The Invisible Yellowstone National Park

We are used to seeing the world around us in visible light. However, there are many other types of light, including x-rays, gamma rays, ultraviolet, infrared, microwaves and radio waves, which we cannot see with our eyes. Each of these types of light gives us a unique view of the world around us. In this lesson we will examine infrared images taken in Yellowstone National Park. All objects emit infrared. The amount of infrared emitted depends on the object's temperature. Hot objects emit more infrared than cold ones do. Infrared images give us special information that we cannot get from visible light pictures. In these lessons a special infrared camera was used to create infrared images which will be used to help students learn about infrared light. Infrared images of geothermal features and everyday objects will provide students with a unique and interesting view of the infrared world. In addition, the Infrared Yellowstone activities will give students a new perspective and new view of the interesting features of Yellowstone National Park.

In 1872 Yellowstone National Park was established as the world's first national park. It is located in northwest Wyoming and extends into Montana and Idaho. Covering 2,219,791 acres, it is about the size of Rhode Island and Delaware combined! Yellowstone National Park is in a huge volcanic basin which was the site of several massive volcanic eruptions, the last of which occurred about 600,000 years ago. Yellowstone National Park is a region of incredible beauty, abundant wildlife and amazing geothermal features. Among the geothermal features found in Yellowstone are numerous geysers, hot springs, bubbling mud pots, fumaroles and hot spring terraces. These features can be explored in a unique way through infrared imaging.

Infrared images show the relative distribution of heat as a false color map and can reveal information not found in visible light images. By comparing and contrasting visible light images and infrared images, learners will discover the importance of using different regions of the electromagnetic spectrum to study objects. Though not expressed in this particular lesson, this infrared exploration can be extended into exploring additional applications of infrared imaging on Earth and in space. Viewing objects using different types of light gives us a more complete understanding of these objects.

In this lesson:
Learners explore the differences between visible light images and infrared light images of geysers, mudpots, hot springs, and hot springs terraces located at Yellowstone National Park. The explorations focus on compare and contrast skills, observation skills, and learning about infrared images. By using the features of Yellowstone National Park as the backdrop they will also gain a basic understanding of some characteristics of geothermal features, though the geology is not the focus of this lesson.

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I. GENERAL INFORMATION

Title: The Invisible Yellowstone National Park

Brief Description: Learners explore the differences between visible light images and infrared light images of geysers, mudpots, hot springs, and hot springs terraces located at Yellowstone National Park. The explorations focus on compare and contrast skills, observation skills, and learning about infrared images. By using the features of Yellowstone National Park as the backdrop they will also gain a basic understanding of some characteristics of geothermal features, though the geology is not the focus of this lesson.

Primary Goal: Use these activities to introduce learners to infrared imaging and the information that such images contain. Observation, compare and contrast, and reasoning skills are emphasized.

Activity Description: Learners are introduced to a visible light image of the Old Faithful geyser and are asked to express questions on what they are seeing. They are guided to ask a question about the temperature of the water, which one cannot answer using the visible light image. Infrared imaging is introduced using the *Exploring Infrared Imaging* lesson. The next activity calls upon their observation skills and new knowledge of infrared images. They compare and contrast visible and infrared light images of Old Faithful. The extension activity focuses on other geothermal features of Yellowstone National Park (mudpots, hot springs, and hot spring terraces) and they are again asked to compare and contrast visible light and infrared light images. The conclusion of this lesson is a discussion where learners express their understanding of gaining a larger "picture" of an object by using two different types of light.

Learning Goals: Provided here are general learning goals for this entire lesson. You may have additional learning goals for your particular classroom and curriculum as these activities can be easily tailored to your own needs.

At the conclusion of this lesson set, your learners will be able to:

- Explain the differences between an infrared image and visible light image of the same object/scene.
- Explain that infrared light traces heat. Using infrared light, one can remotely study the temperature of an object.
- Correctly interpret an infrared image with false color map and temperature scale information.

Target Audience: Grades 5-8

Teacher Preparation Time: 1-2 hours the first time, 15 minutes each subsequent use

Estimated Activity Time:

Day 1:
- Engage Your Learners: 10-15 minutes
- Explore Infrared Imaging: 25-45 minutes

Day 2:
- Infrared Old Faithful: 30-60 minutes

Day 3:
- The Infrared Yellowsone: 45-60 minutes, time varies

Materials Needed:

- Ability to download large files off the internet
- Ability to open, view, and print PDF files
- Ability to print in color (Resolution is at 72 dpi. PDF files are print-ready for any professional printing establishment (e.g., Kinko's or OfficeMax)
- Ability to laminate or otherwise protect printed images

- Ability to project images, either via computer or color overhead transparency
- Large learning space for groups of students to work comfortably and not disturb each other
- Optional: Internet ready classroom with projection unit
- Optional: PowerPoint presentation capabilities and projection unit

Authors and Idea Makers:

The ideas presented in this lesson are the collaborative effort of the teachers in the *Invisible Universe Online* course during the spring 2003 semester. This particular lesson has been organized and written by Adrienne Gauthier (Instructional Technology Specialist, University of Arizona) with the help of Linda Hermans-Killam (Spitzer Science Center/Caltech) and Doris Daou (Spitzer Science Center/Caltech). This lesson has been evaluated by the Origins Education Forum at the Space Telescope Science Institute.

National Science Education Standards (NSES):

Changing Emphases (…More Emphasis On…)

The NSES envision change through out the system. Below are descriptions of how this lesson supports the changing emphases:

- Understanding scientific concepts and developing abilities of inquiry.
- Learning subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science.
- Implementing inquiry as instructional strategies, abilities, and ideas to be learned.

Changing emphases to promote inquiry:

- Investigations over extended periods of time.
- Communicating science explanations.
- Doing more investigations in order to develop understanding, ability, values of inquiry and knowledge of science content.
- Public communication of student ideas and work to classmates.

II. GETTING READY

Pre-requisite Skills for Learners:

Your learners should have the following skills in order to participate efficiently and smoothly in this lesson:

- Ability to work in small collaborative groups of 3-4 students each
- Ability to work independent of direct instructor facilitation as the instructor will be wandering the classroom and helping all groups
- Ability to communicate findings, reasoning, and work to others
- Cognitive ability to recognize patterns that have not been introduced/explained before hand

Pre-requisite Content Knowledge for Learners:

Prior to this lesson, learners should be familiar with the following concepts:

- Temperature is a measure of the average heat or thermal energy of the particles in a substance.
- Heat can move from place to place.
- Minor geology content: learners need to know that geothermal places (like a volcano) exist and that they are "hot" places. They do not need to know how or why geothermal features like geysers, mudpots, and hot springs work or are formed.

Common Misconceptions:

Misconception: The spectrum of electromagnetic radiation consists of only visible light.
Reality: The electromagnetic spectrum consists of: radio, microwaves, infrared, visible, ultraviolet, x-rays and gamma rays, listed from lowest energy to highest energy (also longest wavelength to shortest wavelength). The visible spectrum is a very tiny slice of the whole electromagnetic spectrum.

Misconception: All radiation is harmful.
Reality: All components of the electromagnetic spectrum are considered radiation but only the most energetic, ionizing radiation is harmful (x-rays and gamma rays). Radiation with wavelength equal to or longer than visible light is considered harmless (radio, infrared, and visible light). Ultraviolet light can cause damage to a person's skin but it is not considered ionizing.

Misconception: Heat and Temperature are the same thing.
Reality: Heat and temperature are related to each other, but are different concepts. Heat is the energy an object has because of the motion of its atoms and molecules. Temperature is a measure of the average heat or thermal energy of the particles in a substance. Temperature is not energy, but a measure of it. Heat is energy.

Preparation Work for the Instructor:

1. Print out and make laminated copies of the infrared and visible images from **Image Appendix, Image Set 1: Old Faithful (Section VII, A**)

Image Appendix, Image Set 1: Old Faithful (Section VII, A) – a separate MS word or pdf file.
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet1.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet1.pdf

Each learning group will need its own complete set of Old Faithful infrared and visible images. Note that the infrared and visible images are given out at different times during the activity, so have them separated. Additionally, make color transparencies of this Old Faithful image set or have available a computer and projector.

2. Print out and make laminated copies of the infrared and visible images from:
Image Appendix, Image Set 2: Mudpots (Section VII, B) – a separate MS word or pdf file.
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet2.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet2.pdf
Image Appendix, Image Set 3: Hot Springs (Section VII, C) – a separate MS word or pdf file.

http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet3.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet3.pdf

Image Appendix, Image Set 4: Hot Spring Terraces (Section VII, D) – a separate MS word or pdf file.
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet4.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet4.pdf

Each person in each learning group will need their own complete series of infrared and visible images of the particular geothermal feature their group was assigned. For example: there are 3 features: Mudpots, Hot Springs, and Hot Spring Terraces. You will divide the class into small groups and assign each group a feature. Each person in a group will need their own complete image series (Mudpot series (Image Set 2), Hot Spring Series (Image Set 3), Hot Spring Terraces series (Image Set 4) for their feature. If you have 24 students you can make 6 small groups of 4 students each. You will then have 2 Mudpot groups, 2 Hot Spring groups, and 2 Hot Spring Terraces groups. Therefore, you will need to print out 8 Mudpot series, 8 Hot Spring series, and 8 Hot Spring Terraces series.

3. Print out and make copies of **Observation Log A**, **Observation Log B**, and **Observation Log C**. You will find these worksheets at the end of this lesson guide in **Section VI. Worksheets**. Each learning group will receive one each of Observation Log A and Observation Log B. Each learner will receive an Observation Log C.

4. Prepare the ***Exploring Infrared Imaging*** lesson. This lesson is located online here:
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/

5. Download to a computer/projector, or otherwise make available for the classroom, the following movie clip of a geyser from Yellowstone: http://www.gigagraphica.com/geyser/oldfaithful/oldfaithful.html If you cannot access or play the movie during class, you can use one of the visible images of Old Faithful from **Image Set 1** in the Image Appendix (Section VII, A).

Image Appendix, Image Set 1: Old Faithful (Section VII, A) – a separate MS word or pdf file.
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet1.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet1.pdf

6. Make available via color overhead transparency or computer presentation the images from **Image Set 2**, **Image Set 3**, and **Image Set 4** in the Image Appendix (Section VII.B, Section VII.C, Section VII.D respectively). During the conclusion of Day 2 there are class presentations of observations and it is suggested you have a way to display the image set to the entire class for reference during the presentations/discussions.

Image Appendix, Image Set 2: Mudpots (Section VII, B) – a separate MS word or pdf file.
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet2.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet2.pdf
Image Appendix, Image Set 3: Hot Springs (Section VII, C) – a separate MS word or pdf file.
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet3.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet3.pdf
Image Appendix, Image Set 4: Hot Spring Terraces (Section VII, D) – a separate MS word or pdf file.
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet4.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet4.pdf

7. Review the lesson and brainstorm modifications for your particular set of learners. Have ready some discussion questions and points that you want to cover for the lesson to fit into your existing curriculum and state science standards.

8. Design an evaluation rubric for this lesson based upon your learners, how you have tailored this lesson, and where this lesson falls into your curriculum. We do not provide an “evaluation” activity/rubric in this lesson, but we do provide sample learning goals generic to this lesson “as is” in the General Information section for this lesson.

9. Arrange the classroom for group work. Learners will need to have a desk, table, or floor space to spread pictures out without being cramped or too near other groups.

Background Knowledge and Resources for the Instructor:

Provided below are some internet resources to help you get a better grasp on infrared light and imaging. Please note that we have compiled a **Cool Cosmos Teacher's Guide to the Infrared** that can be found here:

- Cool Cosmos Teacher's Guide to the Infrared
  http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/background.html

Other Resources:

- Infrared Tutorial
  http://coolcosmos.ipac.caltech.edu/cosmic_classroom/ir_tutorial/

- Video- Infrared: More Than Your Eyes Can See
  http://coolcosmos.ipac.caltech.edu/videos/more_than_your/

- Heat and Temperature
  http://coolcosmos.ipac.caltech.edu/cosmic_classroom/light_lessons/thermal/

Geology Resources:

- Infrared Yellowstone at Cool Cosmos from Spitzer
  http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/gallery.html

- Yellowstone National Park: Mammoth Hot Spring Terraces and How They Work
  http://www.nps.gov/yell/nature/geothermal/mamterrc.htm

- Yellowstone National Park: Geysers and How They Work
  http://www.nps.gov/yell/nature/geothermal/geysers.htm

- Yellowstone National Park: Mudpots and How They Work
  http://www.nps.gov/yell/nature/geothermal/mudpots.htm

III. DAY 1: LEARN ABOUT INFRARED LIGHT AND INFRARED IMAGING

A. Engage Your Learners

Activity Time: 10-15 minutes

In this section you will be introducing Old Faithful geyser to your learners using a video clips (or still images if video clips are unavailable). It is a cool thing to look at and speculate about. You will engage them by prompting them to ask questions about what they are seeing. If needed, you can use a series of pointed questions to help lead them to the ultimate discovery question about the image, **"I know that this image/movie does not give me enough information and I have many questions. What other resources can I use, or what other information can I gather about this object to help me find answers to my questions?"**

Video Clips:
http://www.gigagraphica.com/geyser/oldfaithful/oldfaithful.html
http://coolcosmos.ipac.caltech.edu/videos/ir_yellowstone/

Many visible light still images of Old Faithful can be found in the **Image Appendix, Image Set 1 (Section VII.A)** (available in MS Word or pdf file)**.**
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet1.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet1.pdf

1. Without informing your learners that they are about to see a geyser/Old Faithful, introduce the activity by telling them they are going to see something really neat and that you want them to come up with questions about what they are seeing.

2. Show your learners the video clip or still visible light image of Old Faithful Geyser. Give them time to formulate questions and curiosities.

3. Guide your learners through a discussion about their questions and how they can or cannot be answered just by looking at the image or video clip. Find out what sparks their curiosity and use that energy to guide the lesson.

Below are some sample questions and curiosities that may be expressed during your discussion. Some of the students may already be familiar with Old Faithful and know that it shoots up hot water and it is located in a volcanic caldera in Yellowstone National Park. Instead of allowing them to halt your activity and the curiosity of your other learners, you can use their prior knowledge to tackle the deeper concept, "**How can you get that particular information from this photo/video?**"

Sample Discovery questions:

- What is this?
- How does it work?
- Why is it shooting liquid upward?
- What is that liquid?
- Is the liquid hot, warm, cool, or cold?*
- Where is it located geographically?
- Where is it located geologically?
- Why does it even matter where it is?

*The temperature of the liquid is a key question to raise since it will tie into the infrared image activities that follow.

4. During the discussion, write on a chalkboard some of the major questions and curiosities your learners have that they cannot seem to answer just by looking at the visible light photo or video clip. You will be re-using these questions on Day 2 so be sure to record them at the end of the day.

5. Ask your learners to quickly brainstorm ways they can get their questions answered. This is where you can lead into the idea of taking different kinds of pictures. Some may be familiar with black and white photos, digital photos, long exposure photos (to show movement), x-ray films, film negatives, and night vision video camera settings. Through this lesson, you have a unique set of images to introduce to them to which may help them get a few of their questions answered. Later, they will be able to use an infrared image to answer the question about the "temperature of the liquid".

B. Exploring Infrared Imaging

Activity Time: 25-45 minutes

In this section you will introduce your learners to the unique images you mentioned at the end of their brainstorm. This lesson is a mini-exploration and serves as an introduction to infrared imaging. At the conclusion of this exploration, your learners should understand the following:

- Infrared cameras can detect how much infrared radiation/light an object is emitting
- Infrared images (like the ones here) show how much infrared light was detected by the camera. Infrared light is used to measure the heat emitted by these objects. This measurement is transferred to color codes and is equivalent to degrees Fahrenheit.
- The infrared image has been scaled to show the temperature of the various areas of the object using a false-color map.
- False-color maps, like the infrared images here, come with a legend that tells the observer which temperatures are associated with which colors. This is how someone can accurately interpret the image.
- By looking at or observing the images, one can determine warmer or cooler areas. One is unable to do this with visible light images.

This activity is common to many of our lesson guides. Please go back to the website (http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/***) and choose Exploring Infrared Imaging to access the lesson guide***

IV. DAY 2: INFRARED OLD FAITHFUL

Activity Time: 30-60 minutes

In this section your learners will be using their "observation skills" to determine what kinds of information can be gathered from visible light images as compared to infrared images. So far they have had unanswered questions and curiosities about Old Faithful and have learned that the infrared images (with an appropriate false color temperature map) can give information on the relative temperature of an object. In this activity they will discover that they can determine a relative temperature of the water from the geyser and also get a sense of the temperatures of the nearby landscape as compared to the geyser water. Please note that the infrared images of the geothermal features in Yellowstone National Park were taken from quite a distance away and the temperatures described by the false color mapping do not represent actual temperatures since the heat reaching the infrared camera drops off with distance from the source. However, the infrared images are very useful for describing objects in the scene relative to each other, as in warmer or cooler, hotter or colder, etc. using the false color map as a guide.

You will be using the Old Faithful visible images (**Image 1a**, **Image 2a**, **Image 3a**) and the Old Faithful infrared images (**Image 1b**, **Image 2b**, **Image 3b**) from **Image Set 1** of the Image Appendix (Section VII.A)**.**

> **Image Appendix, Image Set 1: Old Faithful (Section VII, A)** – a separate MS word or pdf file.
> http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet1.doc
> http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet1.pdf

1. Begin the activity by dividing your learners into small learning groups of 3-4 learners each. Be sure the groups have enough space to spread the images out and discuss without disturbing other groups.

2. Refresh the topic from Day 1 by showing the video clip/still image of Old Faithful and reviewing the main questions and curiosities from the previous day.

3. To each group, hand out the visible light image set of Old Faithful (**Image Appendix - Image Set 1: Images 1a, 2a, 3a**). Make note that the three images are sequential: Image 1a is near the beginning of an eruption, Image 2a is near the middle of an eruption, and Image 3a is near the end of an eruption.

4. To each group, hand out **Observation Log A** (found in Section VI – Worksheets). Assign one person in each group to be "note taker".

5. Discuss the task and scenario with your learners. The ultimate task is for each group to "observe" the images and record their observations and questions about what they see. Sample scenario: They are to take on the roles of explorers and have come upon this interesting geothermal feature. Their sponsoring company wants detailed observation logs to accompany any images they take. It is their goal to describe in detail what they are observing and note questions they are having about what they see.

The below sample observations are some of the main observations of the images and are not <u>all</u> of the observations one could make.

Sample Observation statements on Image 3a:

- We have watched the feature erupt for a while now and there is not a clear stream of water coming up from the ground like in Image 1. The surrounding area is steamy and looks like clouds/fog.
- Is the water hot or cold? Maybe it is hot since there is steam?
- The steam around the feature has increased from Image 1 to Image 3.
- There are trees in the background that seem to not have leaves…is it winter?
- The ground around the feature looks wet and muddy.

6. It should not take very long for the basic observations to be made. Through a brief discussion, revisit the limitations of the visible light images and their prior questions. Discuss any new questions that have come up during their first observation session. End the discussion by asking a very open-ended question, "**How can we**

find the answers to your questions?" Entertain your learners' ideas and guide them towards their newfound understanding of infrared images from Day 1's activity, *Exploring Infrared Imaging*.

7. It just so happens that you have infrared images to accompany the visible images! If you are using the sample scenario of an exploration team, you can tell them that their sponsoring company gave them an infrared camera. They took pictures using a regular camera and the infrared camera simultaneously and are now comparing the visible light images to the infrared images to see if they can obtain more information about the mysterious geothermal feature. Hand out the infrared image sets of Old Faithful (**Image Appendix - Image Set 1: Images 1b, 2b, 3b**) and **Observation Log B** (found in Section VI – Worksheets) to each group. Again, assign a "note taker".

8. First instruct them to complete the top portion of **Observation Log B**. Depending on the skill level of your learners, you may want or need to pause the activity and review the answers to the questions before they proceed with their observations and comparing of the infrared images. The questions help them reflect on Day 1's activity, *Exploring Infrared Imaging*.

- **What do the different colors in the infrared image represent?**

  Answer: The different colors represent relative temperatures. The infrared image is a false color map. By using the temperature scale/legend one can determine which colors in the infrared image symbolize cooler or warmer temperatures. The generic scale is:

Coldest Temperature	← Getting cooler					Hottest Temperature
	→ Getting warmer					
Black	Purple	Blue	Green	Yellow	Orange	Red	White

  Examples:

  - *Black is colder/cooler than purple*
  - *Purple is colder/cooler than green*
  - *Orange is colder/cooler than red*
  - *White is hotter/warmer than yellow*
  - *Blue is hotter/warmer than black*

*Note that this is *reverse* from what learners may experience when learning about light. The students may be confused by the fact that the color blue is representing a cooler color than the color red. Explain to the students that in false-color images, any color can be chosen to represent the different temperature ranges in the images and that this just happens to be the colors which were assigned to represent the temperatures for the infrared images used in this lesson.

- **How can you use the infrared image and visible light image together to learn about an object?**

  Answer: A visible light image can help us see the specific features of an object (like hair, leaves, the colors that our eyes see) that we normally will observe with our own eyes. An infrared image will tell us which areas are cooler or warmer. Together, we can compare and contrast the images to determine which areas are cooler and warmer (infrared image) and then use the visible light image to help us discover clues as to why those areas are cooler or warmer. In essence, the visible light image helps observers determine the context and what objects are in the image. The infrared image offers us a new perspective and new information on those objects in the image and help form a more complete picture of what was happening the image was taken.

9. The next step is for your learners to compare and contrast the visible light images and the infrared images. This is the heart of the activity. They will soon realize that they can answer one of their original curiosities: **Is the**

water hot, warm, cool, or cold? Additionally, they can determine a relative temperature of the surrounding area and realize that the water is not the only thing that is hot! The ground, as compared to the tree line, is relatively warm as well.

The below sample observations are some of the main observations of the images and are not all of the observations one could make.

Sample Observation statements on Image 2a and Image 2b:

- The water in the center (directly spraying upwards) is very hot as compared to the rest of the image.
- The steam seen in Image 2a can be seen in the infrared image. It is cooler than the water that is directly spraying upward in the center.
- The ground is not black or purple, it is blue. It's cooler than the water, but warmer than the trees. Is all the ground warm in this area? Can we walk on it or is it too hot like lava?
- The steam nearest the spraying hot water is warmer than the steam that is farther away. The farther away steam looks more wispy.
- There looks to be a puddle of water near the bottom of the picture and you can see it in the infrared image as a small green area. Since green is warmer than blue, we know it's not ice but warm water.

10. To conclude this activity, ask your learners to prepare their observations to present to the class. Hold a class discussion/presentation forum where they can discuss their observations, what they learned about the geothermal feature, and questions they have about the feature. We suggest you use color overhead transparencies or a computer presentation to have the images available to the entire class for reference during the presentations/discussion. The main goal of this lesson was to compare and contrast the visible light image versus the infrared image. If you have other curriculum goals that deal with the geology content, this will serve as a nice segway into talking about the geothermal hotspot of Yellowstone National Park!

V. DAY 3: THE INFRARED YELLOWSTONE

Activity Time: varies, approximately 60 minutes

Presented here is a basic extension activity idea that you can modify for your own classroom. It can be used, as written here, as a classroom "jigsaw" activity that models the Day 2 Infrared Old Faithful compare and contrast activity. It can double as an assessment activity or as a homework assignment. It may also serve as a springboard to your geology curriculum.

You will be using **Image Set 2, Image Set 3,** and **Image Set 4** of the Image Appendix. (Section VII.B, Section VII.C, and Section VII.D)

Image Appendix, Image Set 2: Mudpots (Section VII, B) – a separate MS word or pdf file.
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet2.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet2.pdf
Image Appendix, Image Set 3: Hot Springs (Section VII, C) – a separate MS word or pdf file.
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet3.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet3.pdf
Image Appendix, Image Set 4: Hot Spring Terraces (Section VII, D) – a separate MS word or pdf file.
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet4.doc
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet4.pdf

1. Divide the class into 3 groups and assign each group a feature: Mudpots, Hot Springs, or Hot Spring Terraces. From these large groups, make smaller learning groups within each feature. You may end up with 2-3 Mudpot groups, 2-3 Hot Spring groups, or 2-3 Hot Spring Terraces groups.

2. Each learner will receive their own image set according to their feature name. *For example:* each person in the Mudpot group will get a complete **Image Set 2** which contains **Mudpot 1**, **Mudpot 2**, and **Mudpot 3**.

3. Each learner will also receive an **Observation Log C** (found in Section VI – Worksheets). To continue on with the prior day's sample scenario, they are still explorers and need to report back on interesting geothermal features they discover! They will again be comparing and contrasting the visible light and infrared images of features as they did with Day 2's Infrared Old Faithful activity.

4. Jigsaw Activity:

Jigsaw-like activities fall into the category of cooperative learning. Each individual is responsible for their own small piece of knowledge during the beginning of the activity. Then they work together with other learners who are also responsible for that same piece of knowledge to better understand their piece. Once a good understanding is established, these topic specific groups are redistributed so that new groups are formed. In these new groups, each learner holds a different piece of knowledge that must be shared and communicated to the entire group. Jigsaw activities employ cooperative learning and peer teaching strategies. There is individual and group accountability. If you would like more information on this innovative technique, please see the Jigsaw Classroom website: http://www.jigsaw.org. If your learners have not yet been in the jigsaw activity Learning environment, you may need to take some extra steps to alleviate anxiety and increase their understanding of individual and group responsibility.

- STEP 1: In the small learning groups you have assembled, students are to complete the **Observation Log C** individually. Explain that they will have a chance to collaborate with others who share the same feature after they make their own observations.
- STEP 2: After individual observations have been made, have the individuals in each small group share their observations with their peers. This is the time that they will collaborate and enhance each others understandings. Explain to your learners that they need to be thorough in their final observations (small group sharing) and will each be presenting what they have observed about the object to their classmates.
- STEP 3: When you feel the small group observations are complete it is time to break up the groups. You will redistribute your learners into new small groups by distributing the features. Each new small group will have at least one of each feature represented. If needed, you can send learners off in pairs to

their new groups. This may help some learners feel comfortable in the new group, to which they will be presenting their work. As an example, a newly distributed group may have 2 Mudpot observers, 2 Hot Springs observers, and 2 Hot Spring Terraces observers. Note: A true jigsaw activity would have only 1 of each observer, however, if you have a large classroom you may want to double up to save time.

- STEP 4: The new task is for the explorers to confer with their colleagues about the feature they observed. Each feature will take a turn and show the others the results of their compare and contrast. After each presentation, the group members should add to the observations to form a more complete observation. Encourage groups to discuss each feature ask questions.

5. To conclude this activity, hold an all-class discussion similar to how Day 2's Infrared Old Faithful activity ended.

The below sample observations are some of the main observations of the images and are not <u>all</u> of the observations one could make.

Sample Observation statements on Image Set 2: Mudpots (Section VII,B)

- Mudpot 1 – you can see the puddle of mud is warmer than the surrounding ground/area
- Mudpot 1 – the mudpot is not an even temperature, it has different temperatures within it
- Mudpot 1 – the mud is warmest near the lower to mid right section and it gets cooler spreading away from that area
- Mudpot 1 – even though it looks smooth, you can see that different temperature mud areas swirl and mix around each other
- Mudpot 2 – you can somewhat see bubbly areas in the visible image, but it still looks fairly smooth
- Mudpot 2 – in the infrared image, you can definitely see the bubbly structure of the mud! You can also see (between both images) that the center of the bubble is hotter than the rest of a "bubble area".
- Mudpot 2 – the ground here isn't much cooler than the larger mud area that the hotter bubble areas are in
- Mudpot 3 – you can't really see much detail in the visible image
- Mudpot 3 – in the infrared image you can tell that there is hot mud and hot bubble areas

Sample Observation statements on Image Set 3: Hot springs (Section VII,C)

- Hot springs 1 – in the visible image you can determine that there is an area filled with water, but you cannot tell if it is cold or hot. It has a greenish color to it and rocky area is rust colored.
- Hot springs 1 – The infrared image reveals that the water is very warm and is mostly an even temperature, though you can tell there are slightly cooler (orange) areas.
- Hot springs 1 – the area on the outside of the spring is cooler than the water, but warmer than the surrounding ground.
- Hot springs 2 – in the visible image you can see water bubbling in the middle and this corresponds to a much warmer area in the infrared image
- Hot springs 2 – the surrounding ground is much cooler than the water, but the rock in the middle of the spring isn't the same temperature as the surrounding ground. It's warmer than the ground, but cooler than the water. Is the rock being heated by the water?
- Hot springs 2 – like Hot springs 1, the infrared image shows that the water is much warmer towards the center of the spring, and cools off near the edges. Or, the immediate ground next to the water is being slightly heated by the much warmer water.
- Hot springs 3 – there is a lot going on in the visible image! Where is the water? It's easy to find in the infrared image because it is the hot pink color. You can see a smaller area of water right in the middle of the image, but you can't see the water there in the visible image! Wow!

Sample Observation statements on Image Set 4: Hot Spring Terraces (Section VII,D)

- Hot Spring Terraces 1 – the visible image just looks like a landscape with rocky areas, trees without leaves, and it may look like snow on the ground?

- Hot Spring Terraces 1 – the infrared image reveals much more about this area. There are warmer/hotter areas in the background. These must be areas of hot water?
- Hot Spring Terraces 1 – the trees, which we assumed would be black in color, are green in the infrared image. Are they being heated by the hot springs terrace?
- Hot Spring Terraces 2 – after seeing the difference in the visible image and infrared image, we are glad we have the infrared image to look at! One might accidentally try to walk across this land and be burned by the hot water!
- Hot Spring Terraces 2 – the hot areas of the terrace are not even. The infrared image shows that there are warmer and cooler areas. Do the hotter areas have more hot water? Is the entire area covered in water or are they like small waterfalls?
- Hot Spring Terraces 3 – in the visible light image you can't tell at all where the hot water and areas are. The infrared image shows where the hot areas area. Is this hot water spilling over the edge or hot rock?

VI. WORKSHEETS

A. Observation Log A
Make 1 copy for each small learning group

B. Observation Log B
Make 1 copy for each small learning group

C. Observation Log C
Make 1 copy for each learner

Observing Group Members:

Observation Log A

_____ _____ _____

In the spaces below, record your detailed observations and questions about the geothermal feature using Image 1a, Image 2a, and Image 3a.

Observations of Image 1a	Questions about Image 1a

Observations of Image 2a	Questions about Image 2a

Observations of Image 3a	Questions about Image 3a

Other Observations and Questions:

Observing Group Members:

Observation Log B

_____ _____ _____

1. What do the different colors in the infrared image represent?

2. What color means the hottest area? _____

3. What color means the colder area? _____

4. What colors do you consider to be warmer colors? Why?

5. What colors do you consider to be cooler colors? Why?

6. How can you use the infrared images and visible light images together to learn about an object?

In the spaces below, record your detailed observations and questions about the geothermal feature using Image 1a & 1b, Image 2a & 2b, and Image 3a & 3b.

Observations of Image 1a and Image 1b

Observations of Image 2a and Image 2b

Observations of Image 3a and Image 3b

Other Observations and Questions:

Observer Name: _____

Observation Log C

Feature Name: _____

In the spaces below, record your detailed observations and questions about the geothermal feature you are observing.

Observations of Visible Light Image

Observations of Infrared Light Image

Other Observations and Questions: