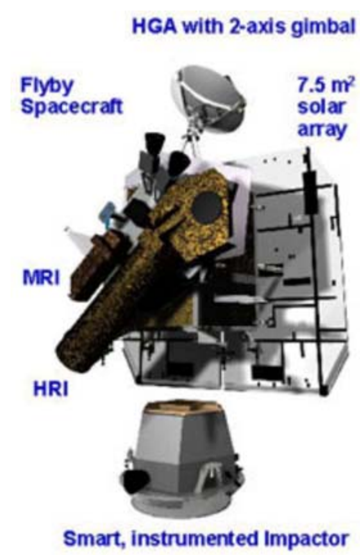
ACTIVITIES

Feel the Impact

What We Learned About Tempel 1 Teacher Guide

Science Background Information

This final section of the ACE *Feel the Impact* materials introduces students to the results of ***800 seconds*** of imaging and data from the Deep Impact (DI) Mission. For this reason, we are listing the pertinent Deep Impact websites as your background material. These websites are being updated as data from the mission is being analyzed.



Deep Impact Spacecraft

Please pay particular attention to the way in which the DI scientists describe the results. You will find wording like “presumed to be”, “we can conjecture”, and “it is suspected”. By using wording similar to this as you discuss the findings from the DI mission, you will keep students focused on the on-going discovery process of sciencing, rather than presenting the findings as “facts” to be memorized.

The topics in this *Feel the Impact* What We Learned About Tempel 1 section include:

- Facts about the Deep Impact Spacecraft
- What is Spectroscopy?
- What did imaging and spectroscopy from the Deep Impact Mission tell us about Comet Tempel 1?

Refer to the following URLs for:
additional details on the spacecraft
http://deepimpact.jpl.nasa.gov/tech/flyby.html
http://deepimpact.jpl.nasa.gov/tech/impactor.html

images and background on the results of the Deep Impact Mission
http://deepimpact.umd.edu/gallery/Temperature_Map.html

A temperature map of the nucleus with different spatial resolutions. These data were acquired with the IR spectrometer using signal between 1.8 and 2.2 µm.

http://www.nasa.gov/mission_pages/deepimpact/media/deepimpact_water_ice.html

This URL contains information about the significance of surface ice found on Tempel 1.

http://deepimpact.umd.edu/gallery/jpg/Making_Composite3.jpg

Excellent image of surface features of comet Tempel 1

http://deepimpact.umd.edu/mission/update.html

http://deepimpact.umd.edu/gallery/images-results.html

These pages are continually being updated to show current images and descriptions of Deep Impact science results.

http://deepimpact.umd.edu/results/excavating.html

This article reviews and highlights portions the paper *Deep Impact: Excavating Comet Tempel 1* written by the Deep Impact science team and published in Science as well as on-line in Science Express, 09/08/05

http://deepimpact.umd.edu/mission/update-200512.html

These pages contain a description of how comets evolve.

http://deepimpact.umd.edu/gallery/spectrometer2.html

These pages show the spectrum of the vapor plume at 0.6 sec after impact.

background on IR Spectroscopy:
http://deepimpact.jpl.nasa.gov/science/spectroscopy.html
http://www.yale.edu/ynhti/curriculum/units/1999/5/99.05.07.x.html
http://genesismission.jpl.nasa.gov/educate/scimodule/PlanetaryDiversity/plandiv_pdf/HereComesHeatTG.pdf

The **After the Impact** section concludes with students considering the following questions, among others. In the **Procedure**, we have included some shortened versions of these more complete answers taken from the Deep Impact website.

"*How much of the ejecta do you think fell back to the surface of the comet? A lot, some, a little, or none? Why do you think so?"*

> There was **material in the [ejecta] curtain was made of smaller, finer particles than expected** indicating that the **strength of the material lying within tens of meters of the comet's surface is very weak and powdery.** Therefore the ejecting gas and dust are able to tear an unexpectedly great amount of material from the crater as it forms. It al so "hung around" rather than falling quickly back to the surface as expected.
>
> **Tempel1's gravity is not very strong** and so it is not able to hold the ejecta back **so most of it is able to escape into space**. However, **some of the dust does fall back** onto the surface of the comet.
>
> Nevertheless the comet's gravity is strong enough to prevent the last ejecta expelled from the crater from getting vary far from the surface. Thus the **bottom of the plume remains essentially in contact with the rim of the crater**. It does not detach from the surface, a phenomenon that was looked for with great interest by astronomers. **Astronomers say that the ejecta is gravity-controlled rather than strength-controlled.**
>
> The comets gravity, although small, overpowered the shear strength of the ice-entrained dust that comprises its interior. Estimates place the depth of the powdery surface layer at tens of meters.
>
> The **shadow of the ejecta cone** on the surface of Tempel1 was greater than 300 meters across at its base than expected.
>
> These excerpts were taken from
> http://deepimpact.umd.edu/results/excavating.html

"*One of the Deep Impact mission's objectives was to observe how the crater forms. Do you think this mission was accomplished? Why or why not?* "*How large is the crater*?"

> Deep Impact scientists wanted to measure the crater's depth and diameter, but the Deep Impact experiment proceeded differently than scientists expected! **They expected to see the dust debris clear and reveal the crater** and its interior. But they did not see the crater.
>
> The ejecting gas and dust were able to **tear more fine-particle material from the crater as it formed than was expected**. The bright dust cloud, consisting of fine dust about 1 to 100 μm, prevented imaging of crater. [For comparison, human hair ranges from 17 to 181 μm.] Although the particles were tiny, there was a lot of dust and it significantly impeded the passage of light through the plume. The ejecta curtain became optically thin relatively slowly. **Even at the 13 minutes its optical thickness was still significant.**

For more details on spectroscopy and analysis of spectra see
http://deepimpact.jpl.nasa.gov/science/spectroscopy.html
http://deepimpact.umd.edu/gallery/313_635_F1.html
http://deepimpact.umd.edu/gallery/313_635_F2.html
http://deepimpact.umd.edu/gallery/313_635_F3.html
http://deepimpact.umd.edu/results/spectrometer.html
http://deepimpact.umd.edu/results/spectrometer2.html

"Another of the Deep Impact mission's objectives was to measure the composition of the interior of the crater and its ejecta. What substances were found in the ejecta?

By comparing the spectrum of the earlier ejecta to the later ejecta, scientists think it might be possible to determine how thick the outer layer of the nucleus material is.

A spectrum taken six tenths of a second after Tempel 1 impact showed the **presence of liquid water, hydrogen cyanide, carbon dioxide and organics.** The gas consisted most of steam and carbon dioxide, at an initial temperature of over 1000 degrees Kelvin. Remember that room temperature is 295 K".

Scientists are still studying the **spectrum taken later after impact**, but there are some indications that there were **large amounts of silicates** in the later ejecta. Silicates are important and common rock-forming minerals formed mainly from silicon and oxygen and combined with various other elements.

"*Deep Impact scientists wanted to discover the differences between the near surface composition of comet Tempel 1 and the composition of interior. Do you think this mission was accomplished? Why or why not?"*

Although the ejecta spectrum will be studied for a long time, we can make some preliminary comparisons between the initial ejecta spectra and the spectra from the surface.

Spitzer Space Telescope's imaging spectrometer and infrared camera observed comet Tempel 1 both before and after impact on July 4, 2005, covering the infrared spectral region between 5- to 35 microns. This is the region where thermal radiation dominates the spectrum. The brightness of the comet increased as time passed after the impact, as compared to before impact. In the spectrum, emission features due to both crystalline and amorphous (glassy) silicates, amorphous carbon, carbonates, clay minerals (phyllosilicates), water in both the gaseous and solid states and sulfides were observed in the spectrum.

Keep checking these URsL for updates on spectral analysis
http://deepimpact.umd.edu/mission/update-archive.html
http://deepimpact.umd.edu/results/index.html

"*Now that the Deep Impact mission is over, what suggestions do you have for "seeing the crater" formed on comet Tempel 1?"* One of the most likely solutions that students will come up with is returning to Tempel 1 to measure the crater. Could the Deep Impact spacecraft return to Tempel 1 and look at the impact site?

Bill Blume and the JPL mission design team answered the question this way:As we expected, there was no chance to get back to Tempel 1 until the next perihelion (5.5 years later), but we were surprised that there really was a viable trajectory to get back to the comet:

This was found by our trajectory expert Dr. Chen-wan Yen shortly after the July 4th encounter. The delta-V for this mission wasn't impossible (about 136 m/s vs. 85-100 m/s for Boethin), but there were a number of sticky issues and we were suddenly in a time crunch to make a decision. This was because the operations staff was rapidly moving off to other projects and a maneuver needed to be executed fairly quickly to target an Earth flyby to enable an extended mission.

The PI, Mike A'Hearn, decided that an attempted return to Tempel 1 too risky because of the following factors:

- The return required two more years in flight, which substantially increases both cost and risk to spacecraft performance.
- There is a long period when the spacecraft is behind the sun as viewed from Earth, which hampers navigation.
- At this encounter, the range to Earth would be 2.3 AU (compared to 0.9 AU at the July 4th impact), which results in lower data rates and more use of the largest 70-m tracking antennas.

The geometry of approach is such that in the imaging attitude the IR spectrometer would be warm and its performance would be seriously degraded.
When weighed against the possibility of studying another comet in the 1-4.8 micron spectral region, the option to target the spacecraft to Comet Boethin was chosen and the Earth-return targeting maneuver was executed on July 20th.
So the Deep Impact spacecraft cannot return to Tempel 1.

Taken from
http://deepimpact.jpl.nasa.gov/results/futureplans.html

National Science Education Standards Addressed
Grades 5-8

Physical Science
- A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample.

History and Nature of Science
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, theoretical models, and explanation proposed by other scientists.

Science and Technology
- Science and technology are reciprocal. Science helps drive technology. Technology is essential to science. Technology provides tools for investigation, inquiry, and analysis

Grades 9-12

Science as Inquiry
- Scientific explanations must adhere to criteria.
- Scientists rely on technology to enhance the gathering and manipulation of data.
- Mathematics is essential in scientific inquiry.
- Results of scientific inquiry—new knowledge and methods—emerge from different types of investigation and public communication among scientists.

Physical Science
- Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance.

Earth and Space Science
- The sun, the earth, and the rest of the Solar System formed from a nebular cloud of dust and gas 4.6 billion years ago.

Science and Technology
- Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanation. Many scientific investigations require the contributions of individuals from different disciplines, including engineering.
- Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.

View a full text of the National Science Education Standards
http://newton.nap.edu/html/nses/6a.html

Student Objectives

- Describe the techniques involved in collecting data during the Deep Impact Mission.
- Explain how the Deep Impact Mission produced different results from those expected.
- Explain the significance of the Deep Impact Mission findings, specifically the confirmation of surface ice, the surface temperature range and the plume constituents.

Materials

Student Texts for What We Learned About Tempel 1

Make copies of each of these student texts and Ejecta and Plume Activity Report Sheet in the most appropriate form—screen reader, low-vision or Braille versions. Click on the title you wish to access.

What We Learned Glossary*
Facts about the Deep Impact Spacecraft
What did the Deep Impact Mission tell us about Comet Tempel?
What is Spectroscopy?
Ejecta and Plume Activity and Report Sheet

The screen reader version of this report sheet has tables for students to complete on-screen. Test them for compatibility with your software.

- The Introduction to Comets Glossary is a separate file so that students can read the definitions of terms that are probably new to them before reading the other student texts and refer to it while reading the texts.

Modeling materials list for What We Learned About Tempel 1

Make copies of Tactile Cards 10-12 and EP0–EP8 templates in either low vision or Braille version for each of your students. Click here to access templates.

Metric rulers with Braille markings or in various contrasting colors with enlarged fonts

Optional (but very useful for modeling ejecta from impact crater)
Star-shaped objects, such as a starfish skeleton
Hoberman Lighting Sphere™ available at http://hoberman.com/fold/Sphere/sphere.htm

To access the instructions for making a Styrofoam and Plaster of Paris model of Comet Tempel 1, click model.

Materials needed for optional activity, Ice Cream Comets, are found in the files describing these activities. Click on the title to access the complete activities.

Procedure for Implementing What We Learned About Tempel 1 Materials

Before the Impact Introduction

1. Introduce the mission results by saying something like:

   "Except for the models of the surface features of Comet Tempel 1 that we examined in the Introduction to Comets section, the materials that we have been exploring up to now contained information that scientists were aware of before the Deep Impact mission".

   "One of the main objectives of the Deep Impact mission was to discover differences between the composition of Tempel 1's surface and its interior."

   "To do this, a battery-powered ***impactor*** *having a mass of about 370 kilograms was programmed* ***so that it intersected the orbital path of Comet Tempel 1****. It produced a crater on impact with the comet's surface. This handout contains some other interesting facts about the Deep Impact flyby spacecraft and the impactor."*

2. Distribute copies of the Facts about the Deep Impact Spacecraft student text to each student in the appropriate format. Allow time for students to read these facts.

   Ask students: *"What facts about the Deep Impact Spacecraft did you find the most interesting?"*

   "*Were any of these facts unexpected?"*

   If students do not comment on any of the following, make sure that they understand the importance of these facts:
   "Did the impactor run into the comet or did the comet run into the impactor?"
   [The impactor intersected the path of the approaching comet…but both objects were moving when they collided.]

   "How fast was the impactor moving relative to the moving comet when it struck the impactor?"
   [The speed of the impactor relative to the comet at the time of impact was 36,800 km/hr, ten times faster than a speeding bullet. This is about 10 km/sec.]

   "Did the impactor affect the orbit of Tempel 1? Did it change the direction in which the comet was traveling?"
   [The impact had no measurable effect on the direction in which the comet was moving because the mass of the impactor was very small compared to that of the comet. The impact was analogous to a pebble hitting a moving truck.]

3. Continue by saying:
   "Starting now, we will be studying what we learned from the results of the mission. Remember that these results were gathered in only 800 seconds of time. How many minutes would that be?"
   [13.3 minutes]

Distribute copies of the student text, What did the Deep Impact Mission tell us about Comet Tempel 1? in the appropriate format for each of your students. Allow time for students to read this text.

They may also need to have available Tactile Card 4 or another model of the comet used in the Introduction to Comets section of these *Feel the Impact* materials to refresh their memories regarding the surface features of Tempel 1.

During the feedback session for What did the Deep Impact Mission tell us about Comet Tempel 1? you may want to ask the questions that are part of the student text to make sure that students remember the surface features of Tempel 1 that were shown in Tactile Card 4.

Ask:

"*Do you remember*

the:shape of the comet?
two large flat areas and the rough areas?
circular rims that may be remains of impact craters?
large depression?

In addition, ask questions similar to the following:

"What instruments were used to determine the surface features that we explored in Tactile Card 4 (or another model that you were provided)?"

[an optical camera]

"What wavelengths of electromagnetic radiation do optical cameras record?"

[400-700 nm which correspond to visible light]

"Do you remember why scientists couldn't see the shape of the comet's nucleus and surface features before the Deep Impact mission?"

[the nucleus is surrounded by the coma]

"Do you think the other side of Tempel 1 is similar or different from the side we have seen? Why do you think so?"

[accept student answers if plausible]

> You may want to refresh student's image of the regions of the electro-magnetic spectrum
>
> Click here for a student text and a template that can be used as a template for a swell form graphic or a Talking Tactile Tablet™ overlay.

"Do you think that Tempel 1 looks the same today as it did one thousand years or one million years ago? Why or why not?"

[They may recall some evidences of Tempel 1's evolution in the student text from the Introduction to Comets section.]

4. Introduce spectroscopy by asking students the following questions and allow sufficient time for students to think about the answers:

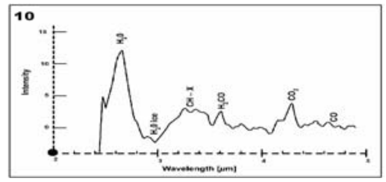
"*What tool do you use to measure the length of an object*"

[meter stick]

"*What tool do you use to measure the temperature of a sample of matter?"*

[thermometer]

"*Are all tools useful to measure the same properties of matter?"*
[no]
"*Do you think optical cameras can be used to determine the chemical composition of Comet Tempel 1's surface?"*
[no]
"*Why not?"*
[Only surface features that are visible to the human eye can be imaged with optical cameras. The chemical composition of the comet's nucleus cannot be determined by visible region imaging.]



5. Distribute copies of the atudent text that answers the question, What is Spectroscopy? and Tactile Card 10 in the appropriate format for each of your students. Allow time for student to read the text and follow the instructions for observing the tactile card. Then ask:

"*What instrument on the Deep Impact spacecraft was used to determine the composition of Comet Tempel 1's surface?"*
[IR spectrometer]

"Why was an IR spectrometer used?"
[Because the presence of water, carbon monoxide and carbon dioxide can be detected in the infrared region.]

"*Are infrared wavelengths shorter or longer than wavelengths of visible light?*
[longer]

Then ask:
"Does the sample spectrum that you observed contain more water or more water ice?"
[water–it has a higher intensity peak]

The intensity units in this graph are 10^{-7}W cm^{-2} sr^{-1} µm^{-1}. If your students have sufficient mathematical background, you will want to discuss these units with them.

You may also want them determine the axes readings at these peaks:

	Intensity	Wavelength
$H_2O(l)$	12	2.7 µm
$H_2O(s)$	- 2	2.9 µm
CH-X	3	3.2 µm
H_2CO	2.7	3.6 µm
CO_2	4	4.3 µm

Note to teachers: Tactile Card 10 shows an **emission** spectrum of liquid water, water ice, CO and CO_2. The Deep Impact IR spectra in the Mission Results website show **absorption** spectra of water and water ice. If your low-vision students are examining the spectra shown in the Mission Results website, you may wish to discuss the difference with your students.

For students who have studied chemical bonding, this would be an appropriate time to review the different vibrational modes of liquid, solid, and gaseous water molecules and how this is reflected in infrared spectroscopy. See http://www.lsbu.ac.uk/water/vibrat.html for an excellent resource.

6. Distribute copies of Tactile Card 11, Surface Ice, to each student in the appropriate format.

Tactile Card 11. Surface Ice

Introduce this tactile card by saying something like,

"So what did infrared spectral data from Comet Tempel 1 reveal? There are three small areas of water ice on the surface of Tempel 1".

"Find the open circle starting dot to the right of the card number. If you follow the solid line to the right of starting dot you will observe that this tactile card shows the same outline of the comet's shape that you used in Tactile Card 4 in the Introduction to Comets section."

"Find the starting dot again. Move to the right and down. Can you find three solid raised regions? There are three areas of water ice on the surface of Comet Tempel 1 indicated by infrared spectroscopy."

Make sure that all students have located all three regions.

> If you wish to give students these measurements in metric, 1 sq ft = 0.0929 sq m, so ice covers 46,450 sq m out of 92,900,000 sq m.

Continue by saying,

"The area covered by this ice is only 500,000 square feet out of more than one billion square feet, the part of the comet's surface that we could image. That means that only 0.5% of this part of the comet's surface is covered in ice. And only six percent of that area consists of pure water ice. The rest is dust. One scientist said that one of the regions is like a skating rink of snowy dirt."

> See Optional Extensions on page 13 of this Teacher Guide.

"Scientists have known that water ice exists in comets because the infrared spectra of comet comas have indicated the presence of water that was outgassed from the comet's nucleus. So, why do you think this discovery is important?"

[Give students time to respond and accept their answers if plausible.]

If student responses haven't included that this is important because it the **first actual evidence of ice on the surface of the comet's nucleus**, be sure to emphasize it.

Continue the exploration by saying

"Now compare Tactile Card 11 with Tactile Card 4. Are there any features that occupy the same area in these two cards?"

[Have students continue observing until they "see" that the middle, lower ice region is in the large depression that was part of the Tactile Card 4.]

Continue by saying:

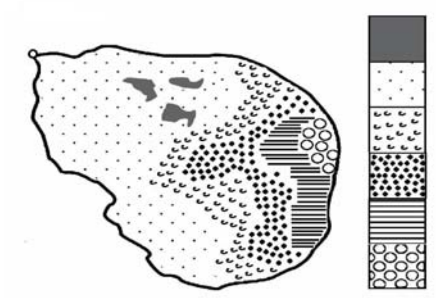
"In fact all three of these regions are in areas of depression. The other two depressions, however, are not so deep as the one we observed in Tactile Card 4.

"Can you think of a reason why these ice regions might be found in depressions?

[Students may think that the dirt in these regions was removed, exposing some under-the-surface ice. Another idea might be that the water vapor condenses from the coma and freezes on the surface in these depressed regions as the comet moves away from the sun. During pilot testing, one student suggested that the ice was forced to the surface by interior pressure.]

7. Introduce Tactile Card 12 showing the different temperature ranges on the surface of Comet Tempel 1 by continuing:
   "The presence of surface ice wasn't the only thing spectrometry told us about the surface of Comet Tempel 1. The IR spectrometer in the Deep Impact flyby spacecraft was also used as a thermometer to map the surface temperatures on the sunlit side of Tempel 1. Tactile Card 12 show the results of this temperature mapping."

Distribute copies of Tactile Card 12 to each student in the appropriate format.



Begin the student's observation of this tactile card by saying:
"We are using the same shape of Comet Temple 1 that we used in Tactile Cards 4 and 11 to observe the temperature regions of the comet's surface. Let's follow the outline of Comet Tempel 1 to refresh our memories. The starting dot on Tactile Card 12 is again just to the right of the card number."

"Now explore the different areas inside the outline. You will note that there are different textures, each of which represents a region with a specific average temperature."

During pilot testing we had to review the relationship between the Celsius and Kelvin temperature scales.

Continue by saying:
*"The attached temperature scale indicates **average** temperatures over fairly large areas."*

"Starting at the top of the scale, feel the texture in the box and then move to the right. What temperature range does that texture represent?"
[Less than 280 Kelvin]

During pilot testing students asked why the temperature range scales are not consistent intervals. We reminded them that this is real data. Since this is not a graph, we do not need to keep scale consistent.

"Now, feel the dotted texture in the second box from the top. What temperature does it represent?"
[290 K]

"What average temperature does the pattern in the next box down represent?"
[300 K]

"*What temperature do the diamond shapes in the next box represent?"*
[310 K]

“And what average temperature the horizontal stripes represent?”
[315 K]

“And the small ovals represent what temperature?”
[330 K]

“As we moved down the scale, was the temperature increasing or decreasing?”
[increasing]

“Now let’s to back to the starting point open circle on the tactile card. Move out in any direction from the starting circle you will feel a region of widely space dots. This is a large area, so continue move your finger down and to the right until you find different textures that border this region or find the solid line outline. According to the temperature scale, what is the ***average*** *temperature of this region when the infrared map was made?”*
[about 290 Kelvin]

“Go back again to the starting point circle. Move to the right along the solid line outline until the outline is rather horizontal. Move down from the outline until you feel three small smooth regions. What does our temperature scale tell us about the average temperature in these regions?”
[less than 280 Kelvin]

“Are these regions colder or warmer that the large region around them?”
[colder]

“From these colder regions, again move to the right through the dotted region. You should feel an area filled with larger textured figures. Follow this textured area from the top outline of the comet to the bottom outline of the comet. This is a rather long, thin region that extends from the top to the bottom of the Tempel 1’s surface.”

Monitor student observation to make sure everyone is observing the correct area.

Ask:
“What is the temperature in this region?”
[300 K]

“Moving again to the right, you will find a region that is filled with diamond-shaped texture. This region also extends from the top to the bottom of the comet’s surface. Do you feel that a bulge to the left about halfway down the comet’s surface? What is the average temperature of this large region?”
[310 Kelvin]

“Has the temperature generally increased or decreased as we moved from left to right across the comet’s surface?”
[generally increased except for those three smooth regions]

“Now move toward the upper right. You should feel a space that is filled with horizontal lines that surrounds a space filled with large open oval shapes. The

region with horizontal lines continues down to the right side of the comet nucleus."

"If you compare these textures with the temperature scale you will find that the temperature in the region with horizontal lines is about 315 Kelvin. The temperature in the area with open oval reaches 330 Kelvin"

"These differences in temperature tell us that there are some warmer and some cooler regions on the surface of the comet".

Ask:

"Is there anything we already know about the surface features of Comet Tempel 1 that might cause the temperature to vary across the surface of the comet?"

[Allow time for students to mention their experience with temperature differences with location here on Earth and relate that to the surface features they have already experienced on Comet Tempel 1.]

Continue by saying:

"As we continue remember that these temperature readings were made on the 'sunny side' of the comet. On a summer day here on Earth, we try to stay in the shade where it is cooler. In the winter, we want to be in the sunlight where it is warmer."

There are also daily and seasonal changes seen on the comet. This would be an opportunity to teach about orientation and the seasons. The comet's axis is tilted, so there are seasons on Tempel 1 just like there are on Earth.

Ask:

"Do you think the sun is shining directly down on this side of the comet? Why or why not?"

[Accept student answers if plausible. If not, ask how they reached that conclusion. It is hoped that they will realize that if the sun were shining directly down that the warmest regions would be in the center of the surface and it would get cooler as you moved out from the center.]

"From what direction do you think the sun was shining on Tempel 1 when this temperature map was recorded?

[It would appear that the sun is shining on the comet from the right (and maybe from slightly above), directly on the upper right bulge.]

"Why do you think so?"

[That's where it is warmest]

"That's correct. The surface of the comet directly below the sun was the hottest and the shadowed regions were the coolest."

8. Continue student analysis of the infrared spectroscopy data by having them compare the features shown in Tactile Cards 4, 11, and 12, saying:

   "*Earlier you observed three regions on Tactile Cards 4 and 11. You found that surface ice was found in a large depression and two other more shallow depressions. Now compare these regions with the same areas on Tactile Card 12. Is there any relationship between the surface features and the temperature of this area?"*

[Allow sufficient time for students to observe the connection.]

Respond to their answers by saying:

"That's right! These were also the regions that registered the lowest temperatures on this side of the comet. So if the sun was shining on the comet from the right, these depressed areas were probably in the shade."

"Remember that Tempel 1 rotates on its axis so, a certain times of the day during its summer season, the sun <u>may</u> shine directly on these depressed regions of the comet's surface. What do you think may happen to the surface ice during these times?

[It might sublime at a faster rate; size of regions would decrease]

"What about during the winter season? Do you think more surface ice would appear?"

[That would depend upon the source of the surface ice, wouldn't it?]

See Optional Extensions on page 13 of this Teacher Guide.

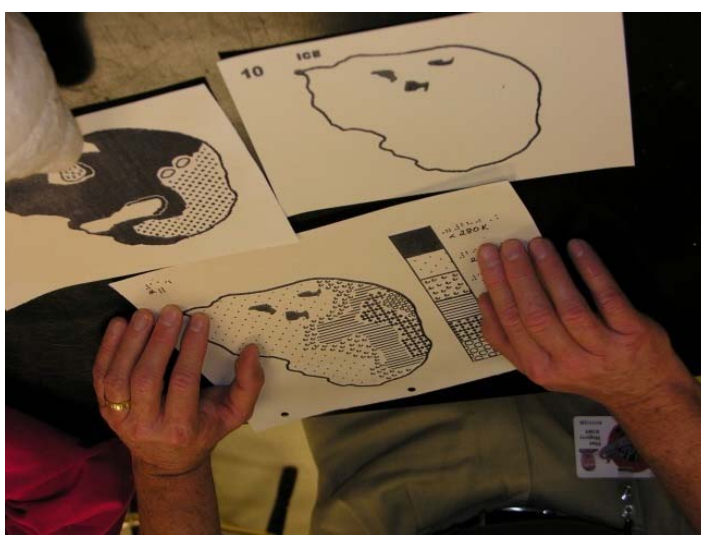
Have students summarize the findings of the Deep Impact mission by asking:

"What do we know <u>now</u> about the surface of Comet Tempel 1 that we didn't know before the Deep Impact Mission?"

[Listen for responses that indicate that students understand that we knew nothing about the surface features or about the presence of surface ice. We also had never had accurate measurements of the comet's surface temperatures.]

"And how did we learn about these features of Comet Tempel 1?"

[Instrumentation like optical cameras and IR Spectrometers aboard the DI flyby spacecraft and the impactor]



Observing Comet Tempel 1
surface data
from Deep Impact Mission

Optional Extensions for ***What We Learned About Tempel1 Before the Impact***

Making Ice Cream Comets is one method of stressing that knowing something about the surface of an object does not mean you what is inside the object. It also emphasizes how cold a comet can be and how we can use our senses as spectroscopes. There is a hotlink to the activity in the **Materials** section of this teacher guide.

Making a connection between Earth and Comet Tempel 1

"You have studied the earth's water cycle. How important is the water cycle to us and other living things on the earth? How has the water cycle changed the earth's surface features?"

[Give students and opportunity to respond to these questions. Prompt students to recall the crater images from the Introduction to Cratering section. Compare the crater image from the Earth with other Solar System bodies.]

Ask:

"So, if Comet Tempel 1 has surface ice, do you think that it has a water cycle?

[Accept student answers and ask for reasons for their answers.]

Compare the temperature ranges over a distance of 7 kilometers on Comet Tempel 1 with those we are familiar with on the surface of the Earth. The temperature the coldest region of Comet Tempel 1's surface was <280 Kelvin, while the warmest region was 330 Kelvin. Have students to convert this temperature difference to degrees Fahrenheit.

[the difference between 330 K and 280 K = 50K or δt = 50º C = 122º F]

Do the temperatures on Earth's surface vary that much during daylight or between daylight and dark?

[not usually]

Have students investigate factors that might account for the difference in temperature ranges between Earth and Comet Tempel 1.

Investigate how the very small atmospheric pressure on Comet Tempel 1 would affect the boiling and freezing point of water? Might this explain the fact that solid water ice sublimes at 200 K, below the freezing point of water here on Earth?

Use these data to help students understand the relationship between atmospheric pressure and boiling points. The average air pressure at the surface of Mars is 6 millibars (compared to 1013 millibars on Earth). At those pressures water can exist as a liquid in a range of 32° to 50° F. How do you think the atmospheric pressure of Comet Tempel 1, which gets swept constantly by the solar wind, compares with that of Mars? See this URL for some very pertinent information: http://xenotechresearch.com/mwater.htm

After the Impact Introduction

1. Introduce the “Ejecta and Plume” student activity by saying something like:
   “Twenty-four hours before impact, the larger ‘flyby’ Deep Impact spacecraft released the smaller ‘impactor’ spacecraft into the comet’s path for a ***planned collision*** *to the comet’s body on the sunlit side”.*

Have the students to put their fists together to simulate the two parts of the space craft. Then tell them to begin to move one fist off and imagine that it was heading towards the comet. The other fist represented the flyby spacecraft that continued on path parallel to the comet and started taking pictures.

Students may need Tactile Cards 4 and 12 during this next section.

Ask:

“How do you think the impactor knew where to go so that it would collide with the comet it at the right location?

[Wait for student responses. During pilot testing one student said infrared radiation, indicating that he understood that technology was involved.]

“Then tell students that the impactor was given instructions to look for the brightest region on the comet and, if necessary, to change its course so that the crater would be formed just to the left of that brightest region.”

“Remember that the surface of the comet directly below the sun is the hottest. It would also be the brightest. So, based on your observation of Tactile Card 12, where do you think the crater was formed?”

[Wait for student responses that indicate their understanding that the hottest regions were toward the right side of the tactile graphic of the comet’s surface.]

“That’s right! The impactor dug a crater in the rough region located to the right and below the lower smooth area—the shoe-sole shaped plateau–on the comet’s surface. If you don’t remember where that is, observe Tactile Card 4 again.”

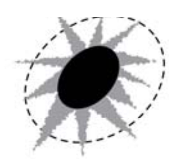
[Make sure that all students have located the region of impact.]

Continue by saying:

“You will learn more about what happened at impact as you complete the ‘Ejecta and Plume’ student activity.

2. Distribute copies of Tactile Card EP0 in the appropriate form for your students.

Tactile Card EP0.
Ejecta Pattern



Continue by saying:

“This tactile card is a detailed image showing the shape of the ejecta after the impactor spacecraft entered Tempel 1’s nucleus.

“The solid oval at the center of the graphic represents the impact site.The shaded areas that extend out from the crater show the patterns that the ejecta formed in the atmosphere above the impact site.”

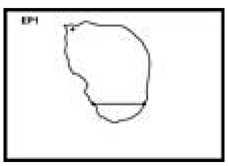
“Note that the ejecta particles were not expelled evenly (or homogeneously) in all directions and that the ejecta did not travel as far in some directions as in others. This is similar to what you experienced as you did your cratering research in the last section.”

Have a starfish skeleton or a similar object that models ejecta available so that students can it observe tactilely.

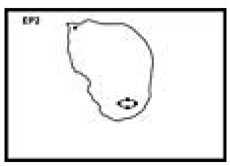
“Continuing out from the crater, there is a dashed ellipse that includes the outer limits of the most ejecta extensions and encloses the area in which the ejecta is being expelled. You will be measuring the axes of ellipses similar to this in the ‘Ejecta and Plumes’ activity.”

3. Distribute Impact Tactile Cards EP1 – EP8 in the appropriate form for your students.

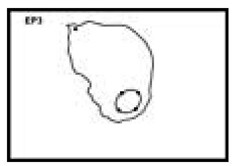
These eight tactile cards are numbered in the upper left corner. Note that they are labeled as EP1 through EP8. The letters “EP”, which stand for ejecta and plume, distinguish them as the tactile images that accompany the student activity.



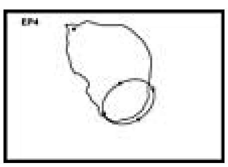
0 sec



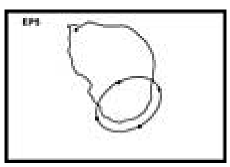
0.84 sec



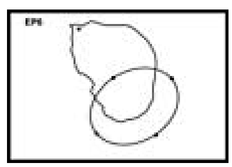
1.68 sec



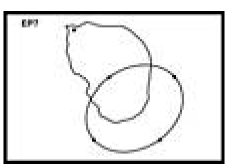
2.52 sec



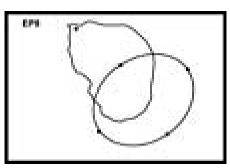
3.36 sec



4.20 sec



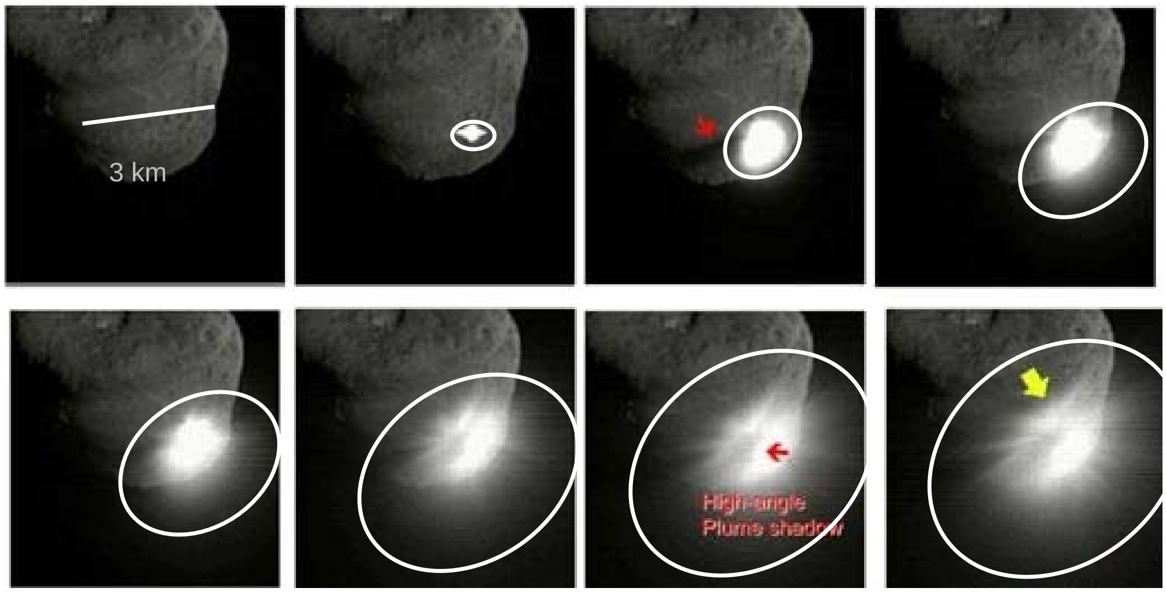
5.04 sec



5.88 sec

These images are based on those found at:
http://deepimpact.umd.edu/gallery//jpg/T1_Ejecta_Devel.jpg

0 | 0.84 sec | 1.68 sec | 2.52 sec



3.36 sec | 4.2 sec | 5.04 sec | 5.88 sec

Tell students to spread the eight images out in order EP1 to EP8 in two rows of four so that they can follow the description of what happened as the comet approached and collided with the Deep Impact impactor.

Depending upon the age and mathematics ability of your students, you can have students either make measurements individually or work in pairs to make measurements.

Introduce the images by saying:

"These images show how the vapor plume and the ejecta curtain on Comet Tempel 1 expanded over time. Ellipses similar to that drawn in EP0 have been drawn in each of them, indicating the outer limits of the ejecta curtain. As you make your measurements, remember the variations in the amount of ejecta that you have observed in graphic EP0."

As they convert their measurements in centimeters to scale in meters, calculate areas of the ellipses and area change over time, you could have them work as a class or assign one measurement to an individual or a pair.

"These images were taken every 0.84 second, so you will observe what happened over a period of 5.88 seconds…that is, less than 6 seconds".

You may wish to review the description of the **Impact and Compression Phase** of Cratering found in the Introduction to Cratering Teacher Guide as students observe these tactile images.

"Let's count six seconds of time…one thousand one, one thousand two, one thousand three, one thousand four, one thousand five, one thousand six, That gives you some idea of the very short period of time in which these images were made.

"Now examine Card No. EP1, which shows the distance across comet Tempel 1 in the region where the impact occurred. The distance across the comet nuclei where the line crosses it measures <u>three kilometers from one side to the other</u>. You will be using this measurement as you complete this activity."

Remind students that what they are observing in the remaining cards are simplified versions of the images showing the development of the plume and ejecta curtain after the impactor spacecraft entered Tempel 1's nucleus.

The visual images from which the tactile cards are adapted show the results of kinetic energy being transferred to "flashes of light". There was no mention of light being given off in previous sections of these *Feel the Impact* materials because this occurs in the first few seconds after impact. Whether or not you include the light energy in your description of the impact will depend upon your student{s} and the type of their visual impairment(s). The descriptions of the EP2—EP8 tactile cards that follow are written in two forms—for use either with students who have experienced sight or for those who have not.

The descriptions in this column are for use with students who have never had vision (therefore, not experienced light).	**The descriptions in this column are for use with low-vision students or have had sight before going blind.**
The solid oval line in Card No. EP2 shows the size of the vapor plume at .84 seconds after impact. This plume was probably the result of the impactor and part of Tempel 1 vaporizing.	Card No. EP2 shows the size *of a brilliant flash that lasted less than two tenths of a second*. This was probably the result of the impactor and part of Tempel 1 vaporizing. *This was followed by a second flash, which was brighter than the first*, and probably originated deeper within the comet.
The solid oval line Card No. EP 3 shows the size of the vaporization plume about 1.7 seconds after impact.	The oval in Card No. EP 3 shows the size of the plume *associated with flashes* about 1.7 seconds after impact.
Card No. EP4 is the image taken almost three seconds after impact. The solid oval line outlines the outer edges of the ejecta curtain of hot gas and dust as well as the vaporization plume. The material in the curtain moved outward more slowly than material in the vaporization plume.	The image in Card No. EP4 was taken almost three seconds after impact. The solid oval line outlines the outer edges of the ejecta curtain of hot gas and dust *and the plume associated with the flashes*. The material in the curtain moved outward more slowly than material in the *flashes plume.*
Card No. EP 5 is the image taken at about 3 1/3 seconds, the time at which the flash reached it maximum brightness. The solid oval line shows that the material curtain expanded out of the forming crater forming a cone that was not symmetrical.	Card No. EP 5 is the image taken at about 3 1/3 seconds, the time at which the flash reached it maximum brightness. The solid oval line shows that the material curtain expanded out of the forming crater forming a cone that was not symmetrical.
	Cards No. EP6, EP7, and EP8 show the expansion of the vaporized gas in the plume as well as the material in the curtain, containing gas and dust.

Demonstrating the uneven expansion of ejecta to a student who has never had vision

If you have students who have never had vision and you wish to use the above descriptions that include "flashes", you may want to use an analogy similar to the following to explain what a "flash of light" means:

When you hear a loud noise like a crack of thunder during a storm, the nerve endings in your ears are affected by sudden, very intense sound waves. In a "flash of light", large, sudden, high-intensity light waves affect the nerve endings in our eyes. The optical camera on the Deep Impact flyby recorded these flashes of light that indicated that the comet collided with the impactor.
In both cases, there is a release of energy, either in sound waves or light waves

An effective analogy for the uneven expansion of ejecta is the loss and gain of water pressure as you are taking a shower. High pressure demonstrates an increase in ejecta; low pressure illustrates a decrease in ejecta.

4. Give students the following instructions as you distribute the Ejecta and Plume Activity Report Sheet and metric ruler sticks for visually-impaired or tell them where to obtain them. Tell students whether they will work individually or in pairs.

[If your students have not previously used these measuring sticks, you may need to give them instructions for using them.]

Say:

"*You will now use the images on tactile cards EP1 to EP8 to make measurements that will allow you to calculate the rate of expansion of area that the Tempel 1 ejecta plume occupied over a period of less than two seconds."*

Have students go to **Part 1** of the Ejecta and Plume Activity Report Sheet

Say:

"*The images you just observed are scale images. That is, they are not the actual size."*

"In this activity, you will be using scale images. There is a line on Card EP1 that has open circles at each end. Use your ruler to measure the length of the line in Card EP 1, making sure that you measure the same place on the open circle each time you measure."

Measuring ejecta expansion using a Braille metric ruler

"Record your measurement right above the

data table."

"The length of that line is equal to 3 km in the actual size of the comet."

"Since the outline of the outer limits of the ejecta plume appears to be elliptical, you will need to measure the length of the long axis, which we will call axis a, and the short axis, axis b, of each open circle on each ellipse mark the ends of the long axis, a, and the short axis, b. Make sure that you measure the same place on the open circle each time you measure."

During pilot testing we had each student make one set of measurements and record them in the class data table. So long as the students measure the same place in the open circle, the measurements will be consistent and the overall pattern will be consistent. This option allows everyone to contribute, maintained interest, and saves some class time.

In **Part 2**, students will convert their actual measurements to scale measurements in kilometers. This involves the use of a ratio, 3 km/(the length of the line) in Card EP1 measured in cm.

[Tell students whether they will work individually, in pairs or as a class.]

Measuring ejecta expansion using a large font metric ruler

In **Part 3**, students will calculate the area of the ellipse in each card, using the formula, area = πab.

[Tell students whether they will calculate all the areas individually or in pairs, or whether they will be responsible for calculating the area of only a particular card (or cards).]

In **Part 4**, students will calculate the rate of expansion of the ejecta plume, using the formula
Rate = δ area/ δ time, where δ time = 0.84 sec.

[Tell students whether they will calculate all the rates individually or in pairs, or whether they will be responsible for calculating the rate between a particular card (or cards).]

These completed data tables show samples of the results of completing the Ejecta and Plume activity. See the model spreadsheet using data from pilot testing measurements. Input your students data into the spreadsheet to obtain the calculations and graph from their measurements.

Have a low vision student input the measurements into the model spreadsheet that automatically carries out the calculations and graphs the results.

Click here to learn how to insert a table similar to those in the activity sheet into a Microsoft Word file. The navigator of screenreader software, such as Jaws, will direct the user as to what data to input in a specific cell.

Part One

Measure the lengths of the long and the short axes of ellipses.

Length of line in card EP1 = ____5.0______ cm.

Card No.	Length of long axis a (centimeters)	Length of short axis b (centimeters)
EP 2	2.0	1.0
EP 3	3.0	2.5
EP 4	6.5	4.5
EP 5	7.0	5.5
EP 6	10.0	7.5
EP 7	11.0	8.5
EP 8	13.0	9.0

Part Two

Use the length of the line you measured in Card EP 1 to convert each of your actual measurements in centimeters to scale measurement in kilometers. Record your results in the table below.

Card No.	Length of long axis a (km)	Length of short axis b (km)
EP 2	1.2	0.8
EP 3	1.8	1.5
EP 4	3.9	2.7
EP 5	4.2	3.3
EP 6	6.0	4.5
EP 7	6.6	5.1
EP 8	7.8	5.4

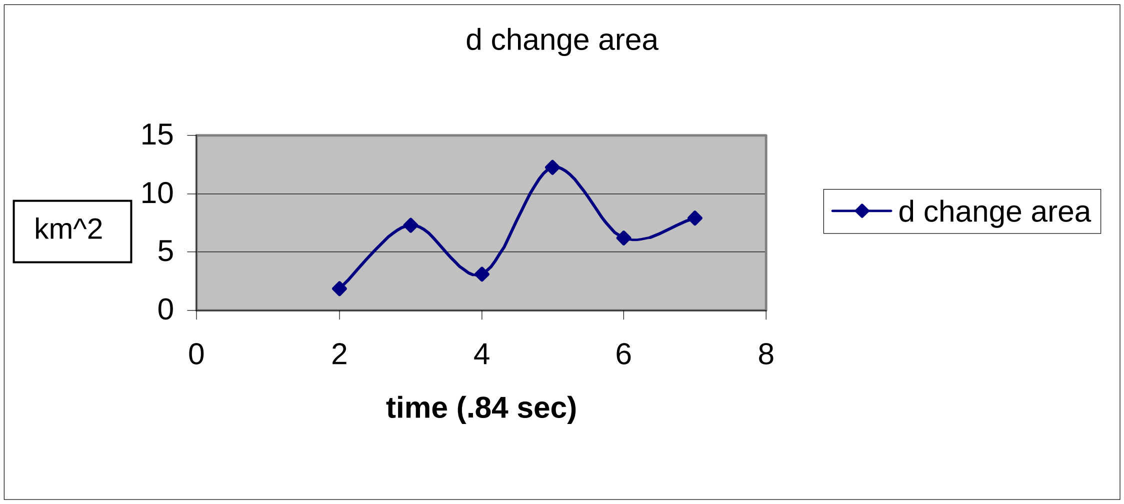
Part Three

Using the lengths of the two axes, a and b, as recorded in kilometers in the Part 2 data table, calculate the area of each of the ellipses.

Card No.	Area = $\pi * a/2 \times b/2$
EP 2	0.59
EP 3	2.1
EP 4	8.3
EP 5	10.9
EP 6	21.2
EP 7	26.4
EP 8	33.1

Part Four
Calculate the rate of expansion of the ejecta plume, using the areas calculated in Part Three. Remember that the images were taken point eight four seconds apart. Record your answers in the data table below.

Card No.	Difference in area (km^2)	Difference in time	Rate of change area change/ time change ($\delta km^2/sec$)
EP2-EP3	**1.5**	**0.84 sec**	**1.9**
EP3- EP4	**6.1**	**0.84 sec**	**7.3**
EP4- EP5	**2.6**	**0.84 sec**	**3.1**
EP5- EP6	**10.3**	**0.84 sec**	**12.3**
EP6- EP7	**5.2**	**0.84 sec**	**6.2**
EP7- EP8	**6.6**	**0.84 sec**	**7.9**



Either print the graph and use the copy as a template for a tactile card or, if you hold the student's finger, you can guide it along the graph without damaging the computer screen.

5. In follow-up session, ask students questions similar to the following:

"*Was the rate of change consistent between the images? What could have accounted for the difference?"*

[It does not appear be consistent. Change in the rate at which the ejecta was emerging may be due to different sublayers of the comet have different components and densities, the ellipse did not accurately reflect the outer limits of ejecta or differences in measurement techniques. Students may have other responses.]

"*Can you think of anything here on earth that might change at the same rate as the ejecta did?'*

[That is a very rapid rate of change. Perhaps an erupting volcano or the blast area of an explosion would come closest. Students may suggest rockets blasting off or jet air planes taking off but that would be linear.]

"*If the ejecta plume had been circular, it would have been symmetrical. That is, the feathery plumes of material would have been ejected evenly in all angles. But the ejecta plume **appeared to be** elliptical. Can you think of any reason why this might be so?*

[due to the angle of impact or the angle at which the camera was imaging]

"*Why might the impact have taken place at an angle when the comet was coming directly toward the impactor?"*

[the impact was in a rough area, so whether the impact occurred straight on or at an angle depended on the terrain in the immediate area]

"*How much of the ejecta do you think fell back to the surface of the comet? A lot, some, a little, or none? Why do you think so?"*

[Accept student answers. Then read or paraphrase some of the following information from the Deep Impact Mission Results website.]

> If you have low vision students you might have the look at images from
>
> http://www.nasa.gov/mission_pages/deepimpact/multimedia/PIA02128.html
>
> http://deepimpact.umd.edu/gallery/almostthere.html
>
> http://deepimpact.umd.edu/gallery?ITS_PressRelease4-PIA02129.html

There was **material in the [ejecta] curtain was made of smaller, finer particles than expected** indicating that the **strength of the material lying within tens of meters of the comet's surface is very weak and powdery.** Therefore the ejecting gas and dust are able to tear an unexpectedly great amount of material from the crater as it forms. It al so "hung around" rather than falling quickly back to the surface as expected.

Tempel1's gravity is not very strong and so it is not able to hold the ejecta back **so most of it is able to escape into space**. However, **some of the dust does fall back** onto the surface of the comet.

Nevertheless the comet's gravity is strong enough to prevent the last ejecta expelled from the crater from getting vary far from the surface. Thus the **bottom of the plume remains essentially in contact with the rim of the crater**. It does not detach from the surface, a phenomenon that was looked for with great interest by astronomers. **Astronomers say that the ejecta is gravity-controlled rather than strength-controlled.**

The comets gravity, although small, overpowered the shear strength of the ice-entrained dust that comprises its interior. Estimates place the depth of the powdery surface layer at tens of meters.

The **shadow of the ejecta cone** on the surface of Tempel1 was greater than 300 meters across at its base than expected.

These excerpts were taken from
http://deepimpact.umd.edu/results/excavating.html

Ask students to predict what the eject pattern might look like on Tempel 1 now. They may want to compare their prediction with images of Solar System impacts from the Introduction to Cratering section of these Feel the Impact materials.

Ask:

"*One of the Deep Impact mission's objectives was to observe how the crater forms. Do you think this mission was accomplished? Why or why not?* "

[Accept student answers. Indicate that the fact that they were able to make measurements of the ejecta formed from actual images taken while the crater was forming was evidence that at least part of the objective was accomplished.]

Continue by saying:

"Another of the Deep Impact mission's objectives was to measure the composition of the interior of the crater and its ejecta. ***What substances were found in the ejecta?"***

[Students will probably remember that there was water ice and carbon dioxide ice in the surface IR spectrum.]

Continue by saying:

"A spectrum taken six tenths of a second after Tempel 1 impact showed the presence of liquid water, hydrogen cyanide, carbon dioxide and organics. ***The gas consisted most of steam and carbon dioxide, at an initial temperature of over 1000 degrees Kelvin. Remember that room temperature is 295 K****".*

"Scientists are still studying the spectrum taken later after impact, but there are some indications that there were large amounts of silicates in the later ejecta. Silicates are important and common rock-forming minerals formed mainly from silicon and oxygen and combined with various other elements.

Continue by saying:

"*Deep Impact scientists wanted to discover the differences between the near surface composition of comet Tempel 1 and the composition of interior. Do you think this mission was accomplished? Why or why not?"*

[Accept student answers.]

Continue by saying:

"*Spitzer Space Telescope's imaging spectrometer and infrared camera observed comet Tempel 1 both before and after impact on July 4, 2005. Ejecta spectrum will be studied for a long time,"*

Continue by saying:

"*How large is the crater? Deep Impact scientists wanted to measure the crater's depth and diameter, but the Deep Impact experiment proceeded differently than scientists expected! They expected to see the dust debris clear and reveal the crater and its interior. But they did not see the crater."*

"The ejecting gas and dust were able to tear more fine-particle material from the crater as it formed than was expected. Even at the 13 minutes the ejecta curtain was still too thick to see the crater."

Ask:

"*Now that the Deep Impact mission is over, what suggestions do you have for "seeing the crater" formed on comet Tempel 1?"*

[Accept student answers.]

"One of the most likely solutions that students will come up with is returning to Tempel 1 to measure the crater. Could the Deep Impact spacecraft return to Tempel 1 and look at the impact site?"

"There is no chance to get back to Tempel 1 until the next perihelion in5.5 years from now), but the return would require two more years in flight, which substantially increases both cost and risk to spacecraft performance."

So the Deep Impact spacecraft cannot return to Tempel 1. However, Stardust might return to Tempel 1. Stay tuned!

Ask:

"*How did these discoveries change scientists' thinking about the formation of the Solar System?"*

[The formation of the Solar System may have been more complex than we have described it prior to the Deep Impact mission.]

Say:

"Listen to the following statement from Deep Impact scientists:"

Before the Deep Impact mission, we expected to see materials that form under cold temperatures representing the great distance from the hot sun, where the comets formed."

When we looked at the dust excavated from beneath Tempel 1's surface…the science team was surprised to see **materials that form**

not only at cold temperatures where ices form, **but also silicate grains that form at high temperatures of >1200K.** Such materials had to have formed close to the sun and have been sent to the edges of the solar nebula where it was collected up into the forming comets. Some models of the early Solar System proposed a mixed and turbulent solar nebula, and that model has been proven to be correct.

Conclude by saying:

"Scientists are still analyzing the spectral data that was collected, so we can expect to know more about the surface and the underlying layers of Tempel 1 in the future."

A follow-up extension could involve students in considering the question:
"What did it take to plan the Deep Impact mission"?