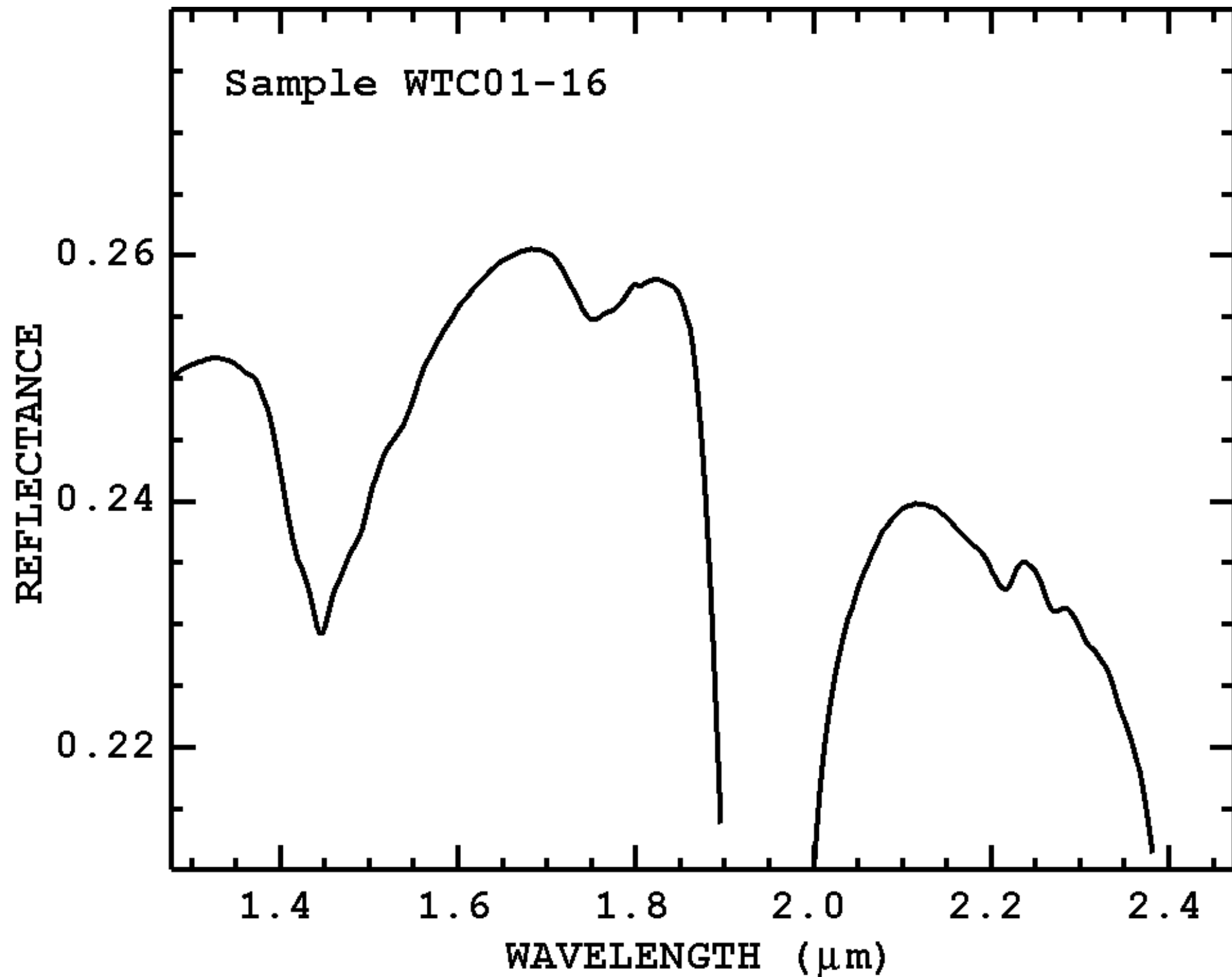
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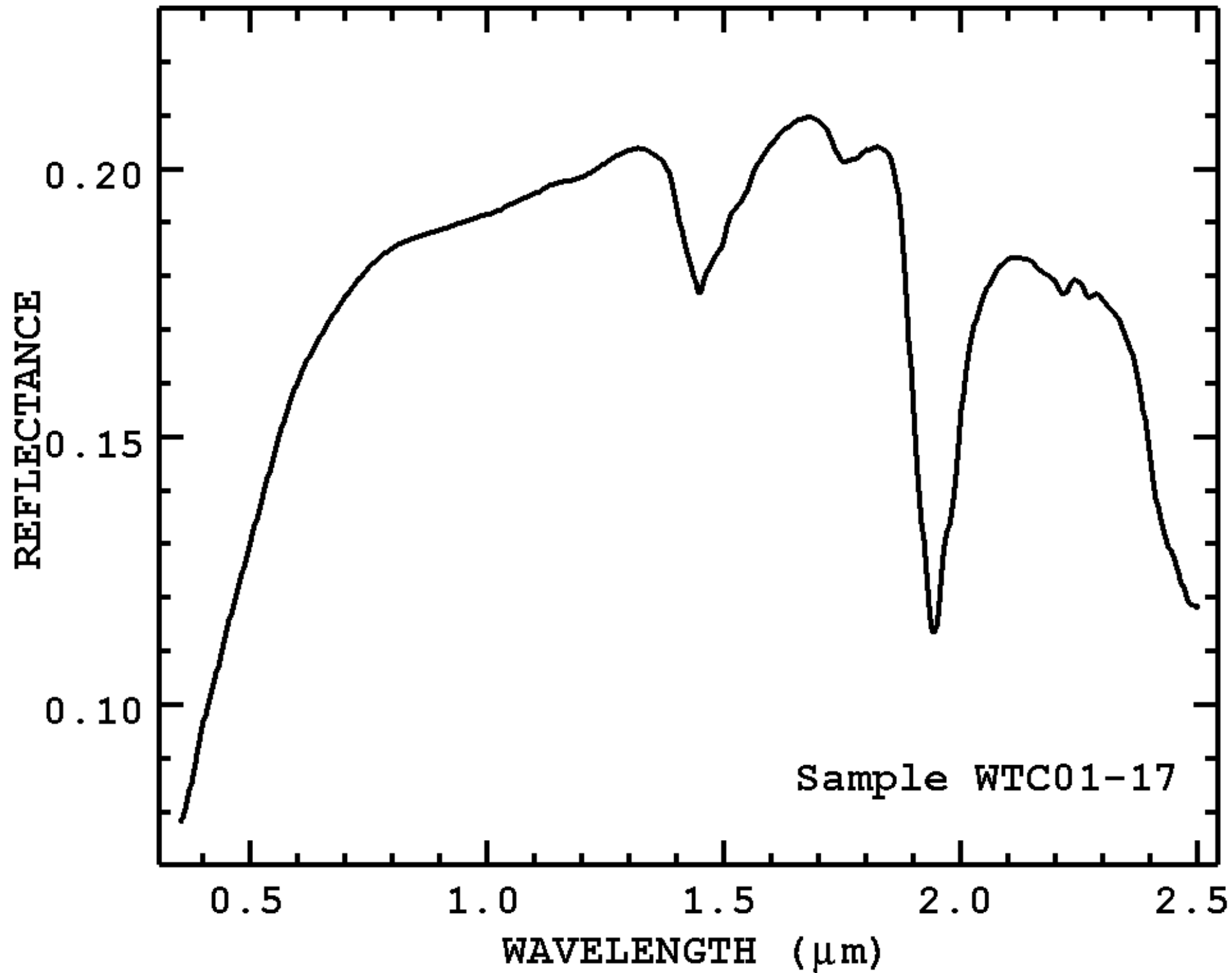
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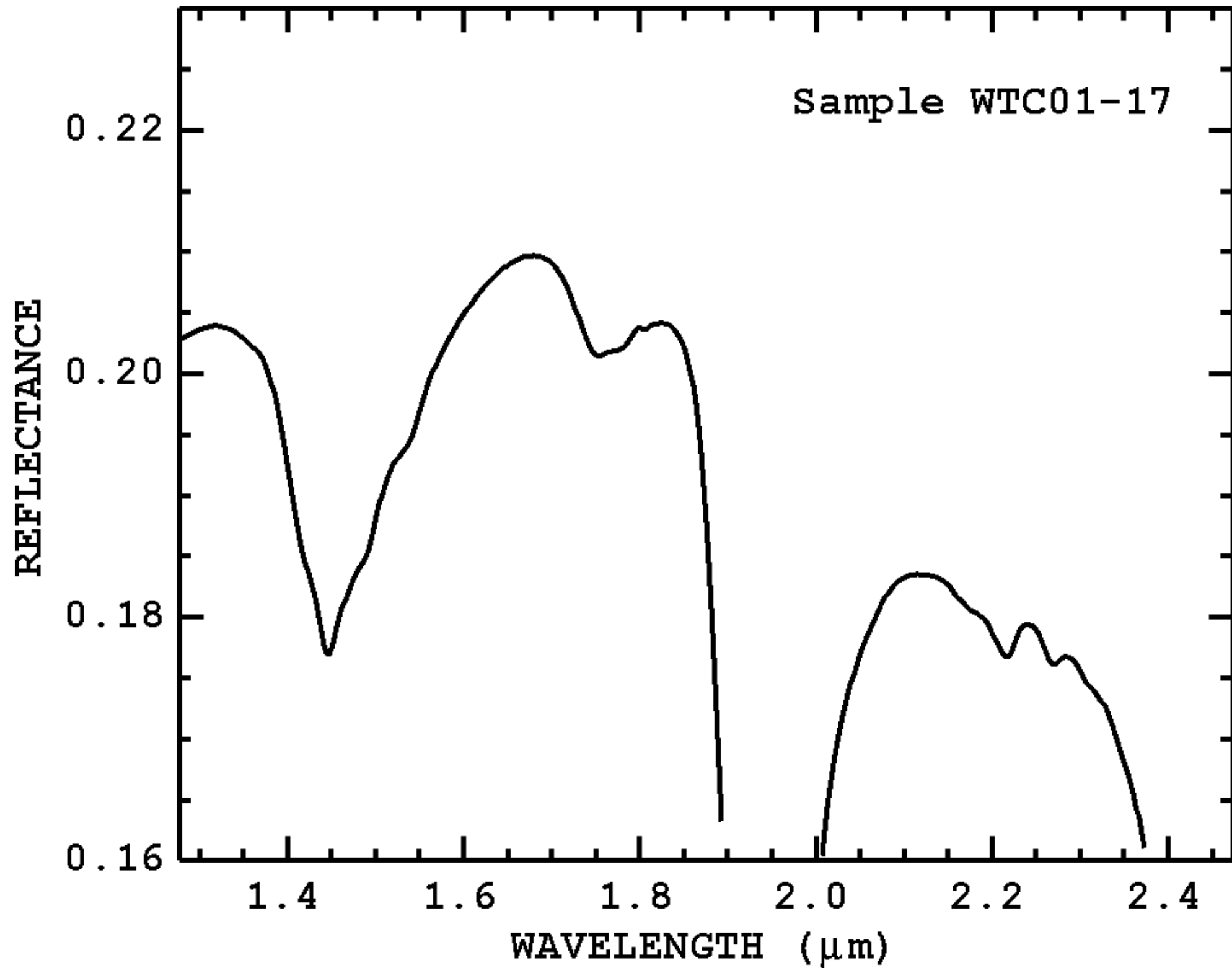
WAVELENGTH (μm)

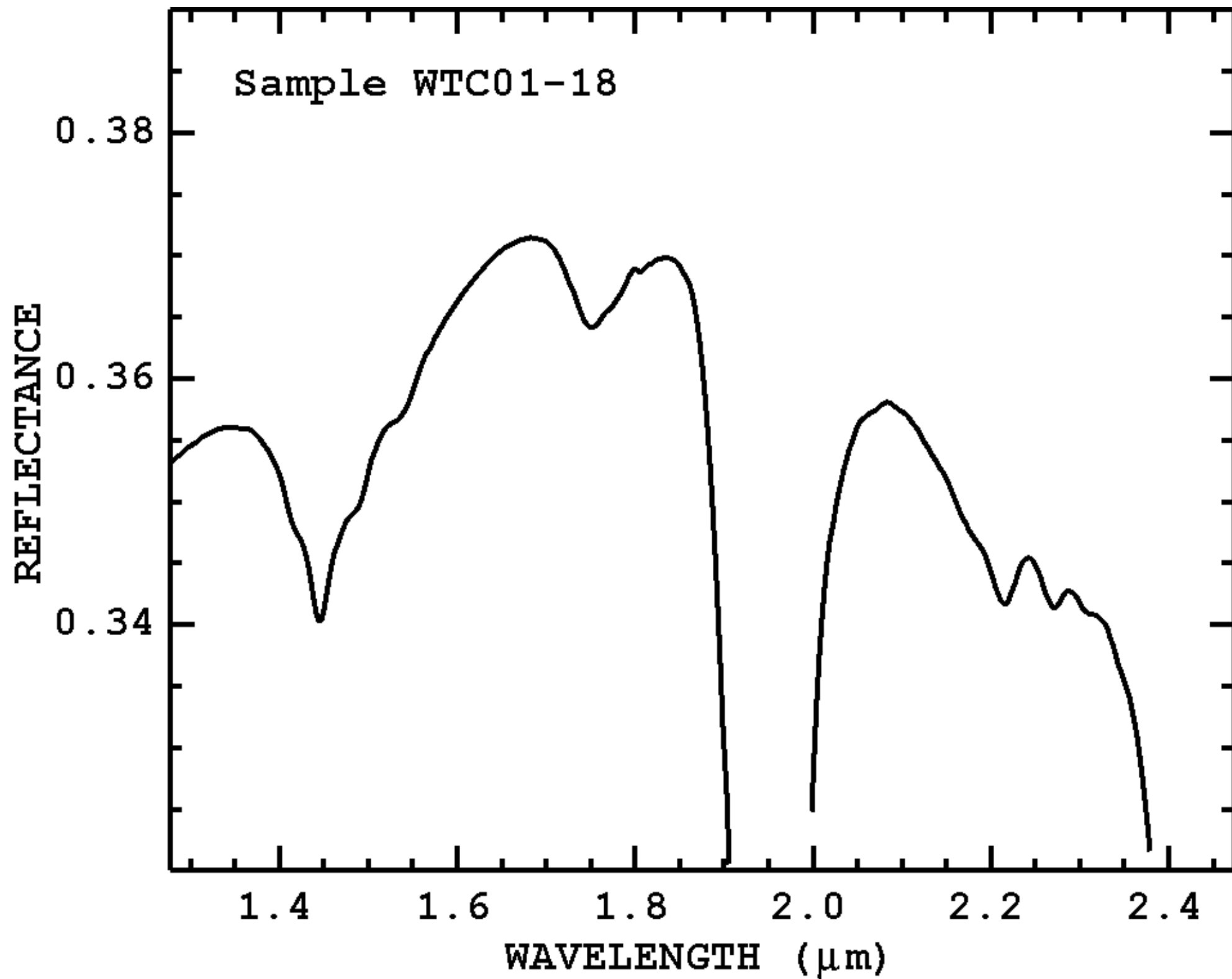


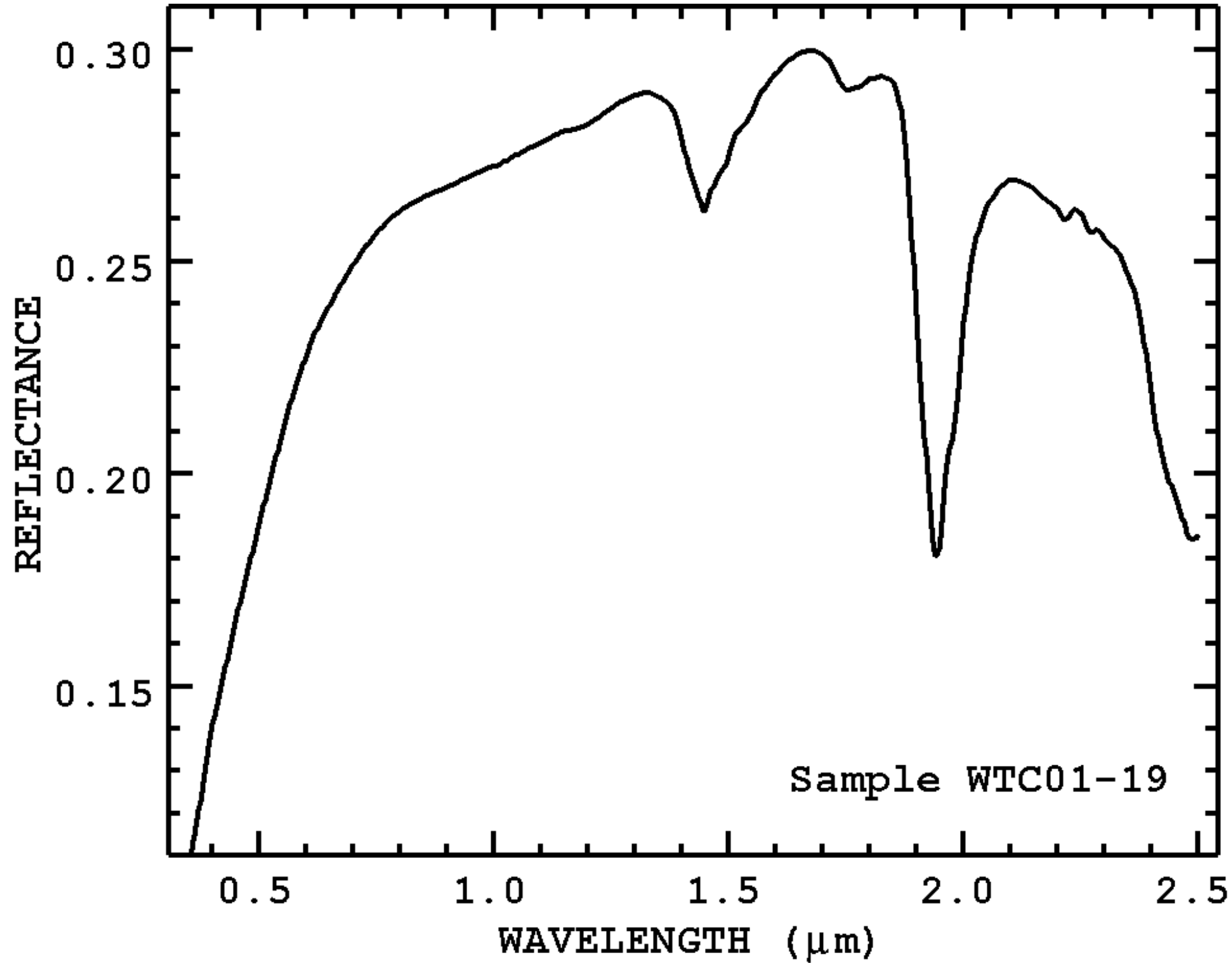


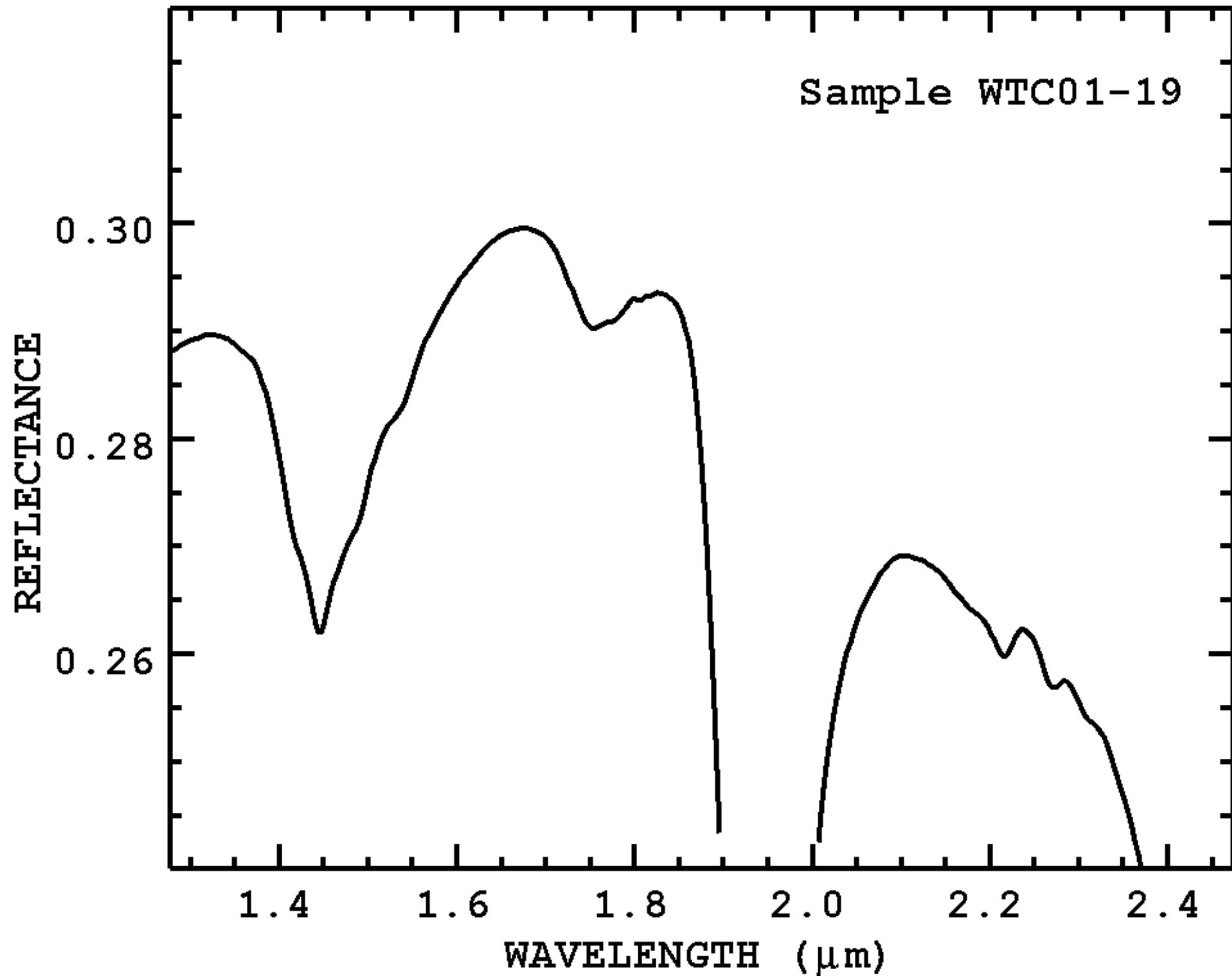


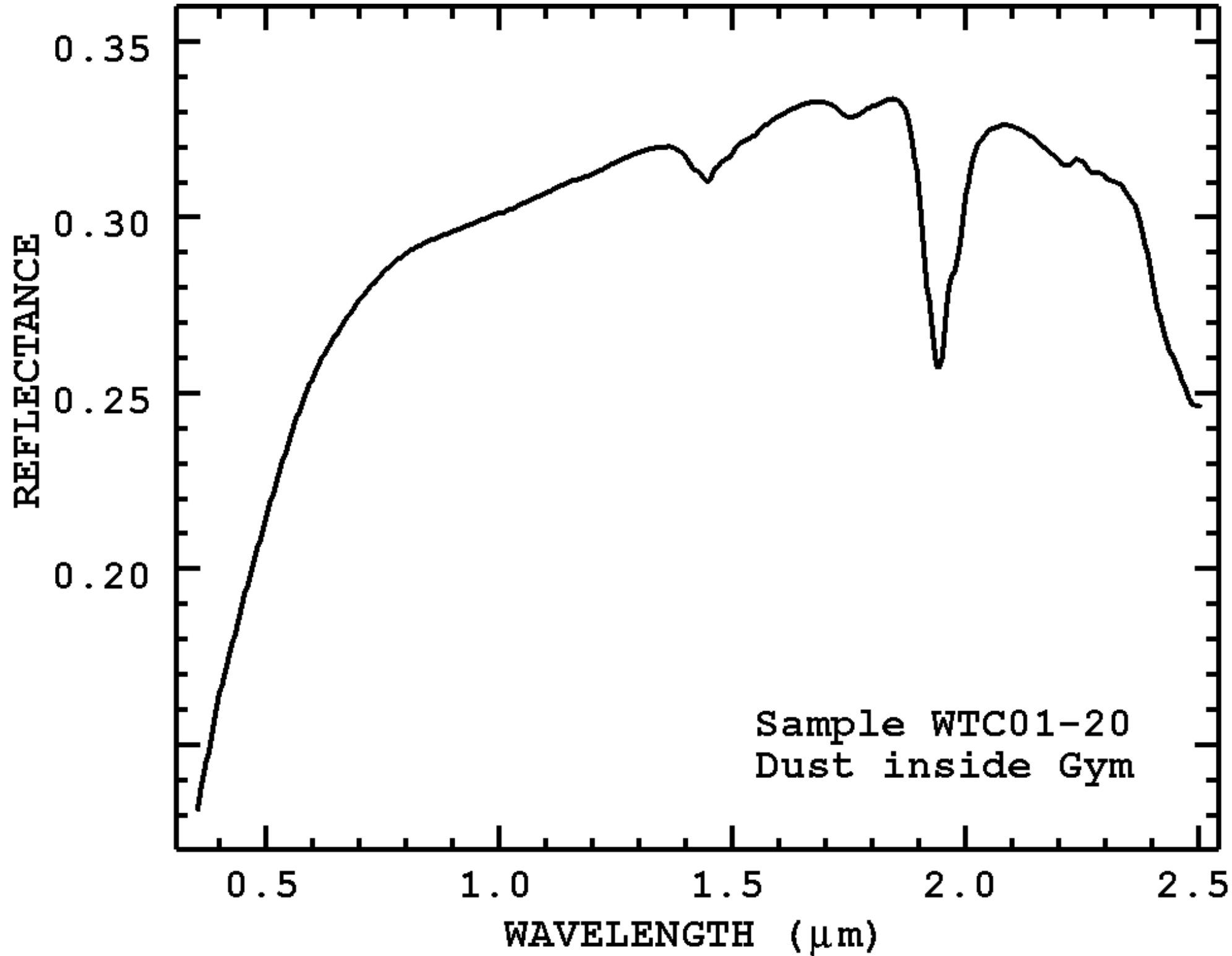


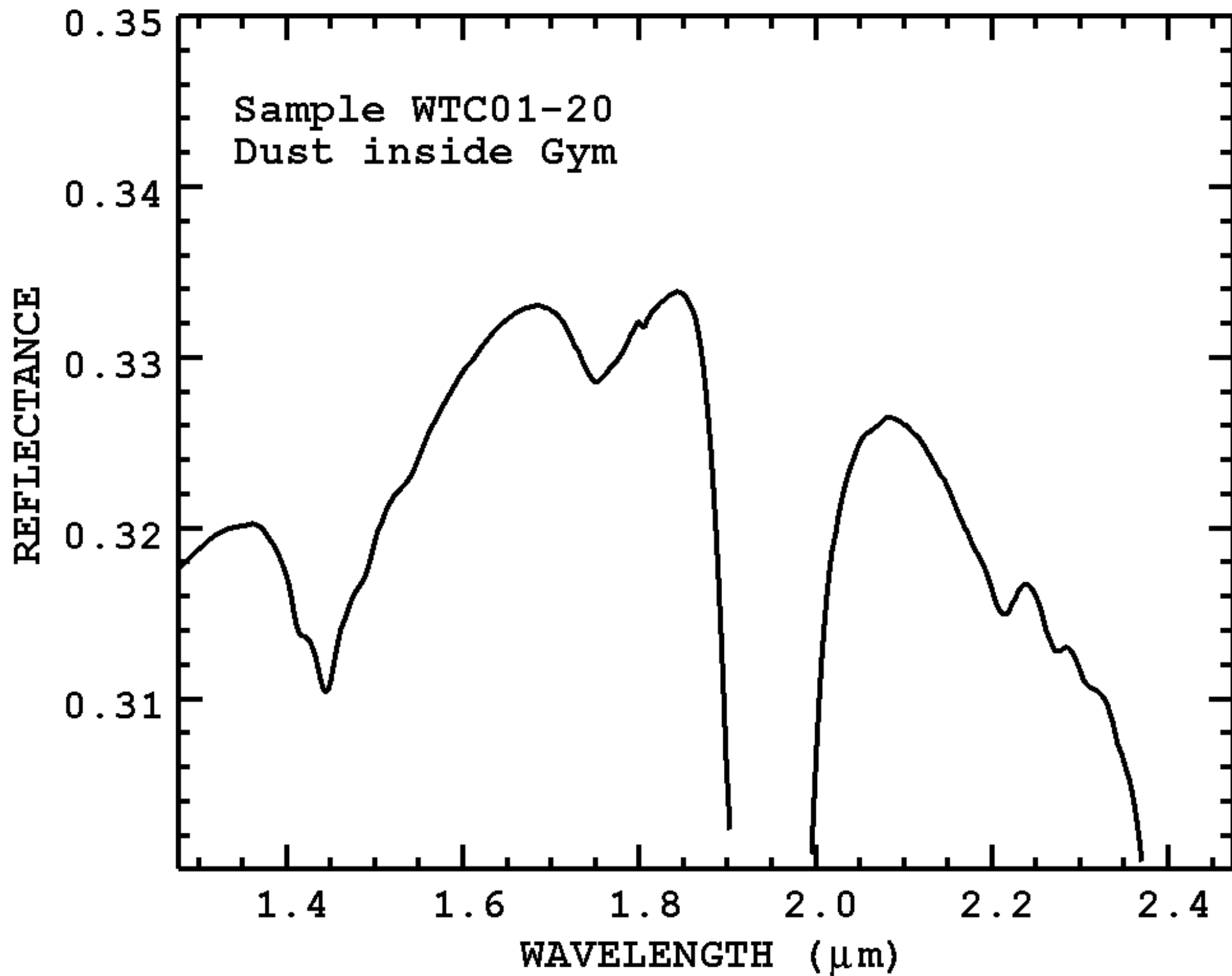


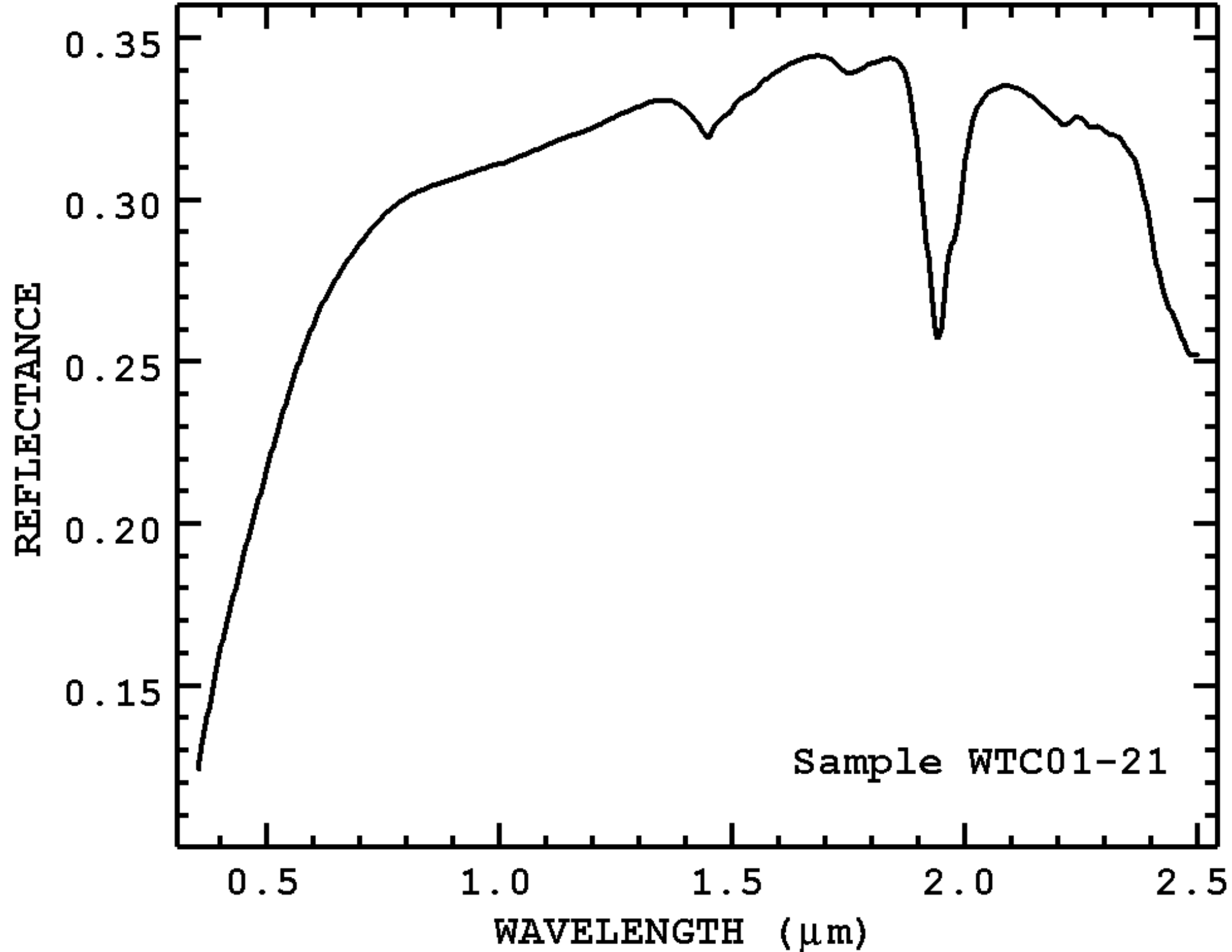


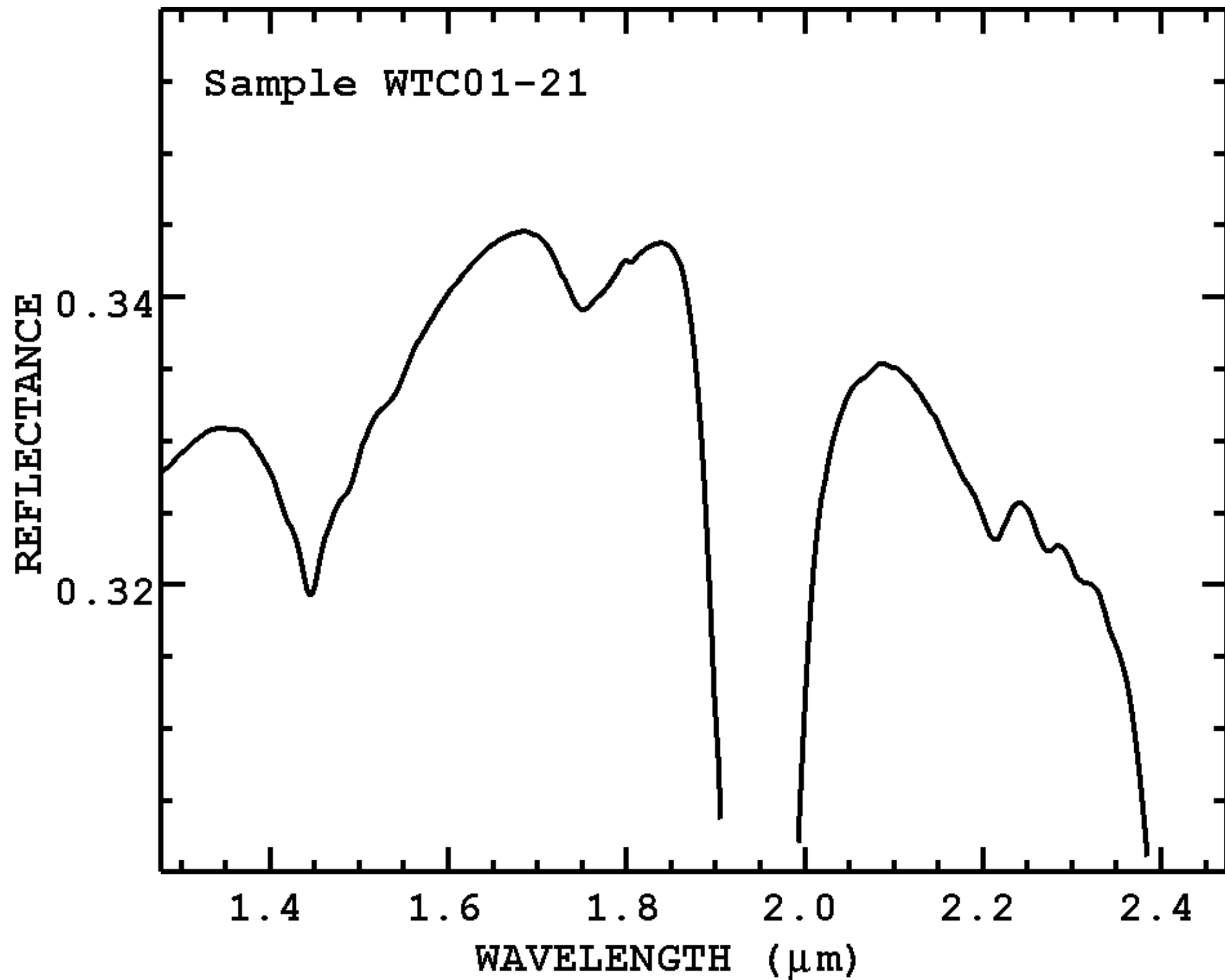


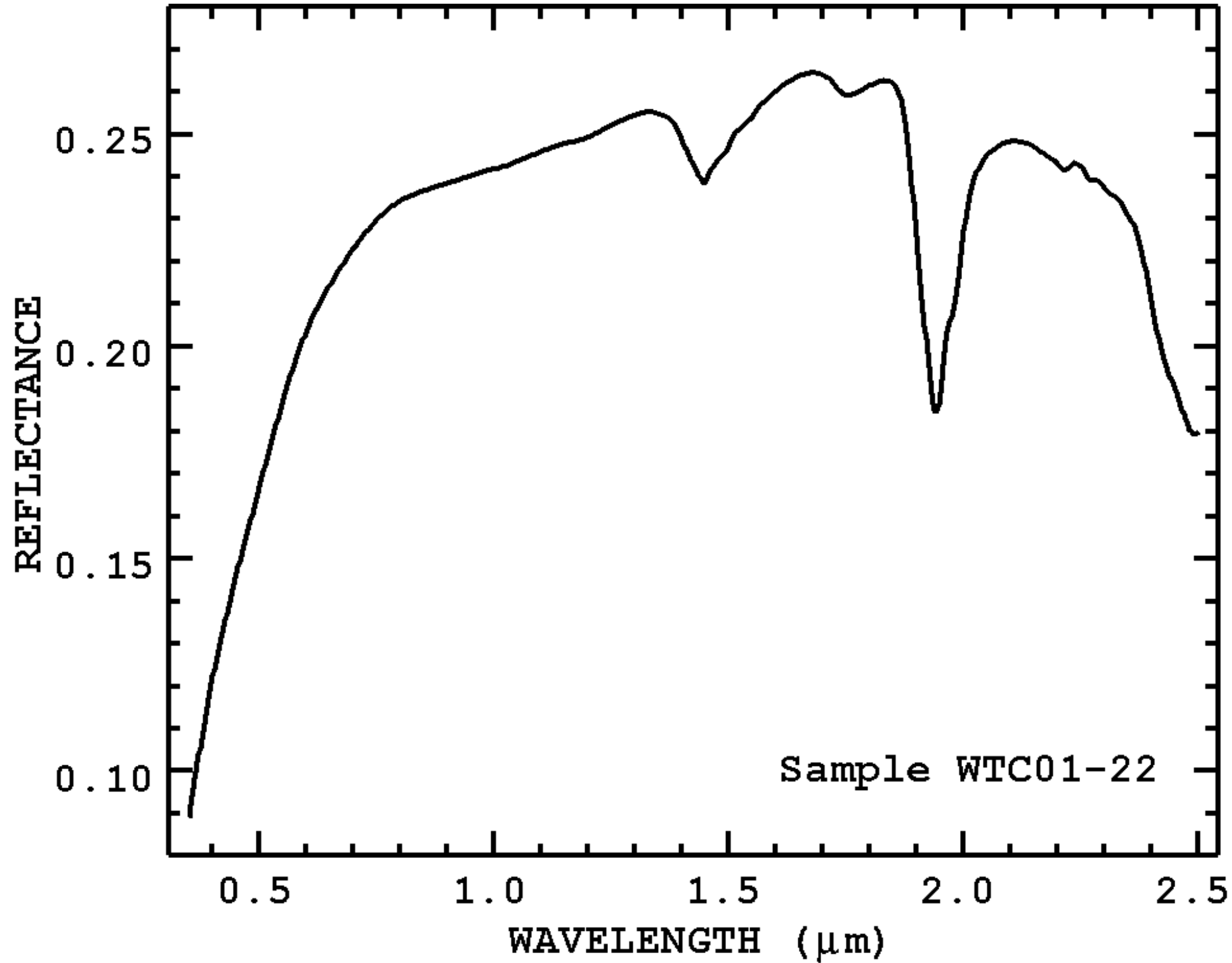


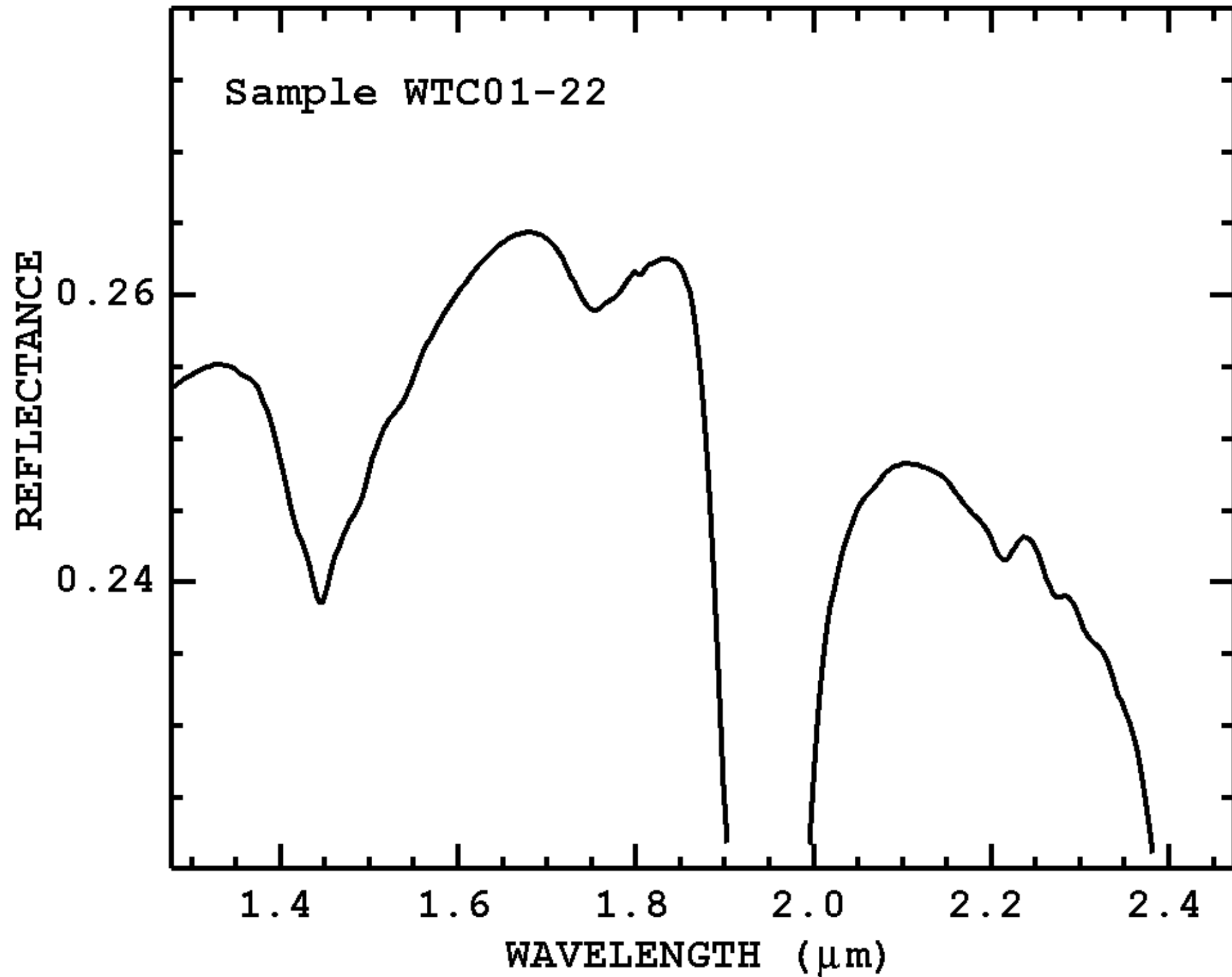


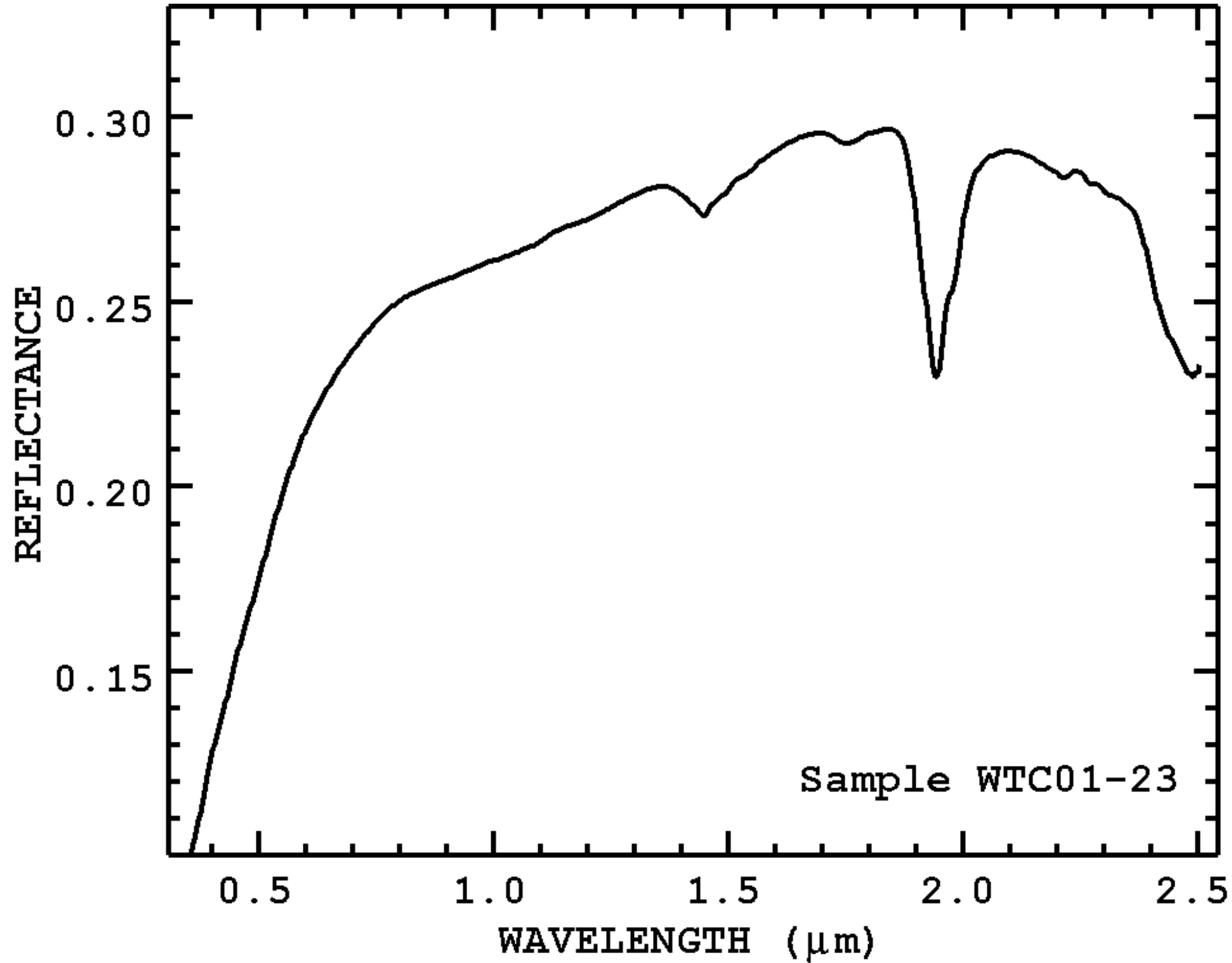


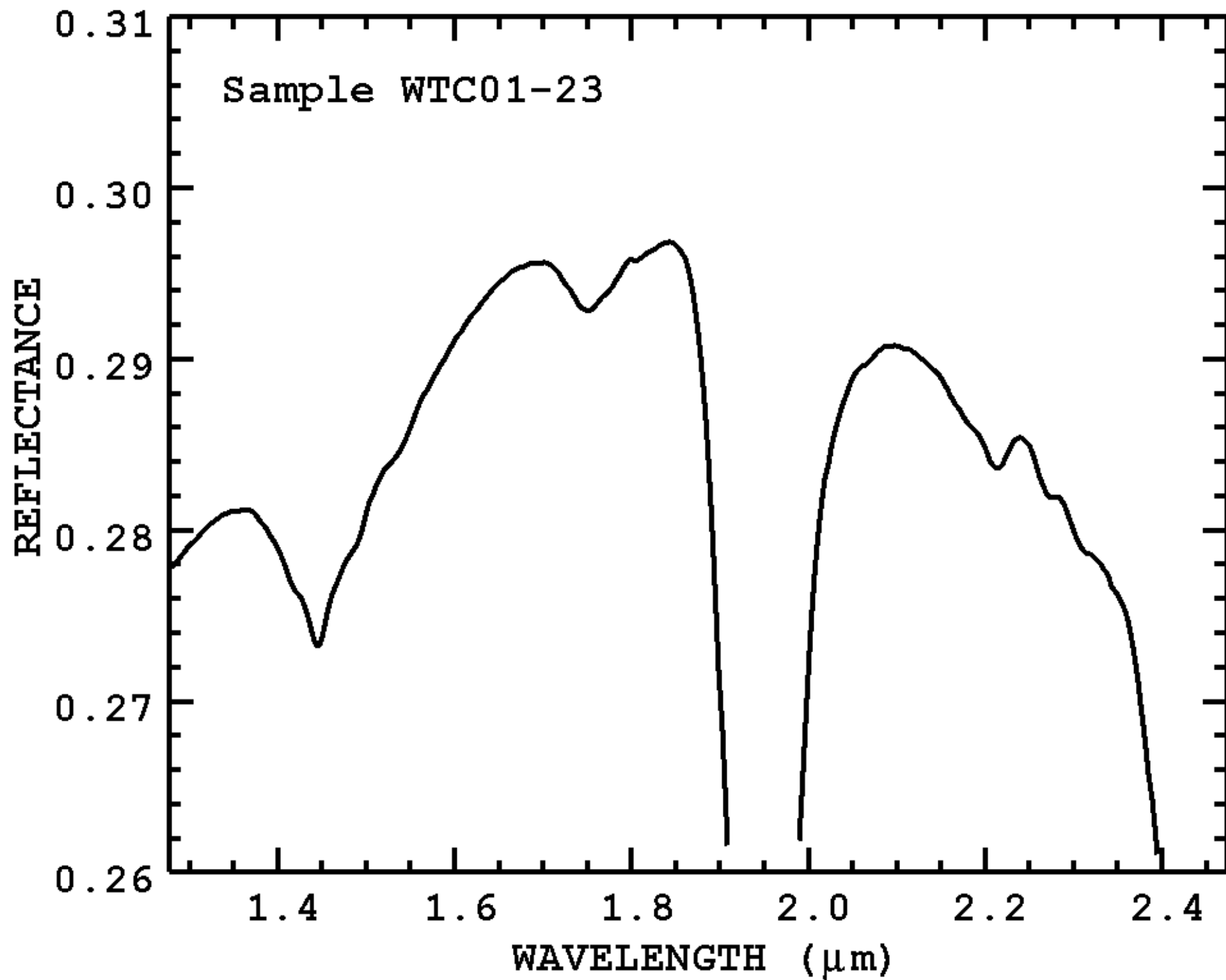


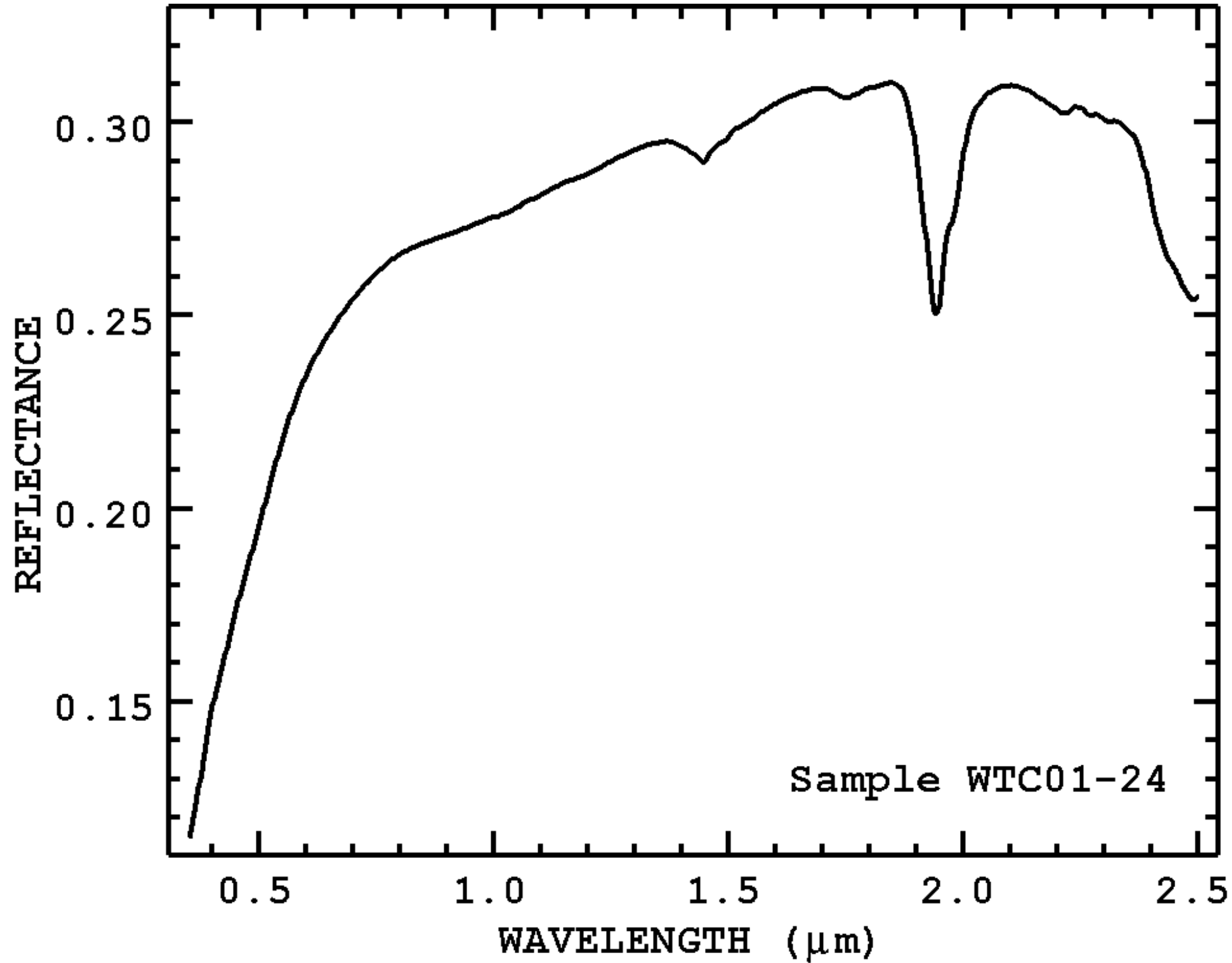


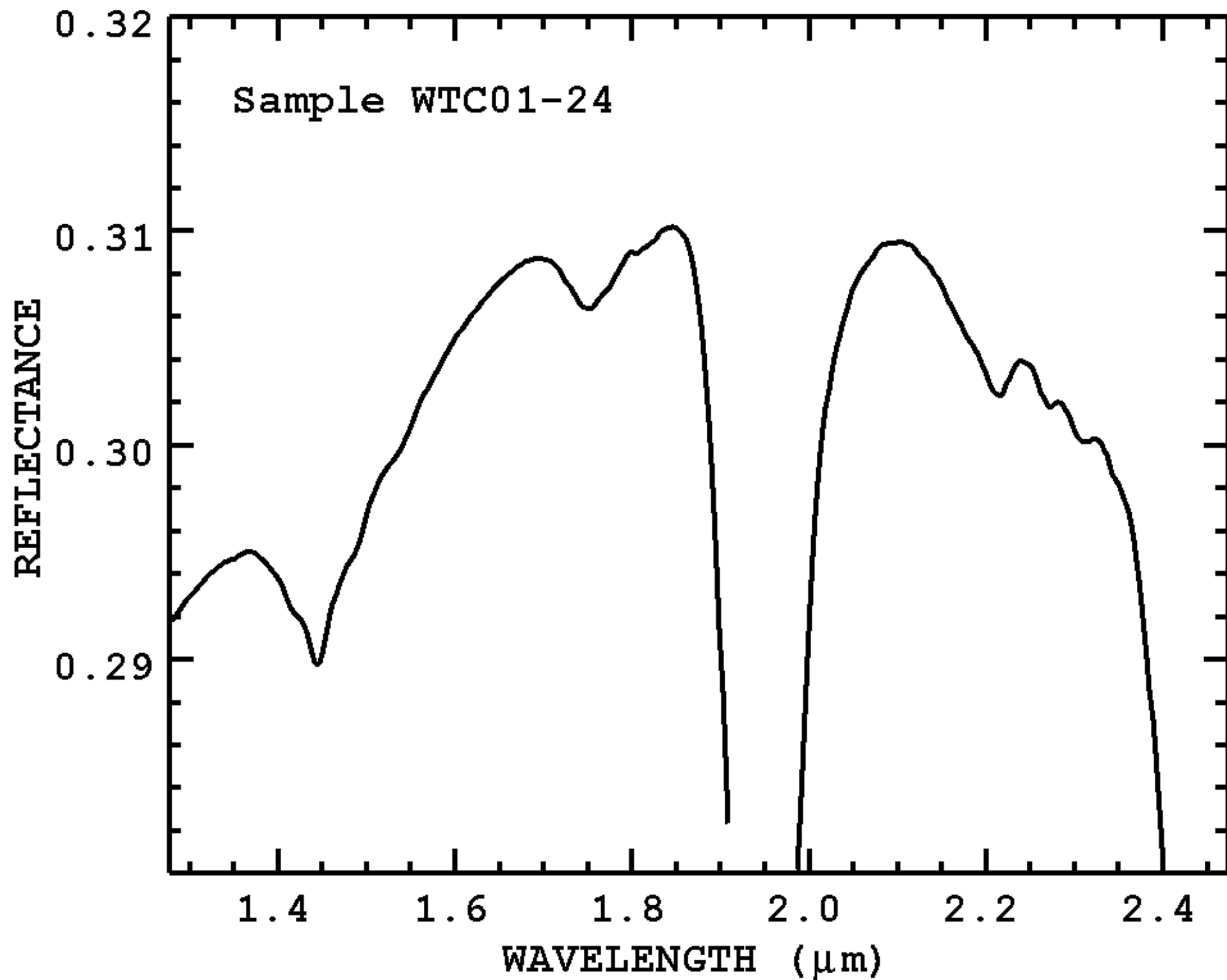


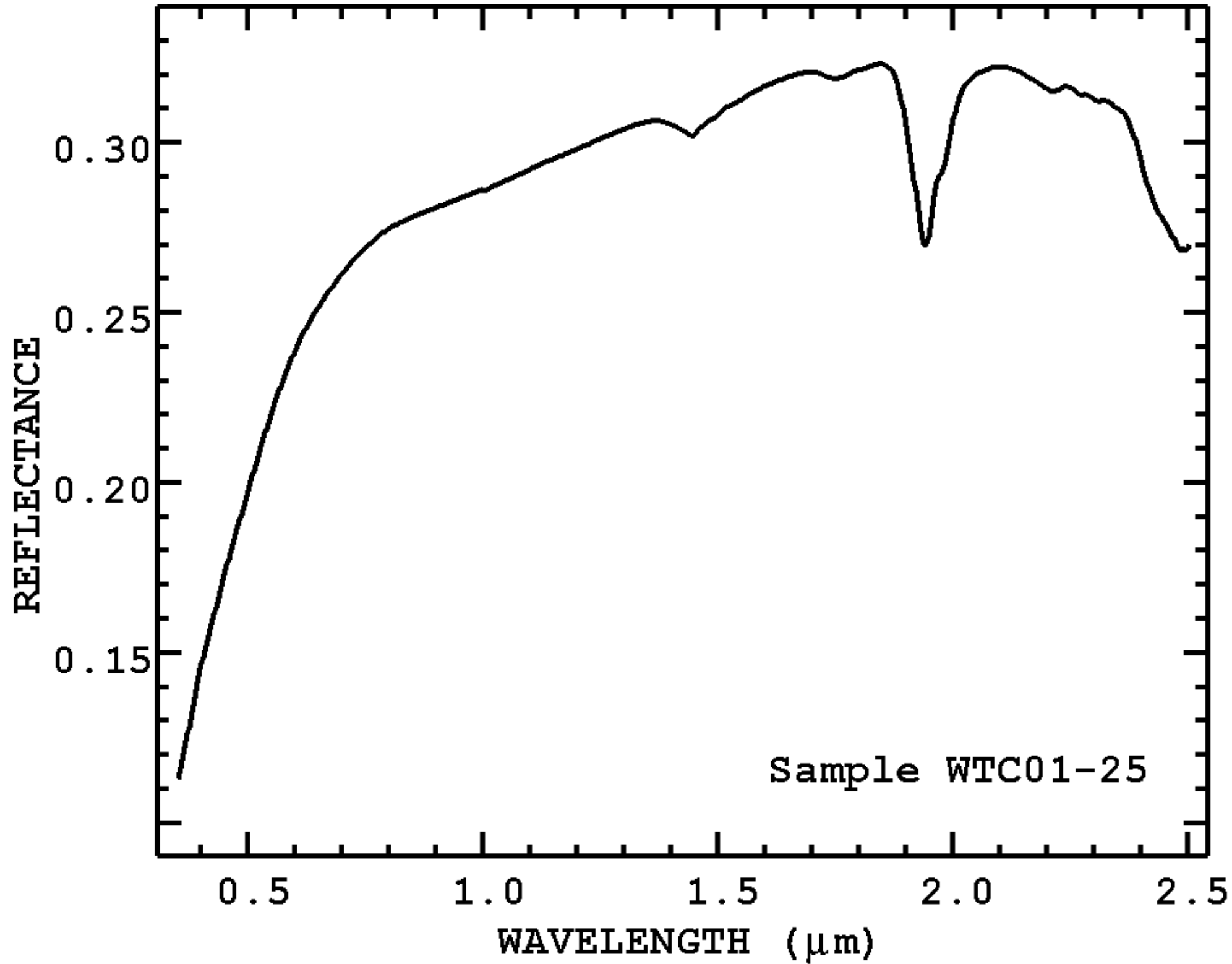


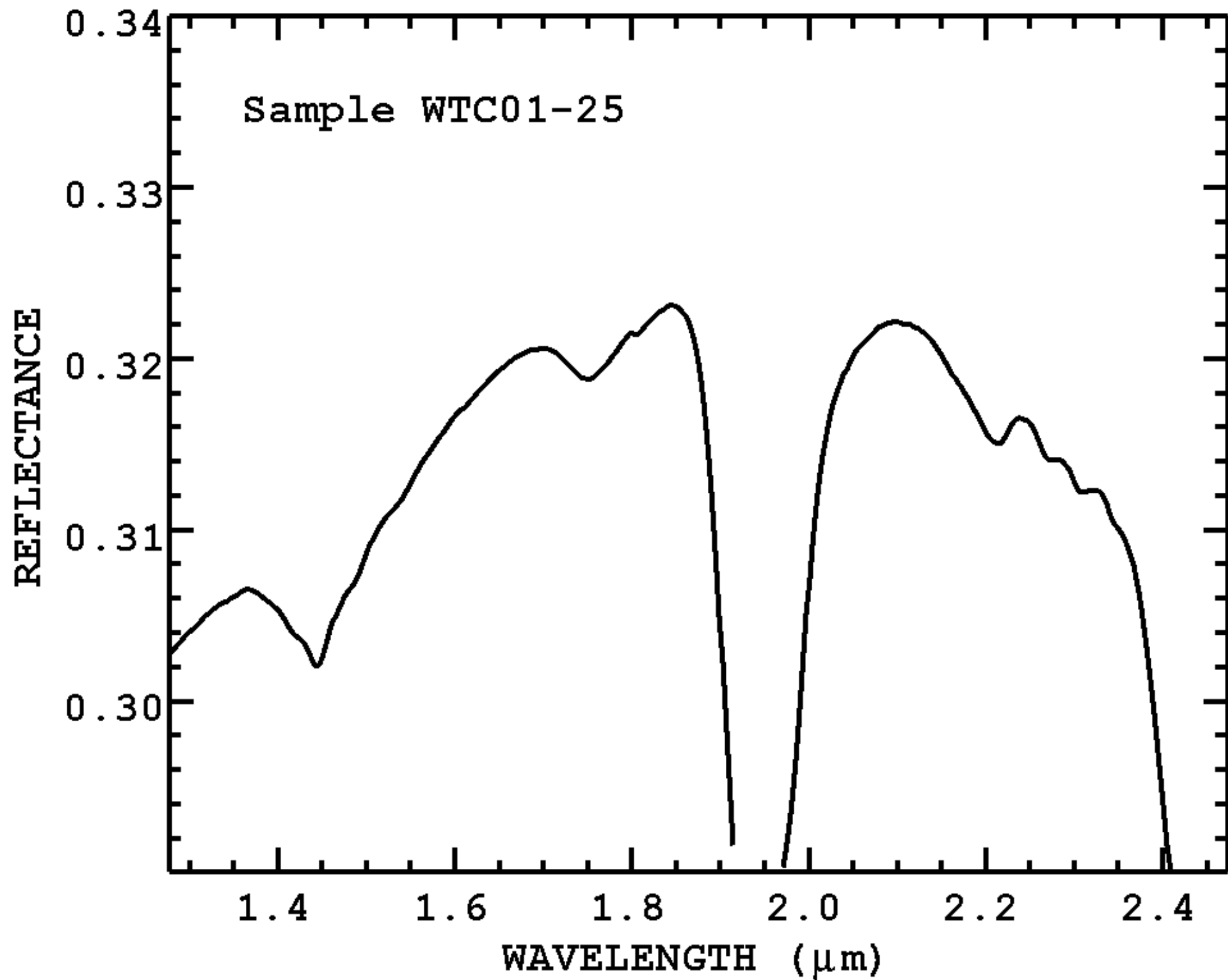


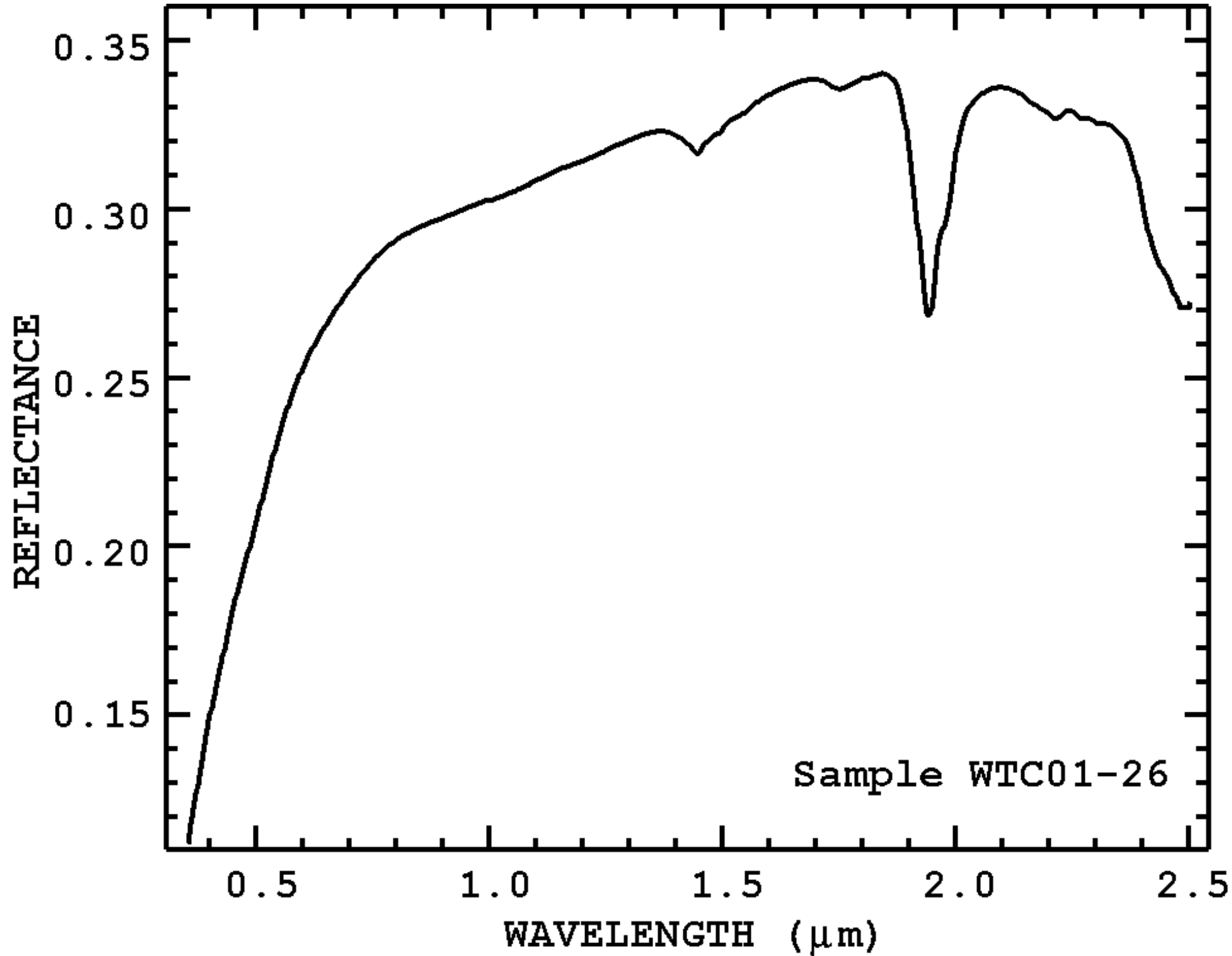


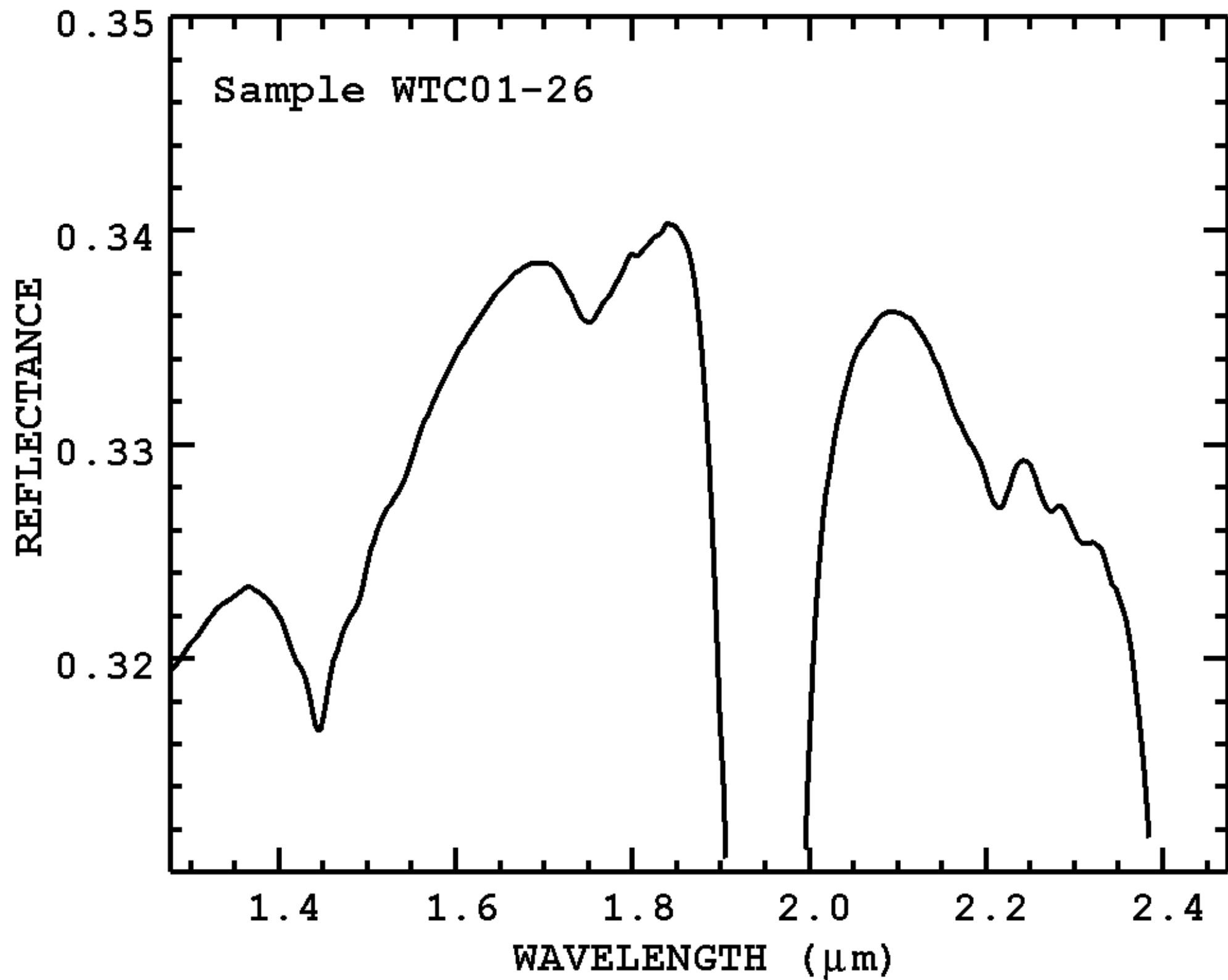


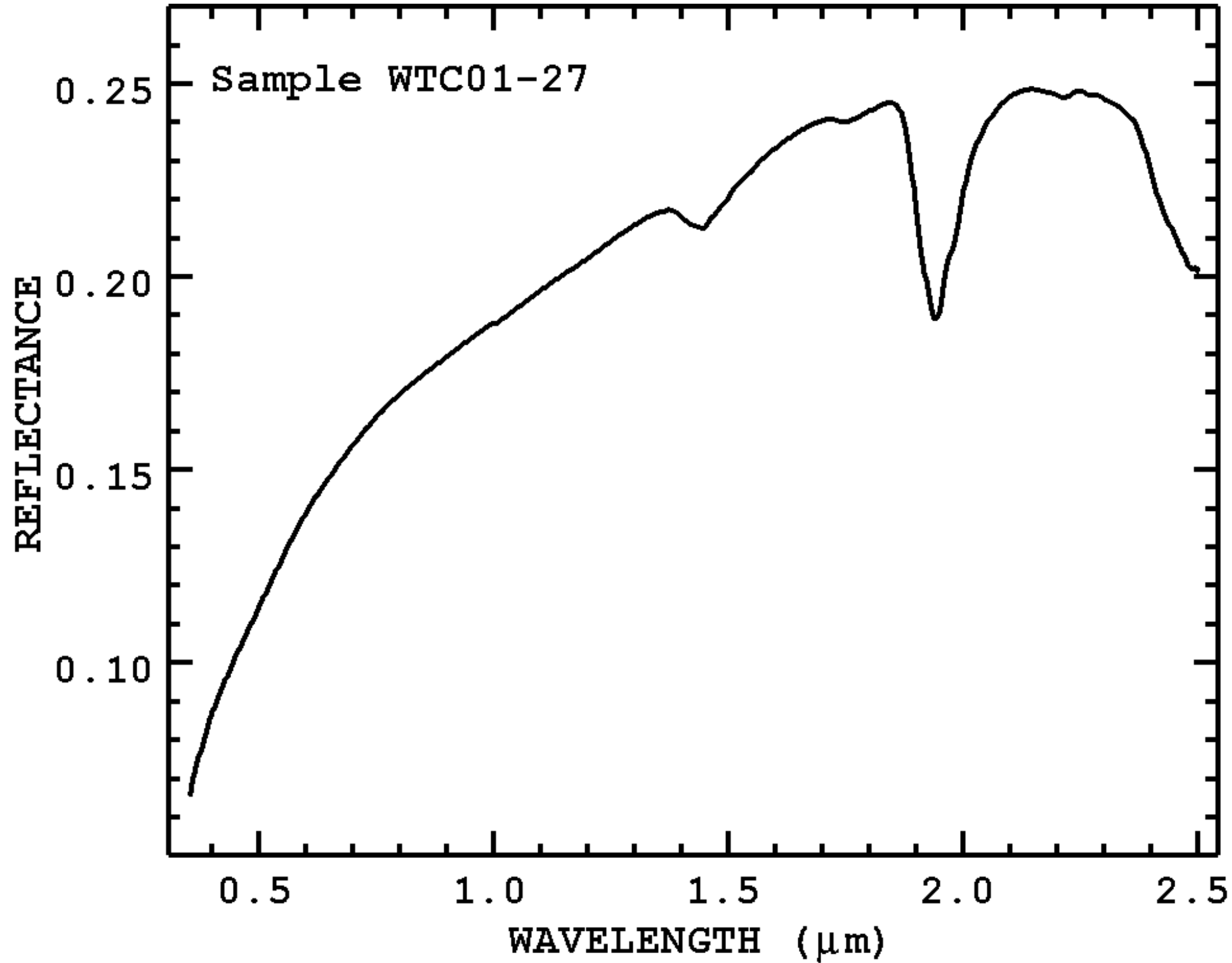


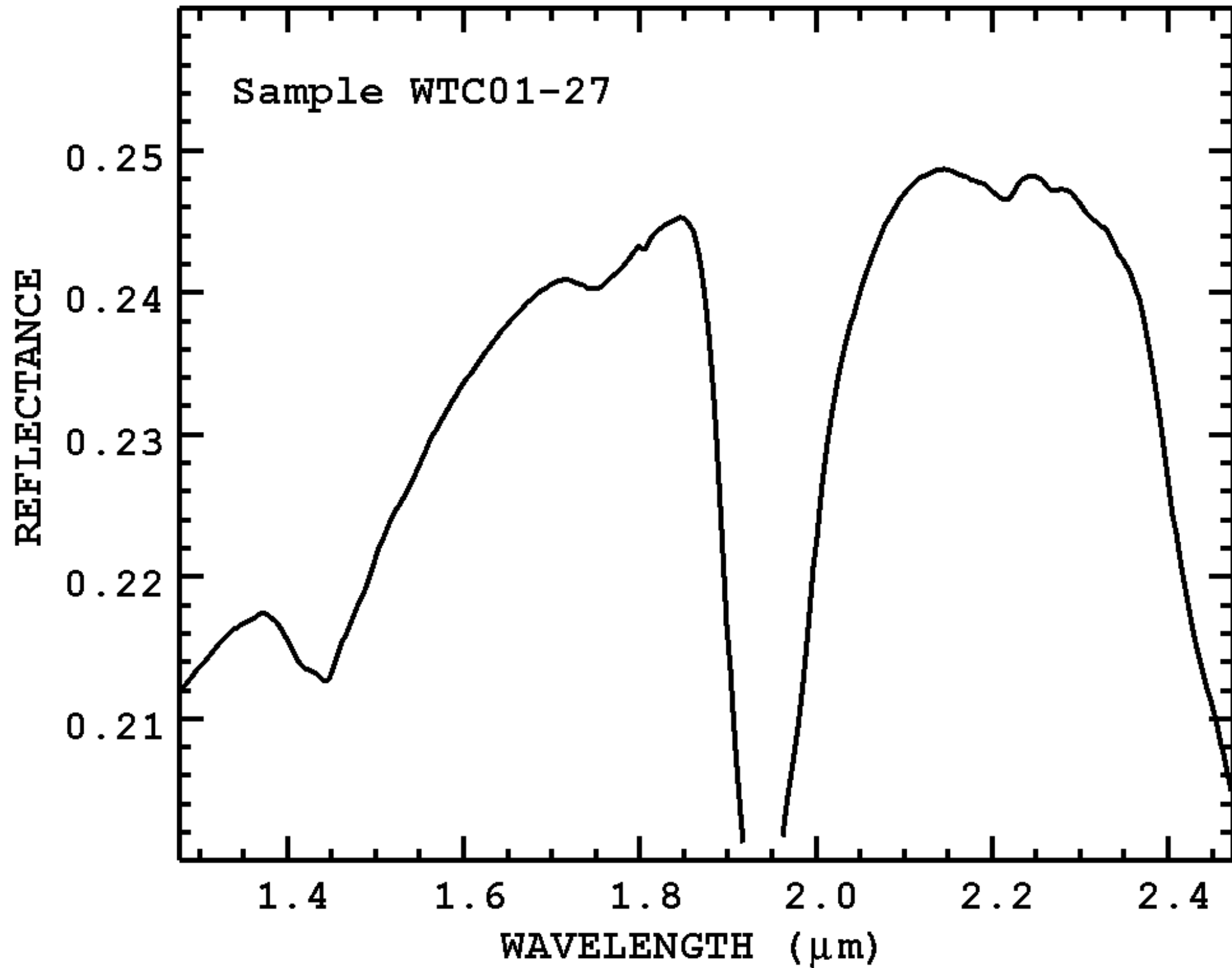


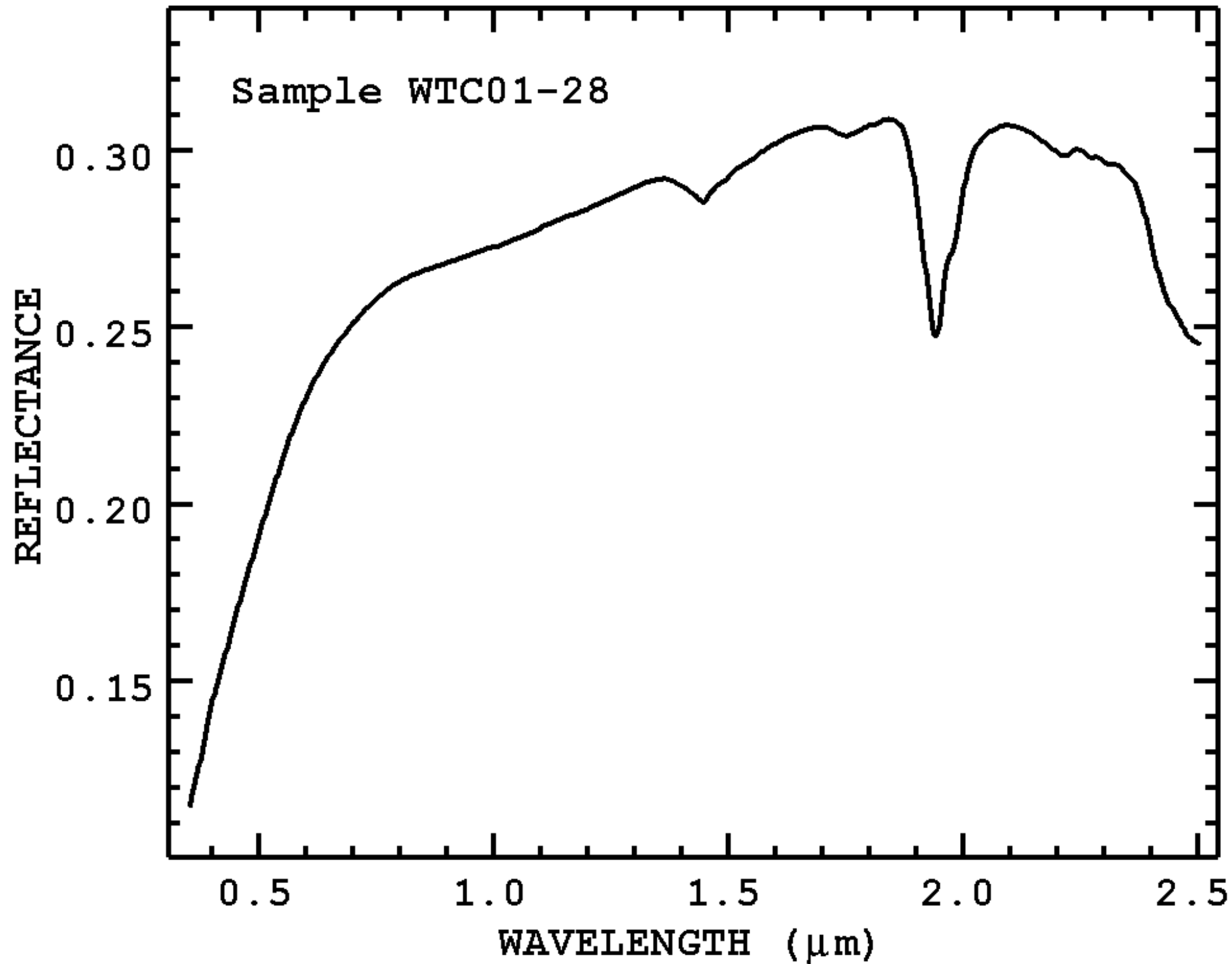


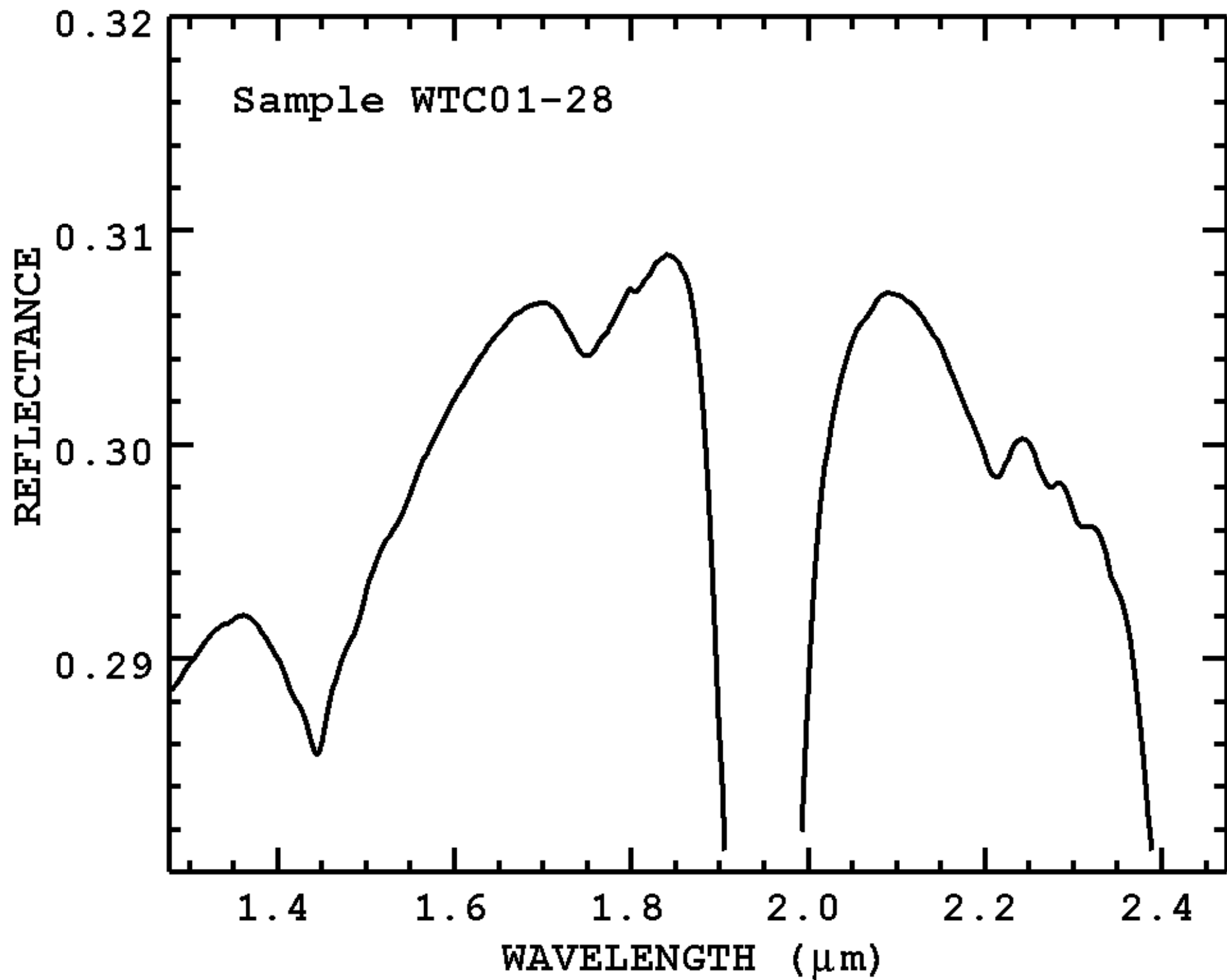


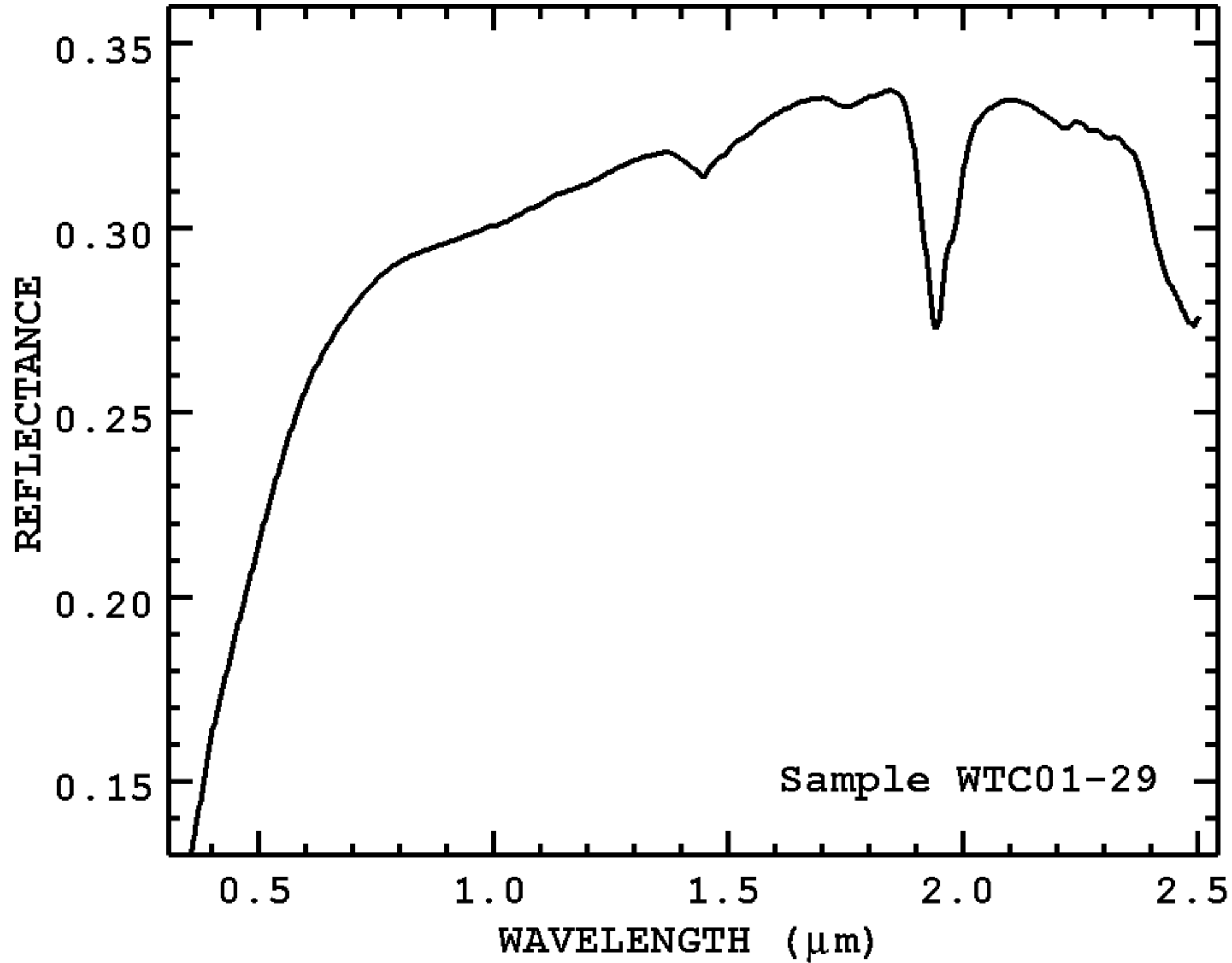


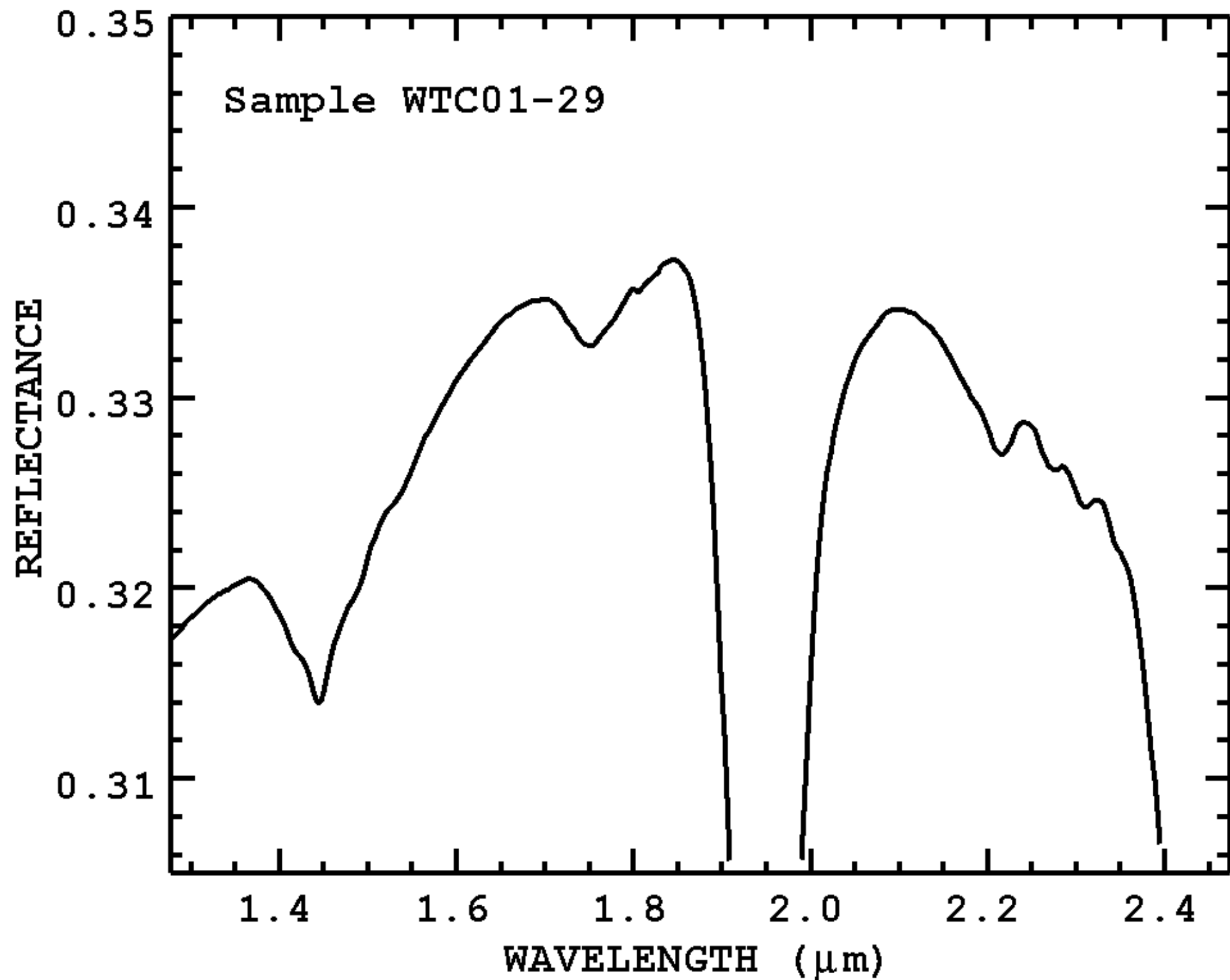


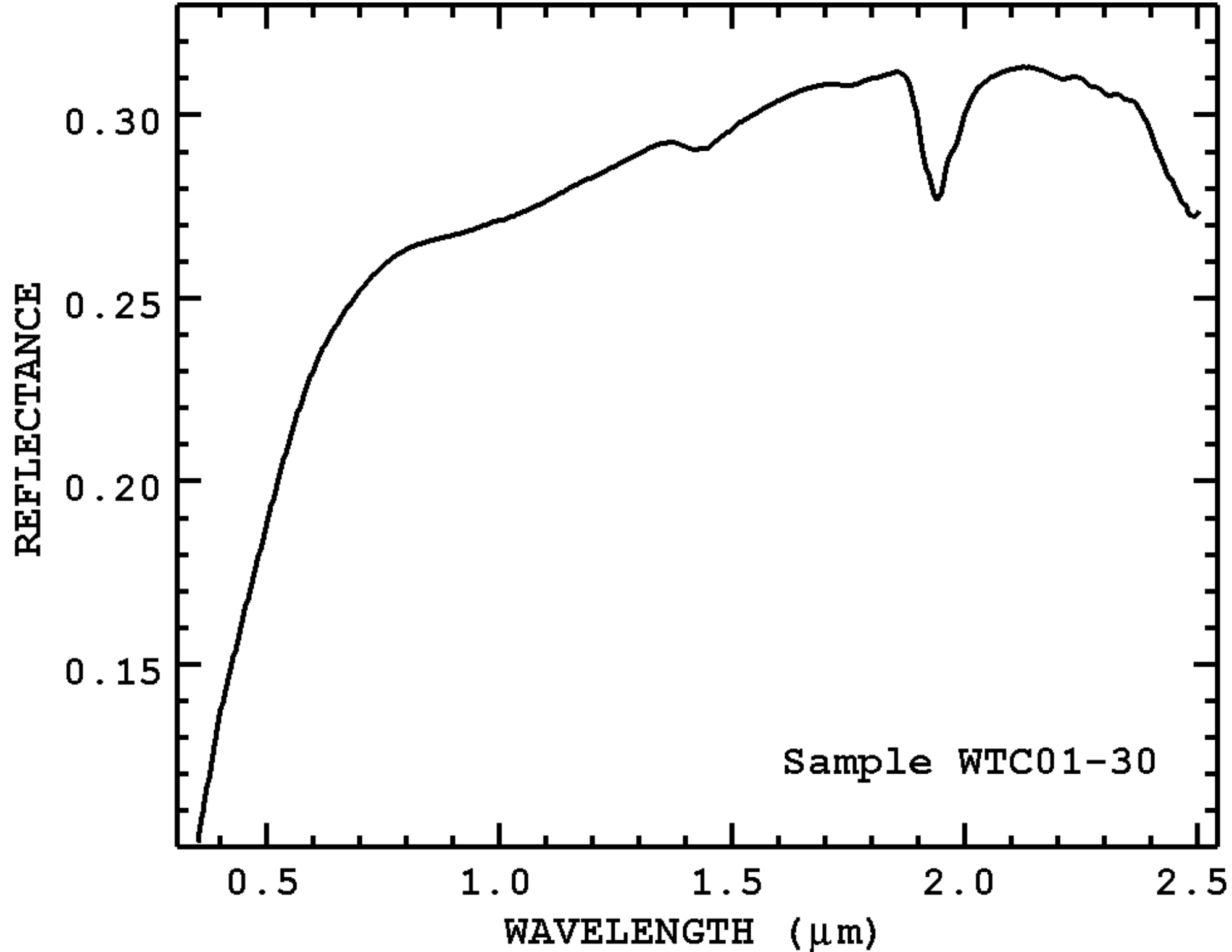


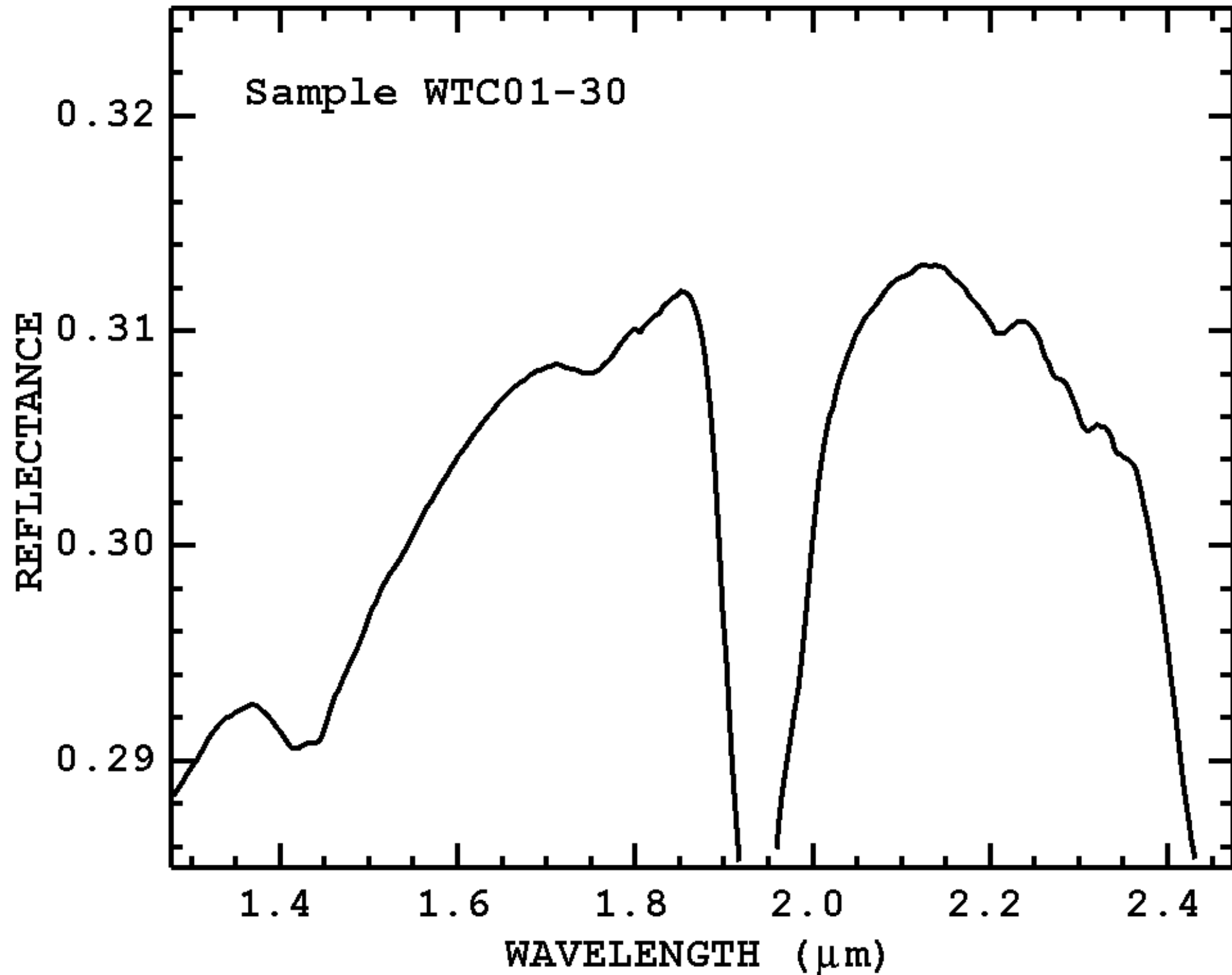


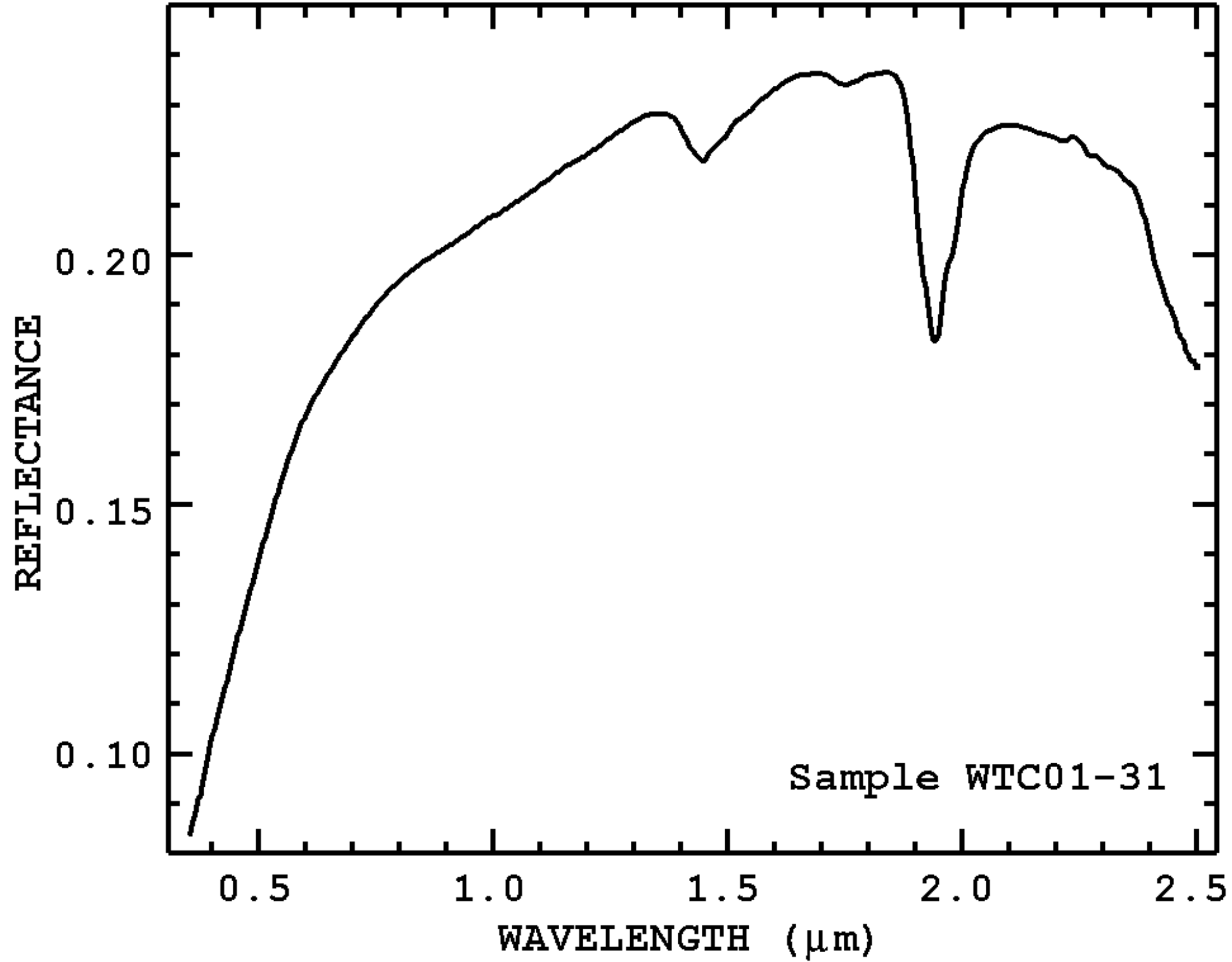


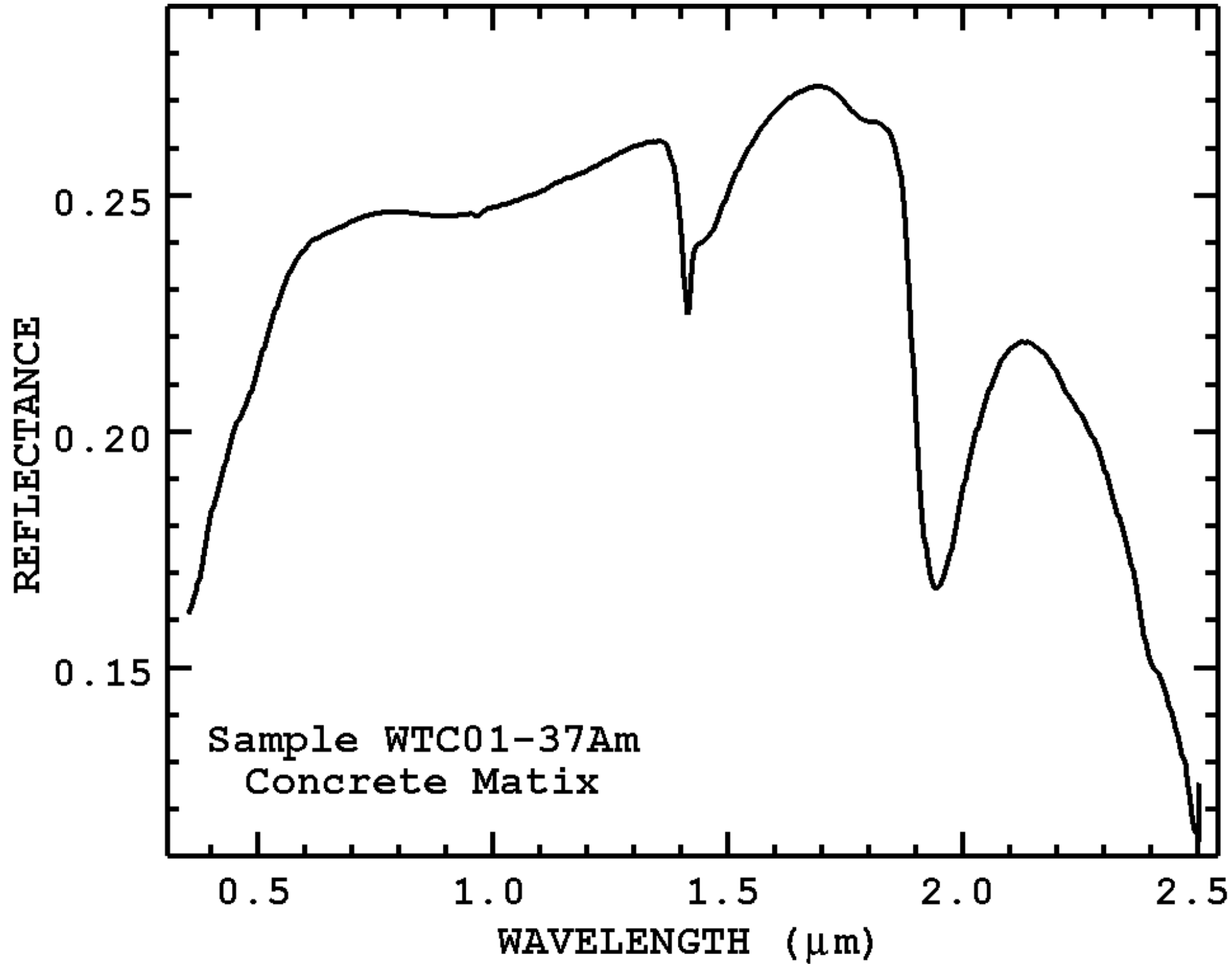


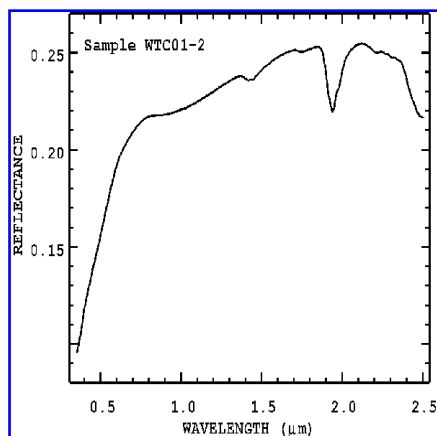




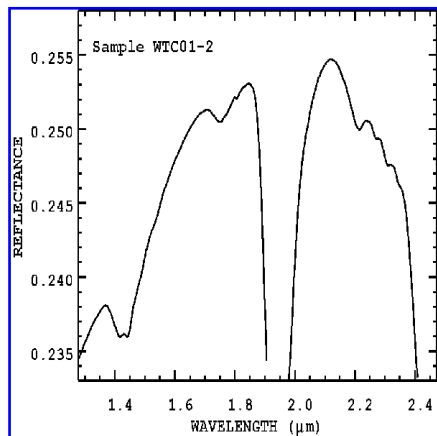






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Dust sample from: Water & Vietnam Vet. Plaza 4506052N 583559E

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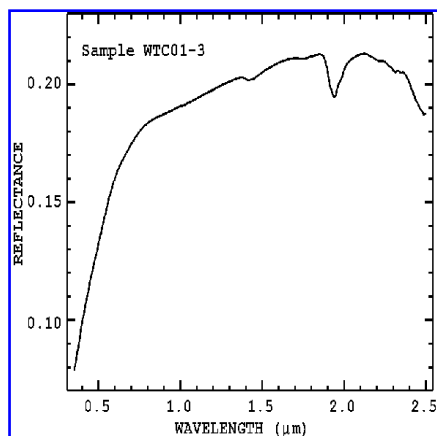
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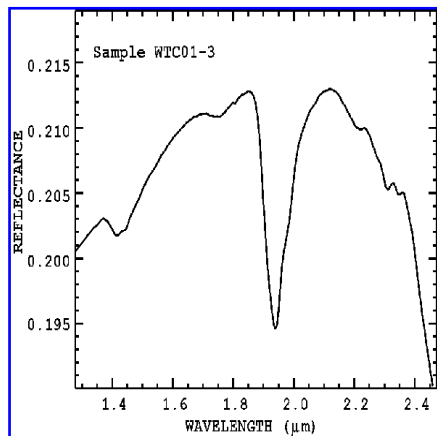
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Location: Battery Park, east central 4506123N 583217E drainage disc



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