



Here's another chance to play geographical detective! The image above was taken by the [Multi-angle Imaging SpectroRadiometer \(MISR\)](#) on NASA's [Terra](#) satellite. It shows an area about 327 kilometers wide by 375 kilometers high, and geographic north is not necessarily at the top of the page.

The questions below refer to a country that fills most of the area in the image. Please answer the questions and then tell us the location shown. You may use any reference materials you need to answer the quiz.

1) Within this country lies a picturesque desert, located at the bottom right of the image. This desert was home to a group of enigmatic ancient people who were known for their skill and resourcefulness. Their capital is a UNESCO World Heritage Site. **Name the desert and the given name of the people.**

2) The wavy lines that cross the middle of the image are natural geologic features that often carry descriptive names of their location. **What is the native word used to accurately describe these features?**

3) The name of the body of water at the bottom of the image is actually a misnomer. The nearby hills that protect the landscape from weather fronts also enable a "rain shadow," thus contributing to the surrounding aridity. **What is the name of the body of water?**

4) At the bottom left, small city developments are visible. One of those cities came

was developed at the beginning of the 20th century. It now accounts for 50 percent of the industrial output of the country. **Name the city.**

5) The landscape dominating most of the image is an extension of a much larger, natural feature. This feature is home to a very limited floristic diversity and to a number of critical and endangered species—though there are no formally protected areas. **Name this feature.**

6) **Name the country that fills most of the area in this image.**


Send your answers, your name (initials are acceptable), and hometown by Wednesday, February 15, 2012, using the [quiz answer form](#). Answers will be published on the MISR web site and on the [Earth Matters blog](#). The names of respondents who answer all questions correctly before the deadline will be published in the order in which responses are received. The first three people who answer correctly, who are not affiliated with NASA, JPL, or MISR, and who have not previously won a prize will be sent a print of the image.

New “Where on Earth...?” mysteries appear periodically. Today’s image also appears on the [Planetary Photojournal](#), and the [Atmospheric Sciences Data Center](#) home page.

Credit: Image courtesy NASA/GSFC/LaRC/JPL MISR Team. Caption by Amber Jenkins and Karen Yuen, JPL.

Instrument: Terra - MISR

Feb. 9, 2012 Geology Chapter 14, 2, 9
Geomorphology, Land forms, topography
Faults, Geologic features, Earthquake
monitoring, Volcanic eruptions, Tsunamis



Atacama Desert in northern Chile, at the foothills of the Andes.

USGS NASA

The Andes Image taken 10/28/2001 by ASTER Vivid colors belie the arid landscape of northern Chile where the Atacama Desert, one of the world's driest, meets the foothills of the Andes. Here salt pans and gorges choked with mineral-streaked sediments give way to white-capped volcanoes.

This image can be found on ASTER Path 1 Row 77, center: 23.91 S, 69.38 W

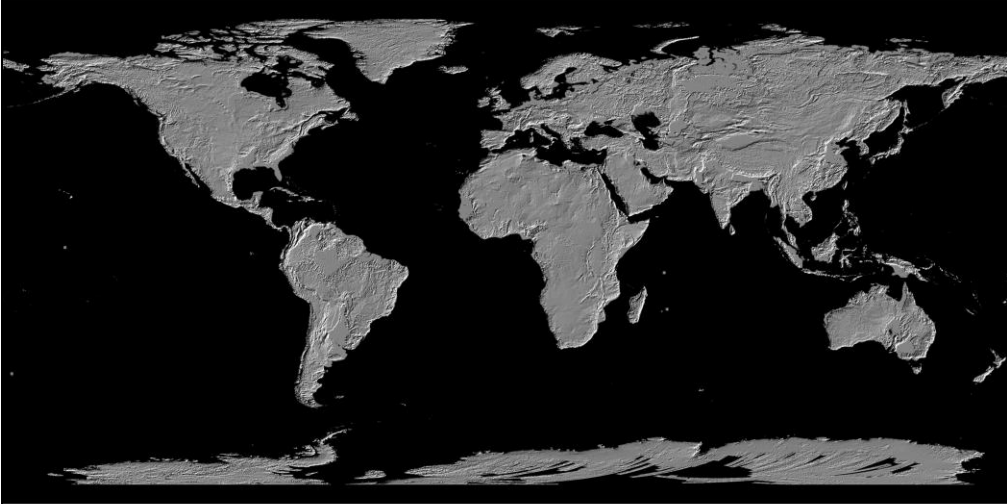
USGS Digital Elevation Model (NED) for Continental US



Digital Topography from the NASA Radar Mapping Mission

Landforms are natural physical features of the earth's surface, for example, valleys, plateaus, mountains, plains, hills, loess, or glaciers. Formed by geologic processes and weathering .

Global DEM Created from ASTER Data



Covers 99% of the Earth's landmass. Created from stereo pairs of ASTER data. First released 2009, V2 in 2011.

The Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) jointly announced the release of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2) on October 17, 2011.

The first version of the ASTER GDEM, released in June 2009, was generated using stereo-pair images collected by the ASTER instrument onboard Terra. ASTER GDEM coverage spans from 83 degrees north latitude to 83 degrees south, encompassing 99 percent of Earth's landmass.

The improved GDEM V2 adds 260,000 additional stereo-pairs, improving coverage and reducing the occurrence of artifacts. The refined production algorithm provides improved spatial resolution, increased horizontal and vertical accuracy, and superior water body coverage and detection. The ASTER GDEM V2 maintains the GeoTIFF format and the same gridding and tile structure as V1, with 30-meter postings and 1 x 1 degree tiles.

Version 2 shows significant improvements over the previous release. However, users are advised that the data contains anomalies and artifacts that will impede effectiveness for use in certain applications. The data are provided "as is," and

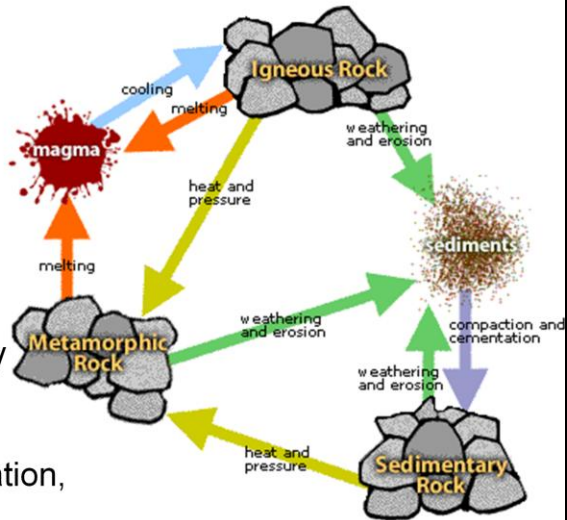
neither NASA nor METI/ERSDAC will be responsible for any damages resulting from use of the data.

As a contribution from METI and NASA to the Global Earth Observation System of Systems (GEOSS), ASTER GDEM V2 data are available free of charge to users worldwide from the Land Processes Distributed Active Archive Center (LP DAAC) and the Earth Remote Sensing and Data Analysis Center (ERSDAC).

Geomorphology

The study of landforms and the processes that shape them.

Understand landform history and dynamics, and predict future changes through a combination of field observation, physical experiment, and numerical modeling.



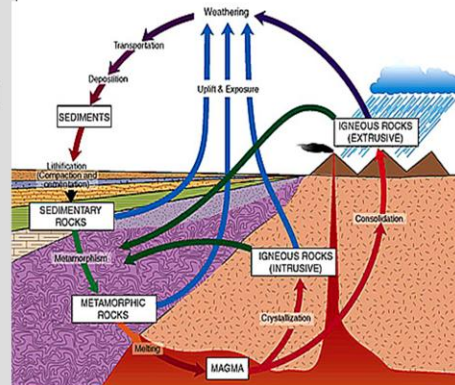
Lithology is the study of rocks and rock formation

Lithology is the field of geology that focuses on the study of rocks and the conditions under which they form. Lithology describes the character of a rock, as derived from the type and mode of aggregation of its mineral contents.

Rock types are formed by:

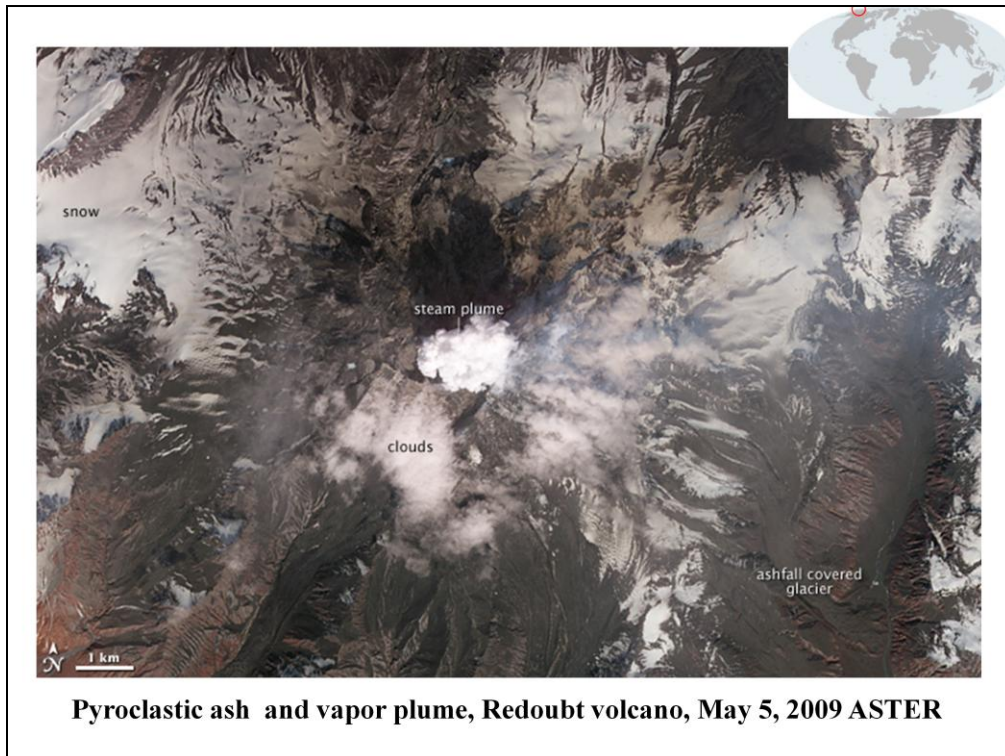
- **igneous rocks** are formed from molten **magma** material; includes volcanic (e.g., lava) and plutonic (e.g., granite) rocks
- **sedimentary rocks** are formed from the **deposition** of sediment and particles of pre-existing rocks and plant and animal remains i.e., sandstone, shale or limestone)
- **metamorphic rocks** are formed by applying **heat & pressure** to previously existing rock (e.g., slate, marble, gneiss, or schist)

Remote Sensing of Geology and Geomorphology



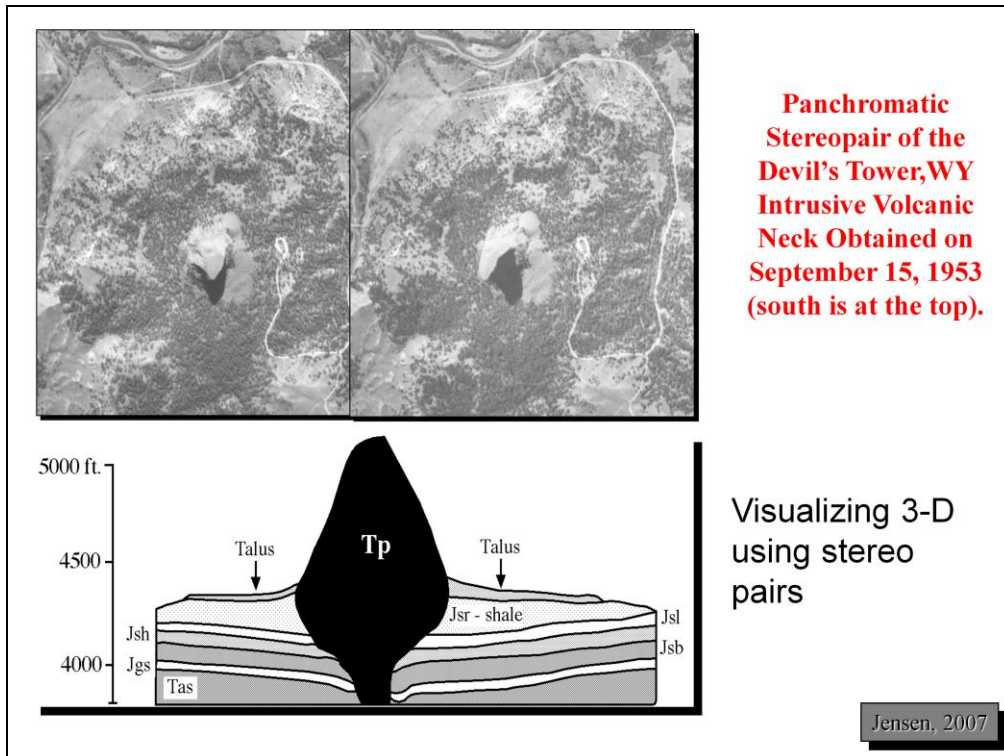
Jensen, 2007

**Remote Sensing of
Igneous
Landforms**



The Advanced Spaceborne Thermal Emission and Reflection Radiometer ([ASTER](#)) on NASA's [Terra](#) satellite acquired this image of Mount Redoubt and its surroundings on May 5, 2009, when the volcano exhibited little visible activity besides a plume of vapor. In this image, made from a combination of visible and infrared light, the bright white steam plume hovers over the volcano's summit. Immediately southwest of this plume, clouds appear fairly thin and dull. North of the volcano, pristine snow rests on the land surface, but southeast of the volcano, ashfall from earlier eruptions has stained the icy surface.

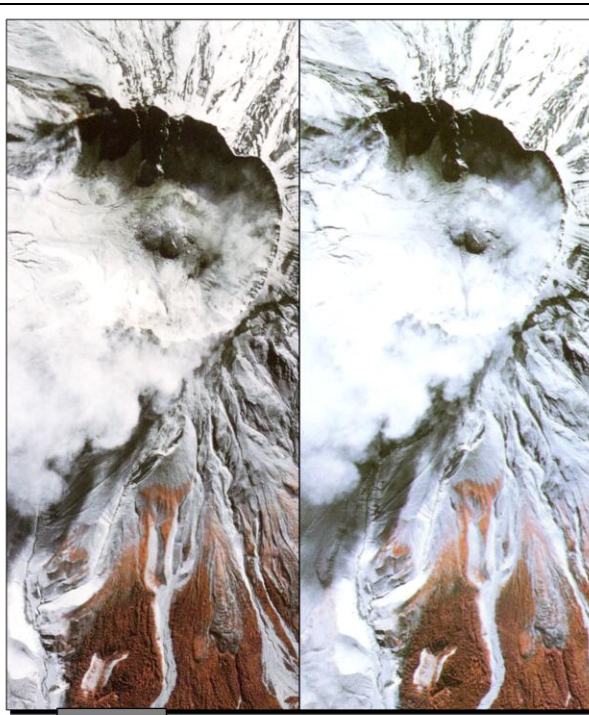
[Redoubt](#) is a stratovolcano—a steep-sloped, conical volcano composed of layers of hardened lava, solidified ash, and rocks ejected by previous eruptions. Starting on March 22, 2009, after weeks of unrest, the volcano suddenly erupted five times in one night. Redoubt remained intermittently active afterwards.



If you defocus your eyes and stare at the two images, with your head about 1.5-2 ft away, you can sometimes see the images form as a single 3-d image. If you can do this you can see the intrusive volcanic neck extending above the surface.

What does this tell you about the other rock material that was there when the neck formed?

What is the advantage of stereo photography? Do any satellites produce stereo imagery? Check out online how any of the pointing satellites work (e.g., SPOT, Ikonos or Quickbird, ASTER) and what you think about doing this with spaceborne instruments.



Jensen, 2007

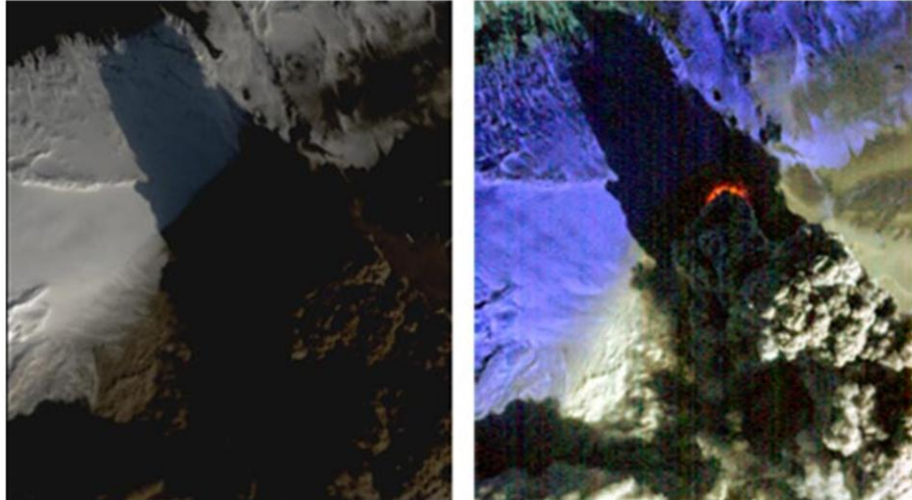


**Mount St. Helens
erupting May 18, 1980**

**USGS High Altitude
Photography stereopair
of composite cone
Mount St. Helens,
Washington
August 6, 1981**

Hyperion on EO-1 Satellite of
Eyjafjallajökull Volcano April 17, 2010

What bands are used?



Visible (left) and infrared (right) images of Iceland's Eyjafjallajökull volcano, acquired April 17, 2010, from the Hyperion instrument onboard NASA's Earth Observing-1 (EO-1) spacecraft. Image credit: NASA/JPL/EO-1 Mi

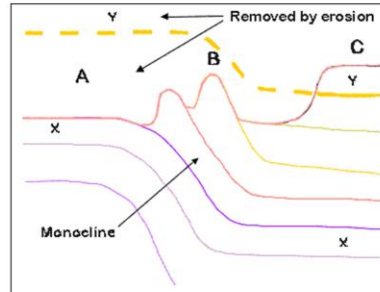
On Sat., April 17, 2010, the Hyperion instrument onboard NASA's Earth Observing-1 (EO-1) spacecraft obtained this pair of images of the continuing eruption of Iceland's Eyjafjallajökull volcano. In the left-hand image, created from visible wavelengths, new black ash deposits are visible on the ground, as well as nearby brilliant unsullied ice and snow and the volcano's brown, billowing plume. The plume's dark color reflects its large ash content. These fine particles of pulverized rock are carried high into the atmosphere, where they create a hazard for aviation and are carried long distances by the prevailing winds.

In contrast, the false-color, infrared image at the right reveals the intense thermal emissions (at least 60 megawatts, or 60 million watts) emanating from the vent at the base of the massive plume. This thermal emission, equivalent to the energy consumption of 60,000 homes, represents only a small proportion of the total energy being released by the volcano as its molten lava interacts violently with ice and water. Each image covers an area measuring 7.7 kilometers (4.8 miles) wide, and has a resolution of 30 meters (98 feet) per pixel. The vertical direction is north-northeast.

The EO-1 spacecraft is managed by NASA's Goddard Space Flight Center, Greenbelt, Md. EO-1 is the satellite remote-sensing asset used by the [Volcano Sensor Web](#) developed by NASA's Jet Propulsion Laboratory, Pasadena, Calif., which is being used to monitor this, and other, volcanic eruptions around the world.
ssion/GSFC/Ashley Davies

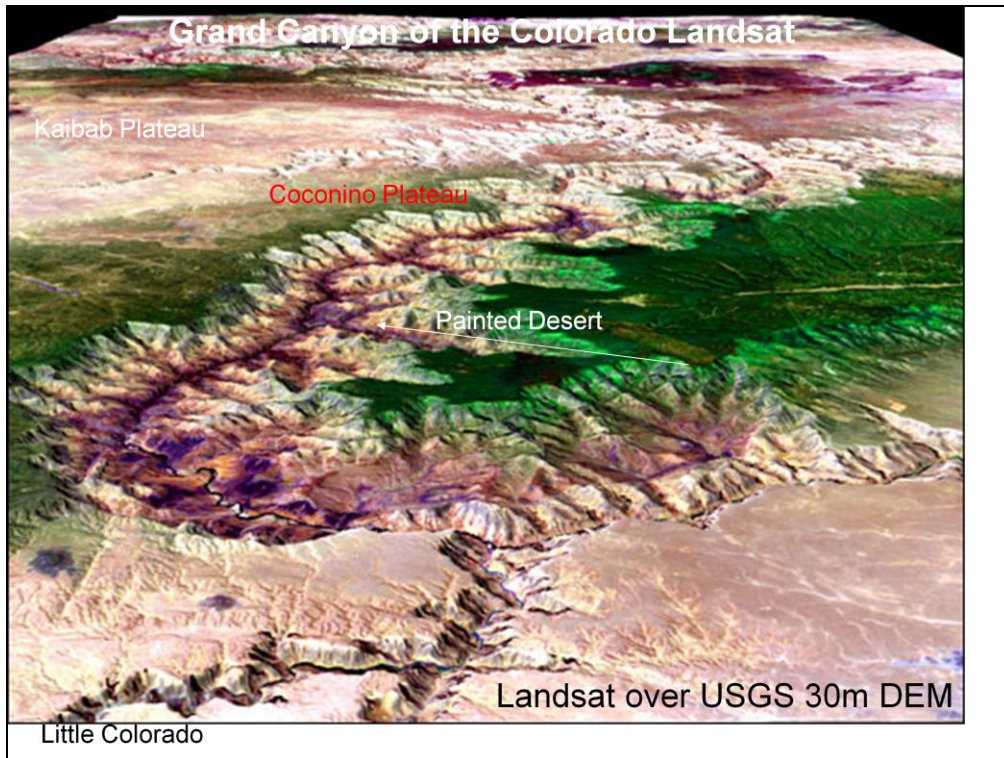
**Remote Sensing of
Sedimentary
Landforms**

Landsat MSS full scene June 13, 1977. showing the northwestern section of the Colorado Plateau, and parts of the Canyonlands.



What Bands?

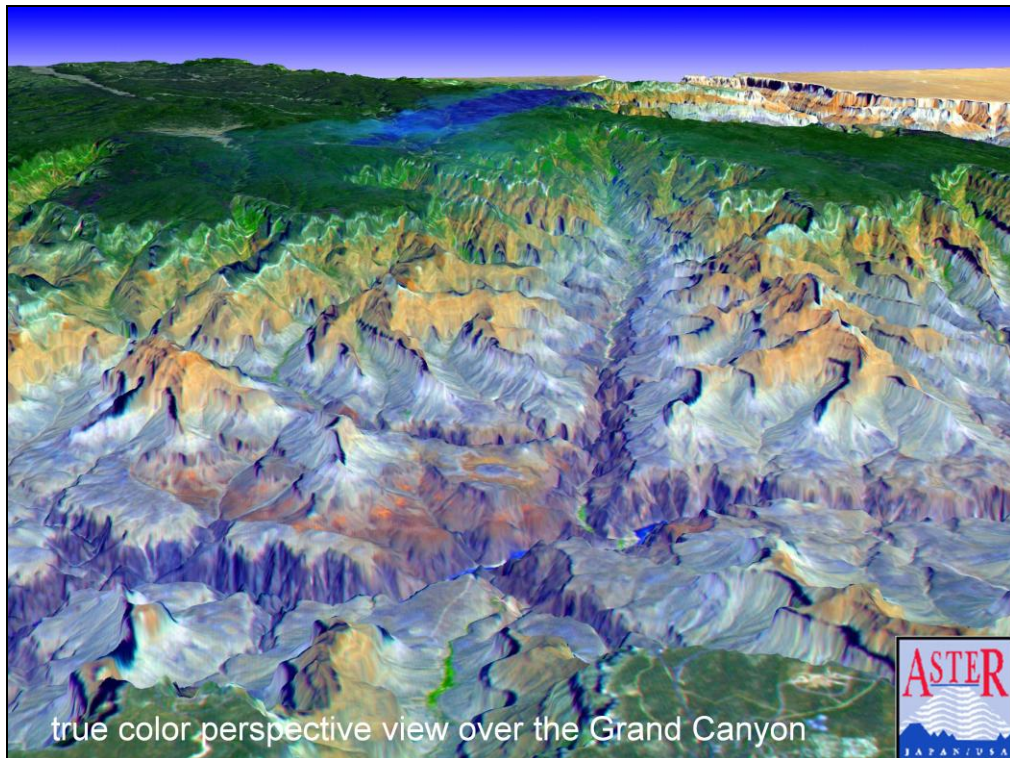
Most of the upper scene lies in Utah but the lowermost areas fall within northern Arizona. Passing through the scene is the Colorado River that, backed up from the Glen Canyon Dam (lower left) near the town of Page, Utah fills the steep-walled canyons to form Lake Powell. The San Juan River joins the Colorado from the east. The prevalent yellow color in this image corresponds mainly to sandstones and some shales that are reds and oranges in nature. The brown tones associate with rocks that are dark reds and browns in the field. Some fields are tinged with reds in the image because vegetation in this IR version. Blues associate with shales that in the field are often grayish. Areas with strong red (IR) tones include the Abajo Peaks (upper right), the Henry Mountains (upper left), and the smaller, isolated Navajo Mountain east of Lake Powell. The northernmost end of the forested Black Mesa appears along bottom center. The cluster of isolated mountains to its north are the collection of mesas and buttes, known as the Hopi Buttes district. Instead of being made from sedimentary rocks, as occurs in Monument Valley to the north, these are actually eroded volcanic necks and diatreme fills.



The Grand Canyon of the Colorado River cuts through the salmon-colored rock of northern Arizona's Colorado Plateau in this westward-looking image made from a combination of observations collected by the Landsat satellite and topographic information collected from National Elevation Dataset (NED). The Little Colorado is flowing in from the east (bottom) across the Painted Desert to join the Colorado River as the big river cuts into the Kaibab Plateau, to the north, and the Coconino Plateau, to the south, both of which are covered in a layer of green vegetation. The multi-colored rock formations that reveal the millions of years of geologic history of the Canyon have been displayed in shades of pink and purple in the image.

Landsat data provided courtesy of the Landsat Project Office, and mosaiced by Ron Hayes. Elevation data obtained from the National Elevation Dataset (NED), a seamless raster product derived primarily from the USGS 30-m Digital Elevation Models (DEMs), along with higher resolution data where available. Visualization by Jesse Allen.

The Grand Canyon is one of North America's most spectacular geologic features. Carved primarily by the Colorado River over the past six million years, the canyon sports vertical drops of 5,000 feet and spans a 277-mile-long stretch of Arizona desert. The strata along the steep walls of the canyon form a record of geologic time from the Paleozoic Era (250 million years ago) to the Precambrian (1.7 billion years ago).

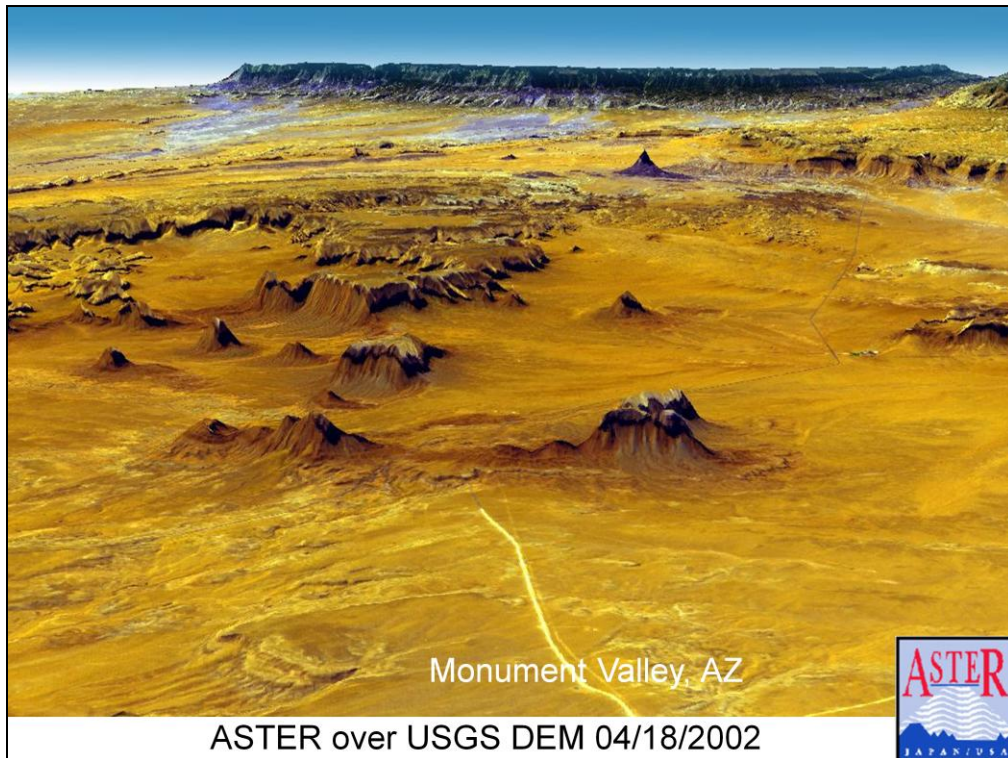


The (right) view was acquired by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument aboard the [Terra](#) spacecraft. Visible and near infrared data were combined to form an image that simulates the natural colors of water and vegetation. Rock colors, however, are not accurate. The image data were combined with elevation data to produce this perspective view, with no vertical exaggeration, looking from above the South Rim up Bright Angel Canyon towards the North Rim. The light lines on the plateau at lower right are the roads around the Canyon View Information Plaza. The Bright Angel Trail, which reaches the Colorado in 7.7 miles, can be seen dropping into the canyon over Plateau Point at bottom center. The blue and black areas on the North Rim indicate a forest fire that was smouldering as the data were acquired on May 12, 2000.

Image courtesy NASA/GSFC/MITI/ERSDAC/JAROS, and U.S./Japan [ASTER Science Team](#) This simulated true color perspective view over the Grand Canyon , looking from South rim up Bright Angel Canyon. It was created from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data acquired on May 12, 2000. The Grand Canyon Village is in the lower foreground; the Bright Angel Trail crosses the Tonto Platform, before dropping down to the Colorado Village and then to the Phantom Ranch (green area across the river). Bright Angel Canyon and the North Rim dominate the view. At the top center of the image the dark blue area with light blue haze is an active forest fire. The image is centered at 36.2 degrees north latitude, 112.2 degrees west longitude.

**Please give credit for these images to:
NASA/GSFC/METI/ERSDAC/JAROS,**

and U.S./Japan ASTER Science Team



Monument Valley provides perhaps the most enduring and definitive images of the American West. The isolated red mesas and buttes surrounded by empty, sandy desert have been filmed and photographed countless times. These beautiful layers of sandstone were formed from deposits of an ancient sea covering much of western USA. The siltstone and shale were deposited here in ancient times and were buried for millennia until, like the rest of the Colorado Plateau, it was uplifted and folded. Eroded by wind and rain, soft red shale undermines the stronger, vertically-jointed sandstone, producing the many buttes and pinnacles. The buttes and pinnacles of Monument Valley were formed ~270 MYA. Cedar Mesa Sandstone. The slopes at their bases are usually composed of Halgaito shale, while many of the spires have cap rocks of red Organ Rock shale, also from the Permian period. This 3-D perspective was created by draping ASTER image data (acquired April 18, 2002) over digital elevation data from the U.S. Geological Survey National Elevation Dataset. The view is centered near 36.8 degrees north latitude, 110.3 degrees west longitude.

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and U.S./Japan ASTER Science Team**

**Remote Sensing of
Metamorphic
Landforms**

Many mountain belts are formed from greenstones (metamorphosed basalt) and ophiolites (deep crustal or mantle rock brought upwards towards/to the surface).

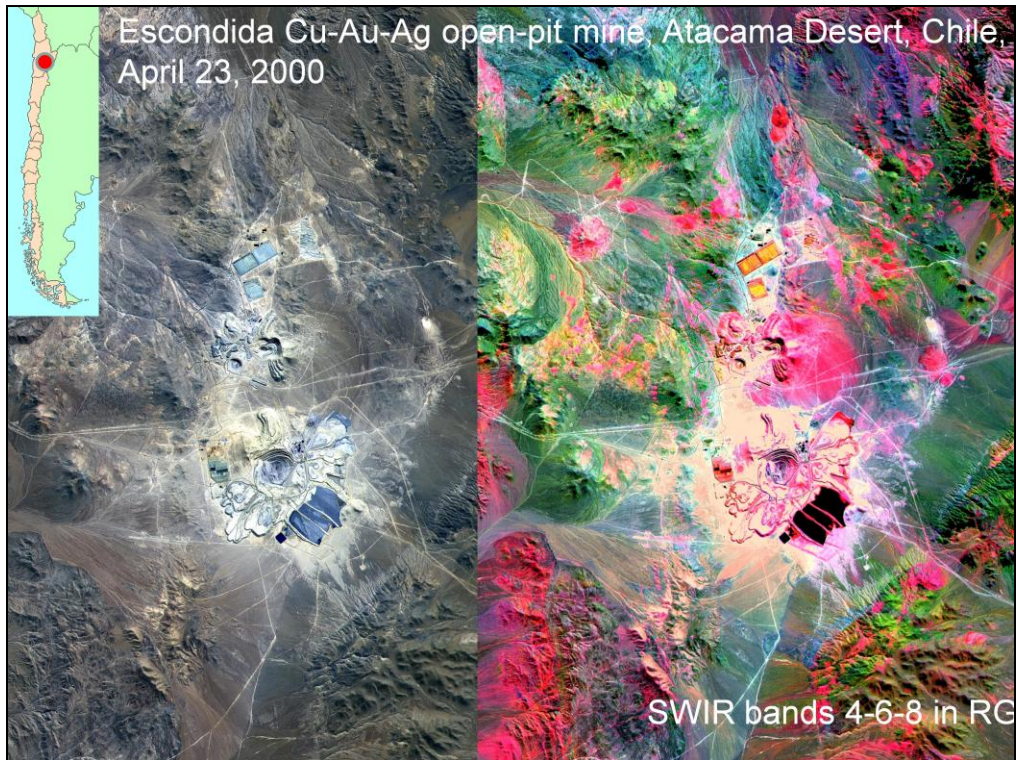


West of Brisbane, Australia: Crust broken and displaced by faults

Metamorphic rocks have originated from previous rocks that have been changed through the processes of *heat, or pressure, or both*. Considerable portions of the surfaces of Australian and New Zealand are covered by this rock type.

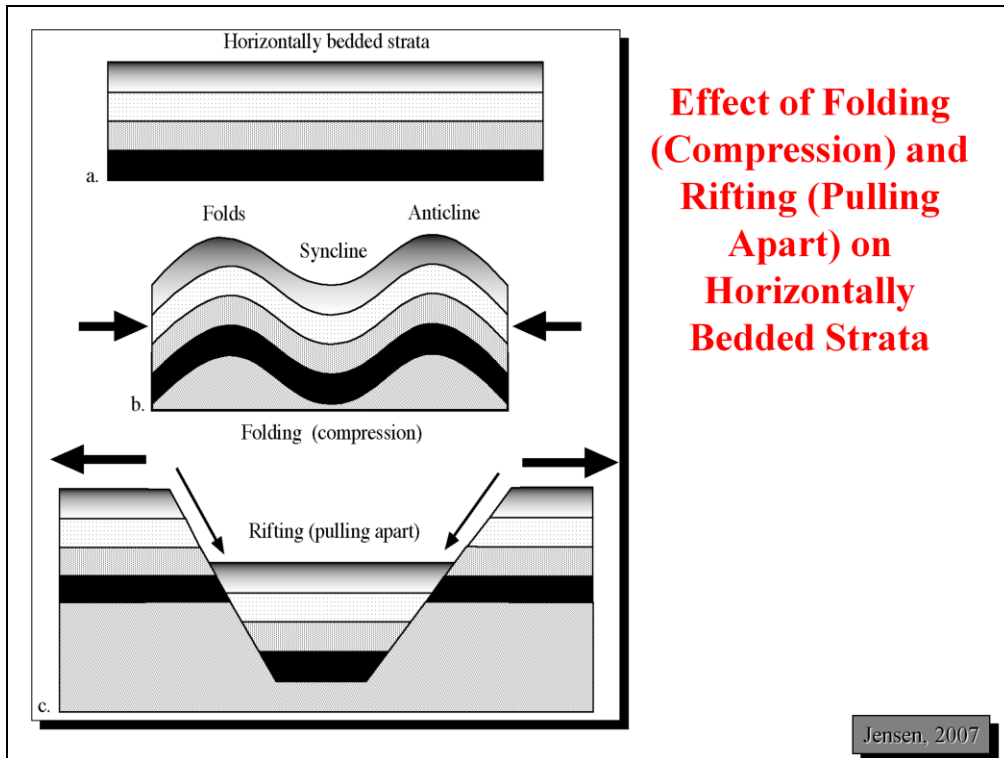
Just west of Brisbane there are clearly visible metamorphic aureoles. In the NZ Alps it is possible to examine a cross-section sequence of metamorphic rocks of different grades.

Large parts of the crust have been broken into blocks and displaced along faults. Two hallmarks of many mountain belts (also called orogenic units) are greenstones (metamorphosed basalt that represents oceanic crust subducted below an overlying crustal block) and ophiolites (deep crustal or mantle rock brought upwards towards/to the surface).



This ASTER image covers 30 by 37 km in the Atacama Desert, Chile and was acquired on April 23, 2000. The Escondida Cu-Au-Ag open-pit mine is at an elevation of 3050 m, and came on stream in 1990. Current capacity is 127,000 tons/day of ore; in 1999 production totaled 827,000 tons of copper, 150,000 ounces of gold and 3.53 million ounces of silver. Primary concentration of the ore is done on-site; the concentrate is then sent to the coast for further processing through a 170 km long pipe. Escondida is related geologically to three SWIR bands 4-6-8 in RGB intruded along the Chilean West Fissure Fault System. A high grade supergene cap overlies primary sulfide ore. The left image is a conventional 3-2-1 RGB composite. The right image displays SWIR bands 4-6-8 in RGB, and highlights lithologic and alteration differences of surface units. The image is located at 24.3 degrees south latitude and 69.1 degrees west longitude.

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and U.S./Japan ASTER Science Team**



Folding occurs when horizontally bedded materials are compressed. The compression results in wavelike undulations imposed on the strata. There are four basic types of folds:

- **monoclines** (a single fold on horizontally bedded material; like a rounded ramp),
- **anticlines** (archlike convex upfold domes - oldest rocks in the center, youngest at the outside),
- **synclines** (troughlike concave downfold - youngest rocks in the center),
- **overturned** (where the folds are on top of one another):

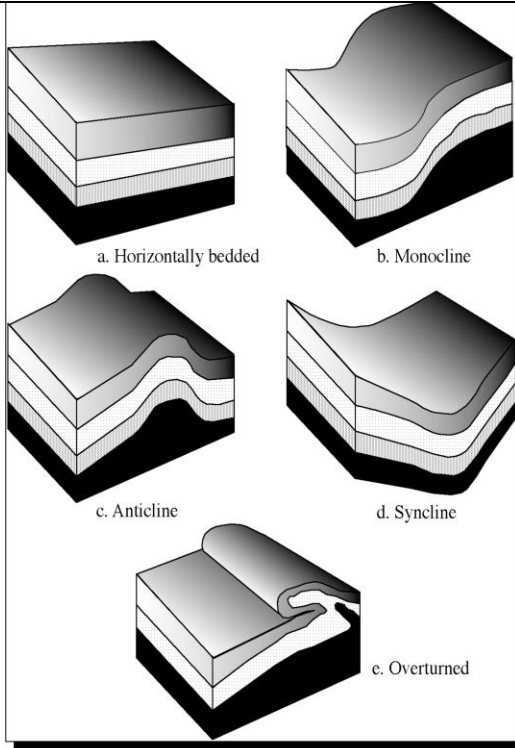
Note on syncline, oldest rocks are on the outside of the fold and youngest rocks near the center

On an anticline, the folding puts the oldest rocks near the center and the youngest on the outside of the fold.

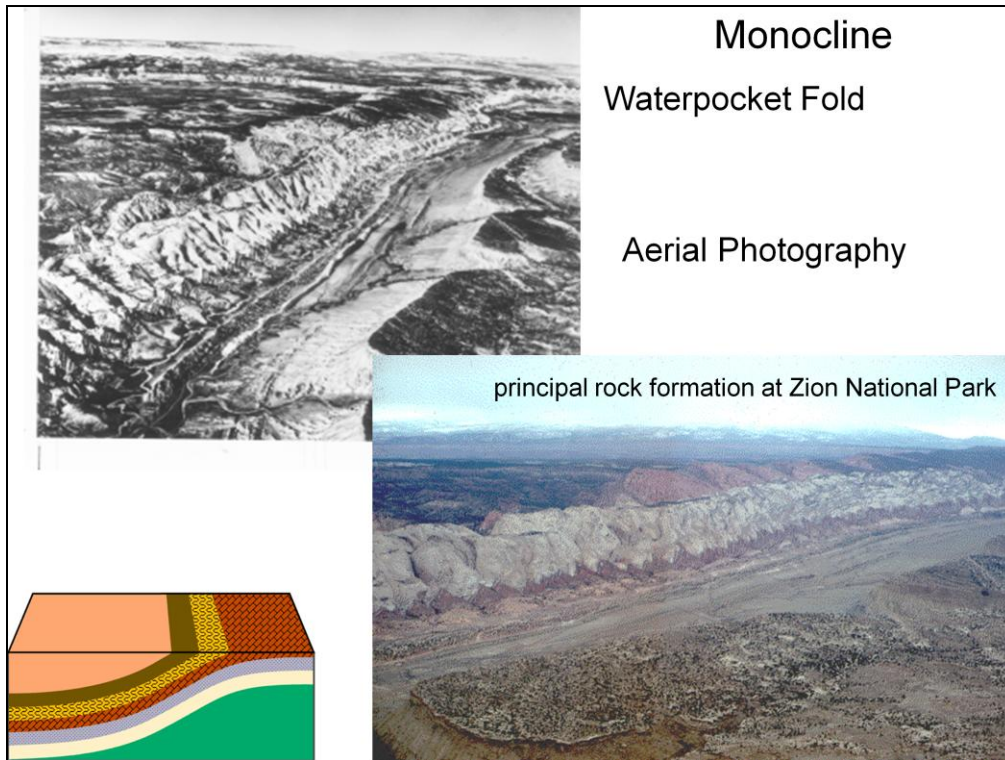
Rifting pulls the beds apart horizontally so the order of deposition remains

the same but the elevational relationship is shifted.

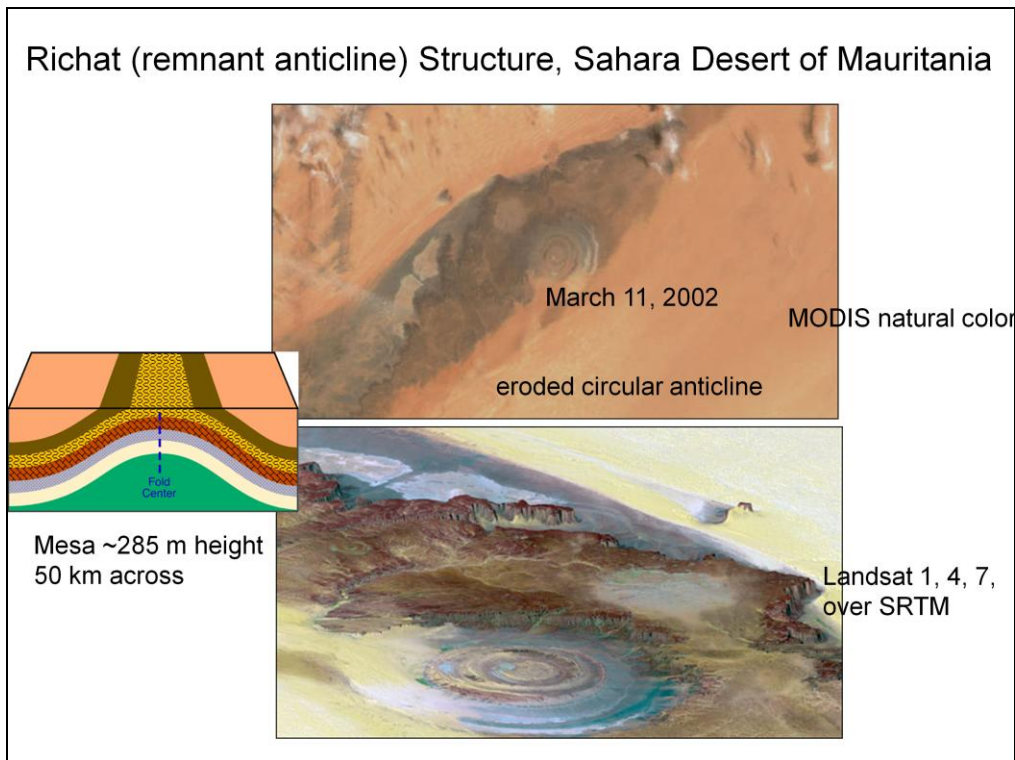
Types of Folds Found on Horizontally Bedded Terrain



Jensen, 2007



This is the situation at the Waterpocket Fold, a monocline which runs across this subscene. A black & white view followed by a color view, both taken looking to the northwest from low-flying airplanes, show a hogback ridge dominated by a whitish unit, the famed Navajo Sandstone (the principal rock formation at Zion National Park) and several other (reddish) units near its base. The thick red unit beyond (west) the Navajo Sandstone is the Wingate Formation. These several units dip at angles as steep as 45 degrees. Younger gently dipping rocks in the foreground (bottom of photo) are part of the lower bench of the Tarantula Mesa whose top (east of the photo) is actually higher in elevation than the fold. We can barely see older rocks below the distant western horizon. These make up the Circle Cliffs.



This prominent circular feature, known as the Richat Structure, in the Sahara desert of Mauritania is often noted by astronauts because it forms a conspicuous 50-kilometer-wide bull's-eye on the otherwise rather featureless expanse of the desert. Initially mistaken for a possible impact crater, it is now known to be an **eroded circular anticline** (structural dome) of layered sedimentary rocks.

This true-color (upper) scene was acquired by the [Moderate-resolution Imaging Spectroradiometer](#) (MODIS), flying aboard NASA's [Terra](#) satellite, on March 11, 2002.

Anticline: convex upward fold with oldest exposed rocks in center.

Extensive sand dunes occur in this region and the interaction of bedrock topography, wind, and moving sand is evident in this scene. Note especially how the dune field ends abruptly short of the cliffs at the far right as wind from the northeast (lower right) apparently funnels around the cliff point, sweeping clean areas near the base of the cliff. Note also the small isolated peak within the dune field. That peak captures some sand on its windward side, but mostly deflects the wind and sand around its sides, creating a sand-barren streak that continues far downwind.

This view was generated from a Landsat satellite image draped over an elevation model produced by the Shuttle Radar Topography Mission (SRTM). The view uses a 6-times vertical exaggeration to greatly enhance topographic expression. For vertical scale, note that the height of the mesa ridge in the back center of the view is about 285 meters tall. Colors of the scene were enhanced by use of a combination of visible and infrared bands, which helps to differentiate bedrock (browns), sand (yellow, some white), minor vegetation in drainage channels (green), and salty sediments (bluish whites). Some shading of the elevation model was included to further highlight the topographic features.

View Size: 68 kilometers (42 miles) wide by 112 kilometers (69 miles) distance

Location: 21.2 degrees North latitude, 11.7 degrees West longitude

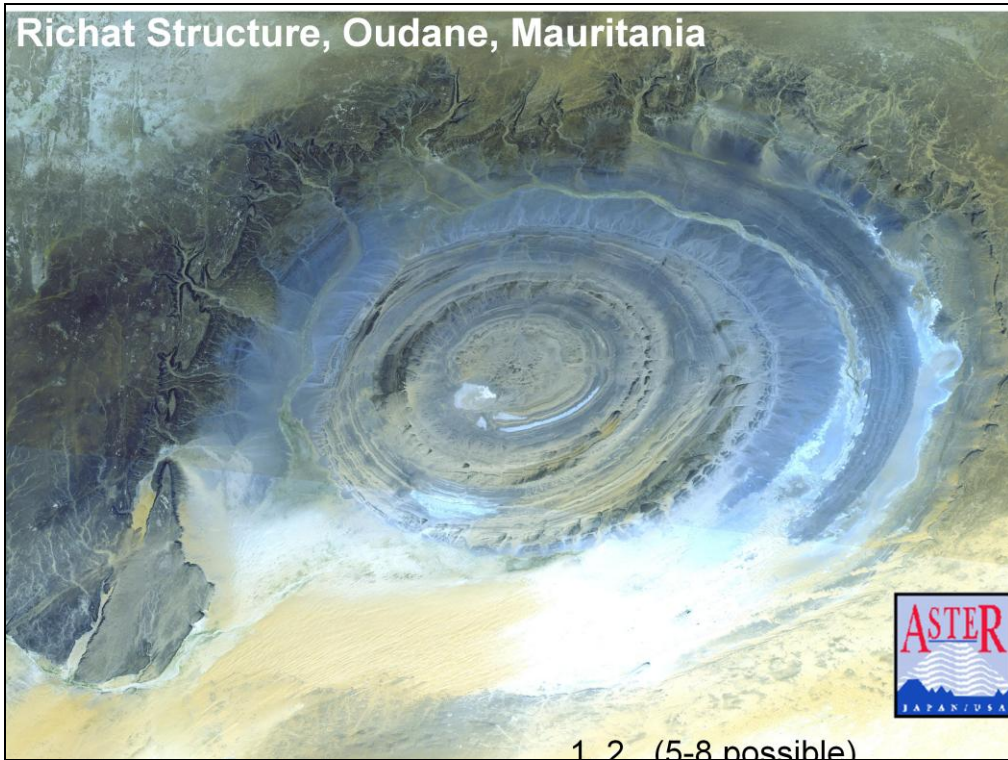
Orientation: View toward west-northwest

Image Data: Landsat Bands 1, 4, 7 in blue, green, red.

Date Acquired: February 2000 (SRTM), January 13, 1987 (Landsat)

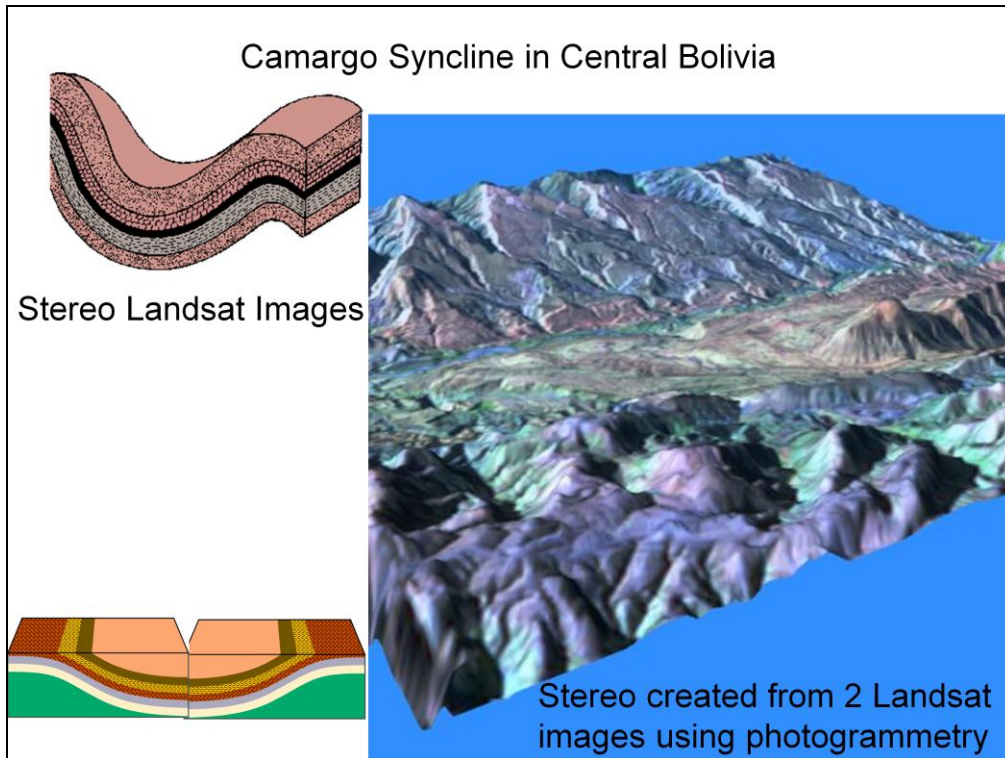
Image Courtesy [SRTM Team](#) NASA/JPL/NIMA

Richat Structure, Oudane, Mauritania



This prominent circular feature in the Sahara desert of Mauritania has attracted attention since the earliest space missions because it forms a conspicuous bull's-eye in the otherwise rather featureless expanse of the desert. Described by some as looking like an outsized ammonite in the desert, the structure [which has a diameter of almost 50 kilometers (30 miles)] has become a landmark for shuttle crews. Initially interpreted as a meteorite impact structure because of its high degree of circularity, it is now thought to be a **symmetrical uplift (circular anticline)** that has been laid bare by erosion. Paleozoic quartzites form the resistant beds outlining the structure. The image was acquired October 7, 2000, covers an area of 45 x 47 km, and is located at 20.9 degrees north latitude and 11.6 degrees west longitude.

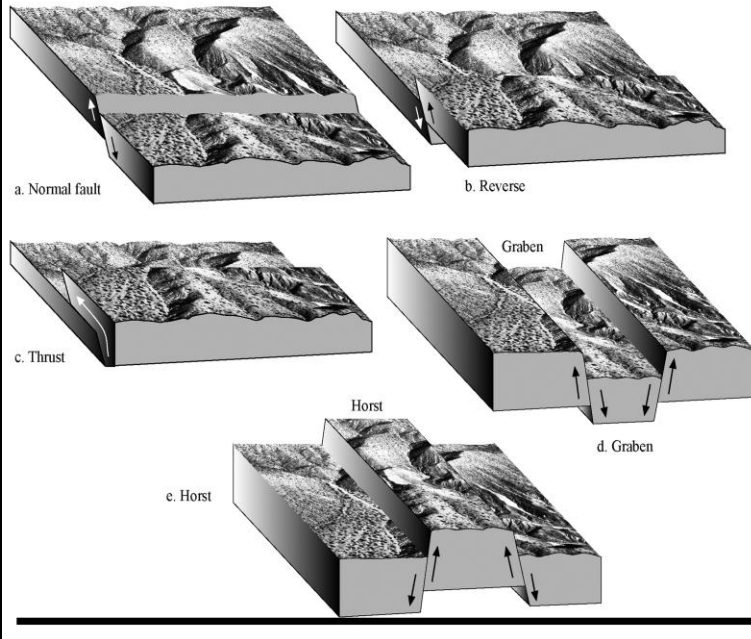
**Please give credit for these images to:
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and U.S./Japan ASTER Science Team**



The Camargo Syncline in central Bolivia. The topographic data for this image was generated by a stereo-matching algorithm developed by Jim Strong (NASA/GSFC Code 932), originally for the Goodyear MPP, then ported to the MasPar MP-1. The algorithm used two Landsat images of the area, which were taken from slightly different angles; it then found matching points in the two images and computed their elevation from the difference in their positions.

**Remote Sensing of
Tectonic
Landforms**

Tectonic landforms originate through land movements

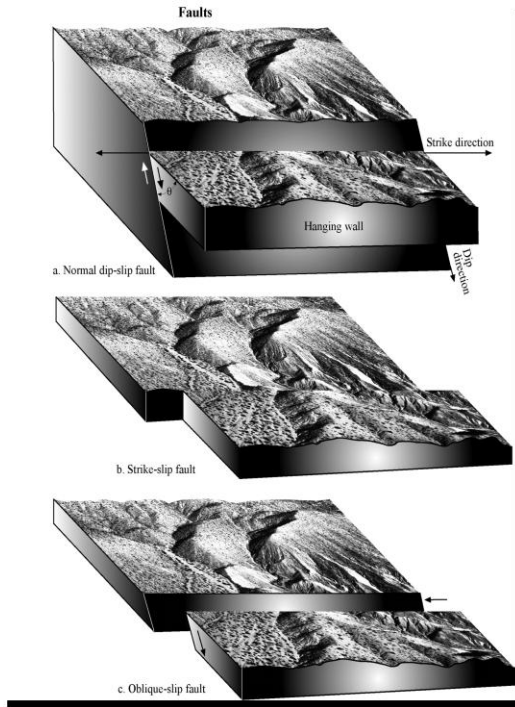


Types of Faults

Jensen, 2007

Landforms from land movements are found widely across areas that are tectonically active - plate movements produce volcanic activity.

Fault Nomenclature



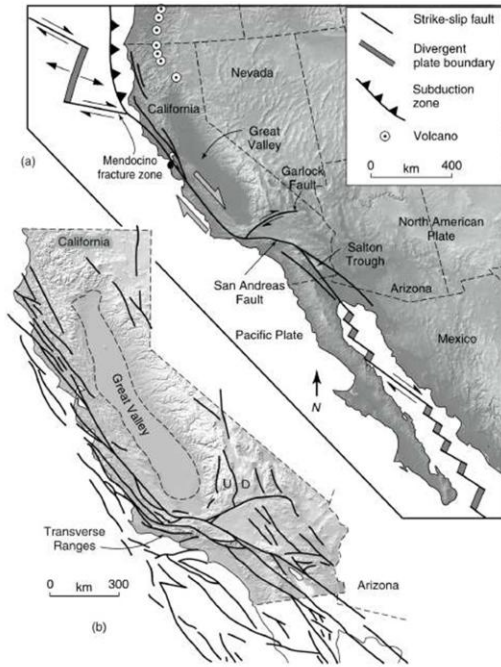
Jensen, 2007

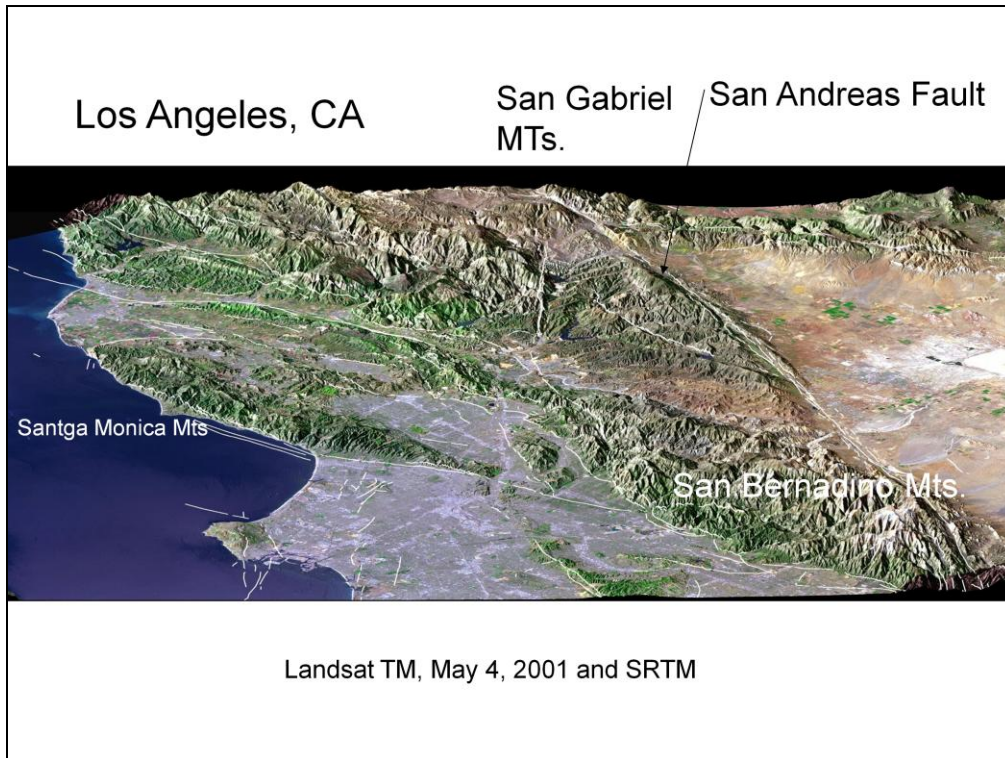
ERTS-1 (Landsat) MSS, 3 Days after Launch 1972



The very first practical use of ERTS-1 (Landsat-1) imagery in any discipline was the drawing by Dr. Paul D. Lowman, Jr. of a geologic structures map superimposed on the first color composite image, based in part on already known field information and in part on his interpretation of this scene. He is a geologist at Goddard Space Flight Center, and an expert on space photography. The image was of the central California coast around Monterey Bay, acquired 3 days after launch. This map confirmed predictions from his studies of astronauts' photos that Landsat would be an efficient tool for recognizing faults and other known structural trends in small-scale imagery. In spite of lower resolutions, these images excel in portraying regional geologic settings and are easily enhanced by digital processing.

Geologic Liniments (linear features)





Los Angeles, Calif., is one of the world's largest metropolitan areas with a population of about 15 million people. The urban areas mostly cover the coastal plains and lie within the inland valleys. The intervening and adjacent mountains are generally too rugged for much urban development. This is in large part because the mountains are "young," meaning they are still building (and eroding) in this seismically active (earthquake prone) region.

Earthquake faults commonly lie between the mountains and the lowlands. The San Andreas fault, the largest fault in California, likewise divides the very rugged San Gabriel Mountains from the low-relief Mojave Desert, thus forming a straight topographic boundary between the top center and lower right corner of the image. We present this perspective image from NASA's Shuttle Radar Topography Mission (SRTM) with a graphic overlay that maps faults that have been active in Late Quaternary times (white lines). The fault database was provided by the U.S. Geological Survey.

The Landsat image used here was acquired on May 4, 2001, about seven weeks before the summer solstice, so natural terrain shading is not particularly strong. It is also not especially apparent given a view direction (northwest) nearly parallel to the sun illumination (shadows generally fall on the backsides of mountains). Consequently, topographic shading derived from the SRTM elevation model was added to the Landsat image, with a false sun illumination from the left (southwest). This synthetic shading enhances the appearance of the topography.

Size: View width 134 kilometers (83 miles); view distance 150 kilometers (93 miles)

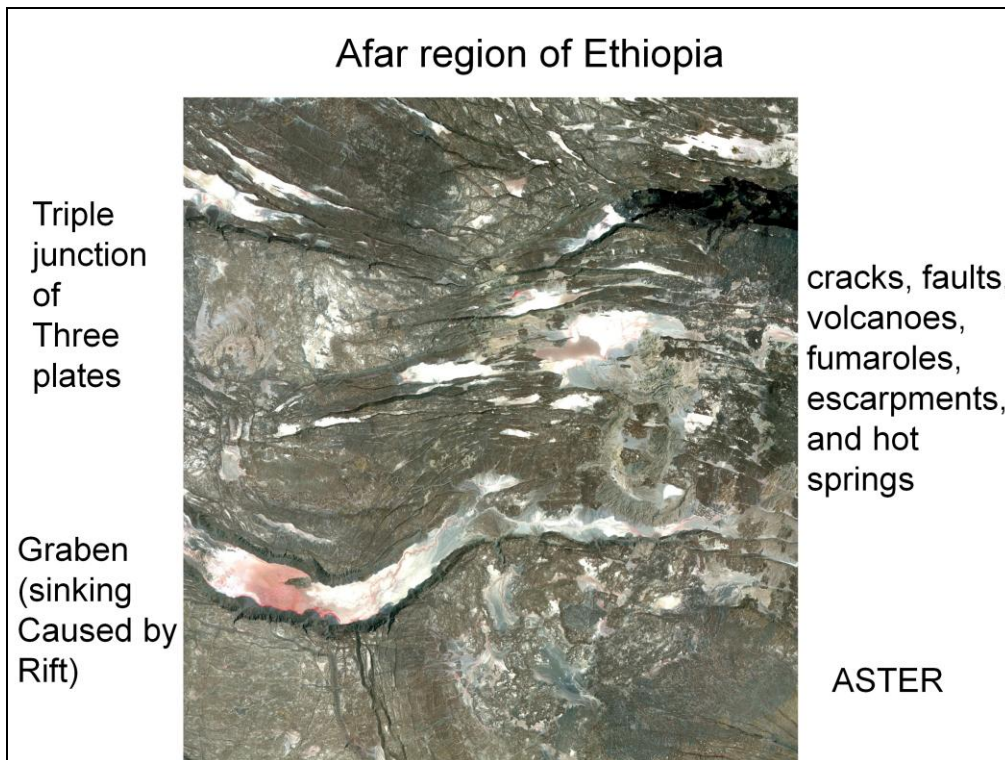
Location: 34.3 degrees North latitude, 118.4 degrees West longitude

Orientation: View west-northwest, 1.8 X vertical exaggeration

Image Data: Landsat Bands 3, 2+4, 1 as red, green, blue, respectively

Original Data Resolution: SRTM 1 arcsecond (30 meters or 98 feet), Landsat 30 meters (98 feet)

Graphic Data: Earthquake faults active in Late Quaternary times Date Acquired: February 2000 (SRTM), May 4, 2001 (Landsat).



In eastern Africa, in the Afar region of Ethiopia, a nearly barren rockscape marks the location of the meeting place of three separate pieces of the Earth's crust. This meeting place is known to geologists as the Afar Triple Junction; the central meeting place for the three pieces of Earth's crust is around Lake Abbe, just to the south of the area shown in this image from the Advanced Spaceborne Thermal Emission and Reflection Radiometer ([ASTER](#)) on NASA's [Terra](#) satellite. The three pieces of Earth's crust are each pulling away from that central point, though not all at the same speed.

The pulling apart creates enormous stress on the rock, producing cracks, faults, volcanoes, fumaroles (gas vents), escarpments, and hot springs in the region along the border of Ethiopia, Eritrea, and Djibouti. In this image, the gray-brown, ancient, basalt rock of the region is crisscrossed by cracks both small and large, many of which are filled with salt and sand, though in this infrared-enhanced satellite image, the tinge of red indicates some hardy vegetation eking out a living in the harsh terrain. The large river-like feature running horizontally across the scene is actually a geologic feature called a "graben," a gulley created not by erosion of a river but by the sinking of the ground when earth on either side pulls apart.

Besides its unusual geology, the Afar region is famous for its fossils. On November 24, 1974, a team of American paleoanthropologists led by Donald Johanson discovered a fossil hominid of a young adult female only a meter tall. While the team examined the find, the Beatles song *Lucy in the Sky with Diamonds* played on the radio, and the team decided unanimously to call the fossil "Lucy." Years later, she got her formal scientific designation: *Australopithecus afarensis*. Radiometric dating of underlying volcanic rocks placed Lucy's age at 3.2 million years old.

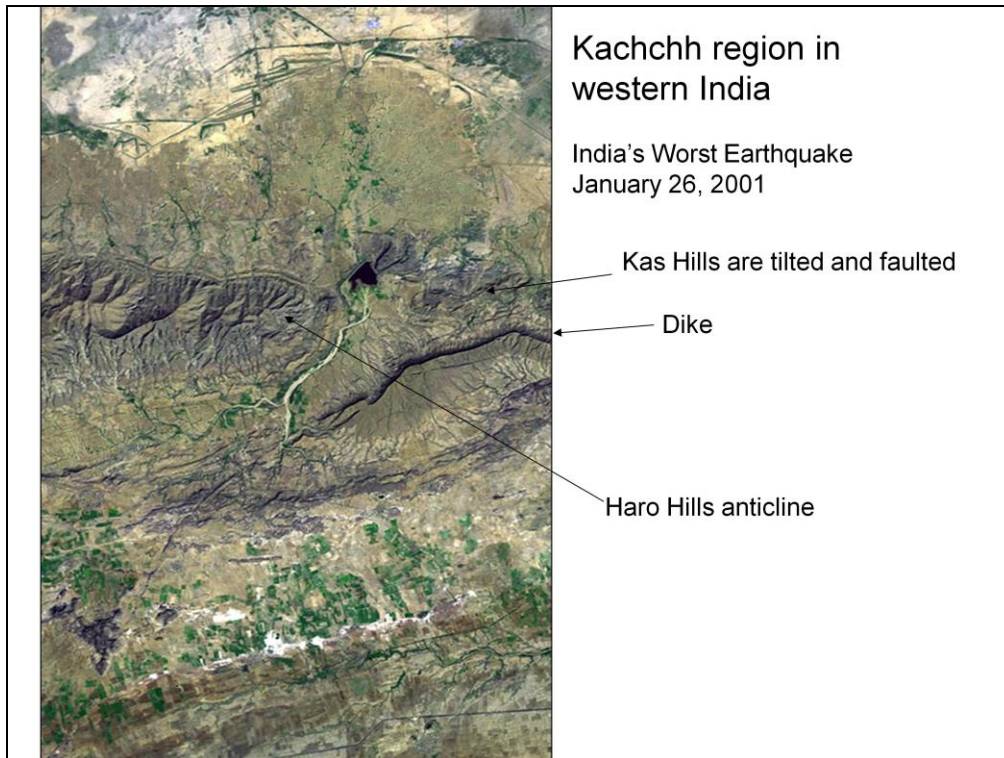
Further Reading:

[Happy Birthday, Lucy!](#)

Lucy in the [flesh](#) by paleoartist [John Gurche](#).

[The Afar Depression](#)

Image courtesy NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan [ASTER Science Team](#)



On January 26, 2001, the Kachchh region in western India suffered the most deadly earthquake in India's history. This stereoscopic view of landforms northeast of the city of Bhuj depicts geologic structures that are of interest in the study of the tectonic processes that may have led to that earthquake. However, preliminary field studies indicate that these structures are composed of Mesozoic rocks that are overlain by younger rocks showing little deformation. Thus these structures may be old, not actively growing, and not directly related to the recent earthquake.

The Haro Hills are on the left and the Kas Hills are on the right. The **Haro Hills are an "anticline,"** which is an upwardly convex elongated fold of layered rocks. The anticline is distinctly ringed by an erosion resistant layer of sandstone. The east-west orientation of the anticline may relate to the crustal compression that has occurred during India's northward movement toward, and collision with, Asia. In contrast, the largest of the **Kas Hills appears to be a tilted (to the south) and faulted** (on the north) block of layered rocks. Also seen here, the curvilinear ridge trending toward the southwest from the image center is an erosion resistant **"dike," which is an igneous intrusion** into older "host" rocks along a fault plane or other crack. The dike also appears to extend northeast from the image center as a dark line having very little topography. Its location between the tilted block and a smaller anticline to the north (directly east of the larger anticline) probably indicates that the dike fills the fault that separates these contrasting geologic structures. These features are simple examples of how digital elevation data can stereoscopically enhance satellite imagery to provide a direct input to geologic studies.

The stereoscopic effect of this [anaglyph](#) was created by first draping a [Landsat](#) satellite image (taken just two weeks after the earthquake) over preliminary digital elevation data from the [Shuttle Radar Topography Mission \(SRTM\)](#), and then generating two differing perspectives, one for each eye. When viewed through special glasses, the result is a vertically exaggerated view of the Earth's surface in its full three dimensions. Anaglyph glasses cover the left eye with a red filter and cover the right eye with a blue filter.

Elevation data used in this image was acquired by the Shuttle Radar Topography Mission (SRTM) aboard the Space Shuttle Endeavour, launched on February 11, 2000.

Size: 22.3 x 14.3 kilometers (13.8 x 8.9 miles)

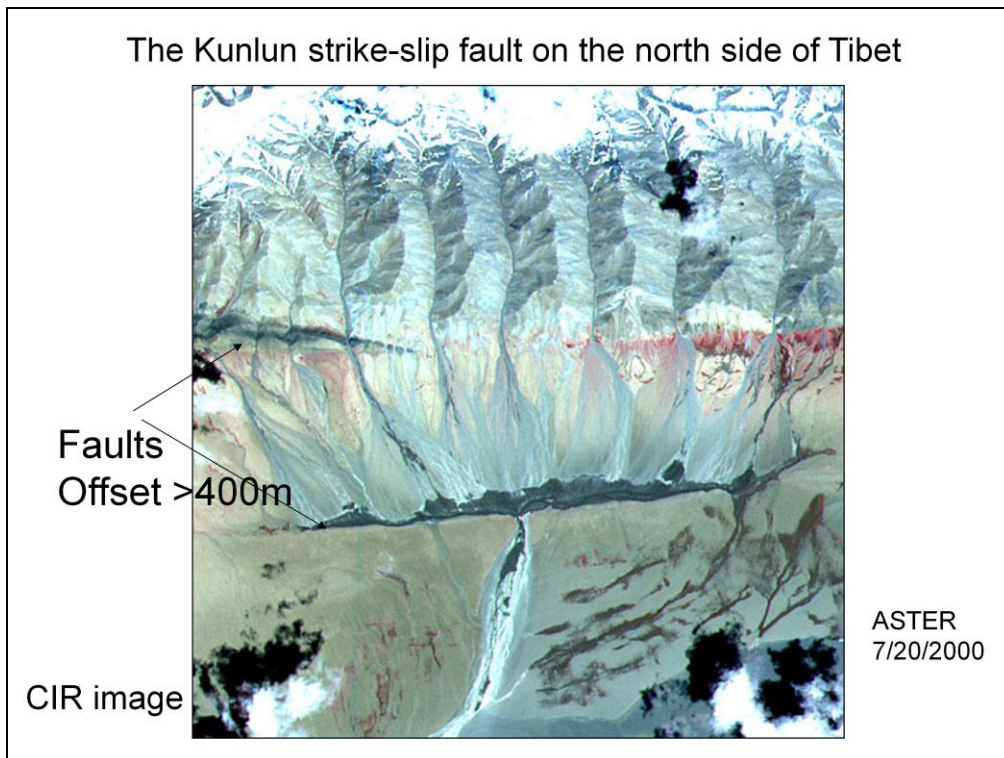
Location: 23.4 deg. North lat., 69.8 deg. East lon.

Orientation: North toward the top Image

Data: Landsat Bands 1, 2+4, 3 as blue, green, red, respectively Date

Acquired: February 2000 (SRTM), February 9, 2001 (Landsat)

Image courtesy SRTM and Landsat science teams.



The Kunlun fault is one of the gigantic strike-slip faults that bound the north side of Tibet. Left-lateral motion along the 1,500-kilometer length of the Kunlun has occurred uniformly for the last 40,000 years at a rate of 1.1 centimeter per year, creating a cumulative offset of more than 400 meters. In this image, two splays of the fault are clearly seen crossing from east to west. The northern fault juxtaposes sedimentary rocks of the mountains against alluvial fans. Its trace is also marked by lines of vegetation, which appear red in the image. The southern, younger fault cuts through the alluvium. A dark linear area in the center of the image is wet ground where groundwater has ponded against the fault. Measurements from the image of displacements of young streams that cross the fault show 15 to 75 meters of left-lateral offset. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) acquired the visible light and near infrared scene on July 20, 2000.

Image courtesy NASA/GSFC/MITI/ERSDAC/JAROS, and the [U.S./Japan ASTER Science Team](#)

Umnak Island Volcano, Aleutian Islands, Alaska



Landsat TM + AirSAR data

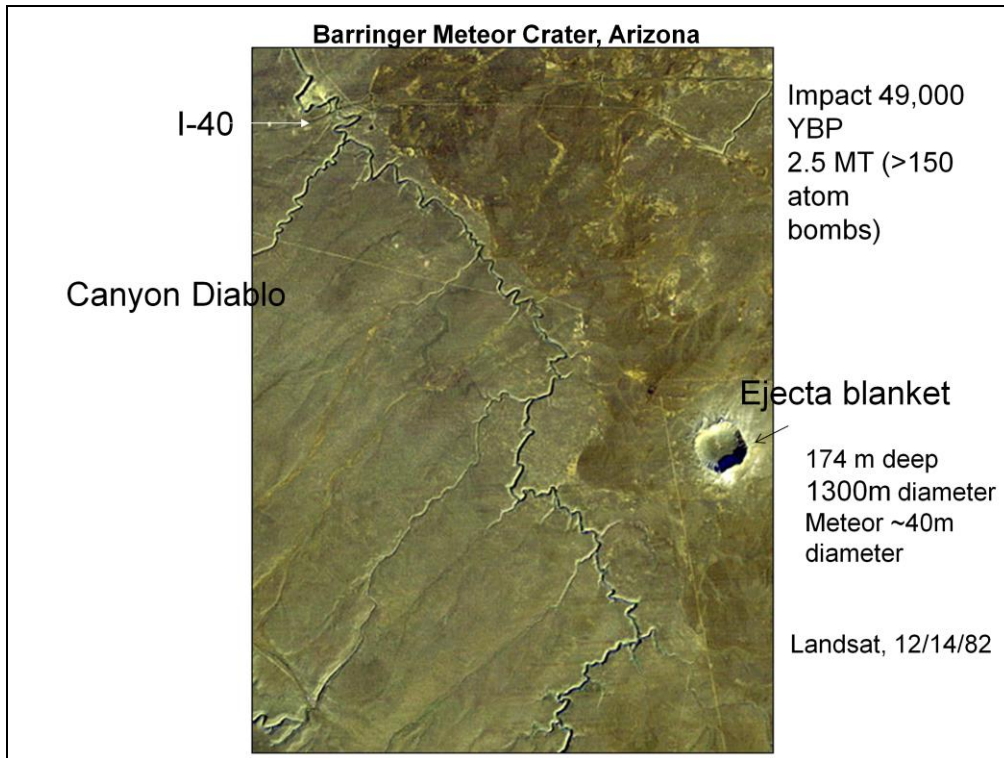
This image is a perspective view of Umnak Island, one of Alaska's Aleutian Islands. The active Okmok volcano appears in the center of the island.

The image was created by draping a Landsat 7 Thematic Mapper image over a digital elevation mosaic derived from Airsar data.

This work was conducted as part of a NASA-funded Alaska Digital Elevation Model Project at the Alaska Synthetic Aperture Radar Facility (ASF) at the University of Alaska Geophysical Institute in Fairbanks, Alaska.

Airsar collected the Alaska data as part of its PacRim 2000 Mission, which took the instrument to French Polynesia, American and Western Samoa, Fiji, New Zealand, Australia, New Guinea, Indonesia, Malaysia, Cambodia, Philippines, Taiwan, South Korea, Japan, Northern Marianas, Guam, Palau, Hawaii and Alaska. Airsar, part of NASA's Airborne Science Program, is managed for NASA's Earth Science Enterprise by JPL. JPL is a division of the California Institute of Technology in Pasadena.

**Remote Sensing of
Impact Crater
Landforms**



The 174m-deep depression is probably the most famous, visible space impact site on the planet. It is certainly the most studied, and was the first terrestrial crater identified as a meteorite impact scar.

Barringer Crater, also known as “Meteor Crater,” is a 1,300-meter diameter, 174-meter deep hole in the flat-lying desert sandstones 30 kilometers west of Winslow, Arizona. Since the 1890s geologic studies here played a leading role in developing an understanding of impact processes on the Earth, the moon and elsewhere in the solar system. This view was acquired by the Landsat 4 satellite on December 14, 1982. It shows the crater much as a lunar crater might appear through a telescope. Morning sun illumination is from the southeast (lower right). The prominent gully meandering across the scene is known as Canyon Diablo. It drains northward toward the Little Colorado River and eventually to the Grand Canyon. The Interstate 40 highway crosses and nearly parallels the northern edge of the scene. The ejecta blanket around the crater appears somewhat lighter than the surrounding terrain, perhaps in part due to its altered mineralogic content. However, foot traffic at this interesting site may have scarred and lightened the terrain too. Also, the roughened surface here catches the sunlight on the southerly slopes and protects a highly reflective patchy snow cover in shaded northerly slopes, further lightening the terrain as viewed from space on this date.

Image Size: 16.9 km x 12.5 km

Colors: Bands 1 (blue), 2 (green) + 4 (near infrared), (red) in blue, green, and red, respectively.

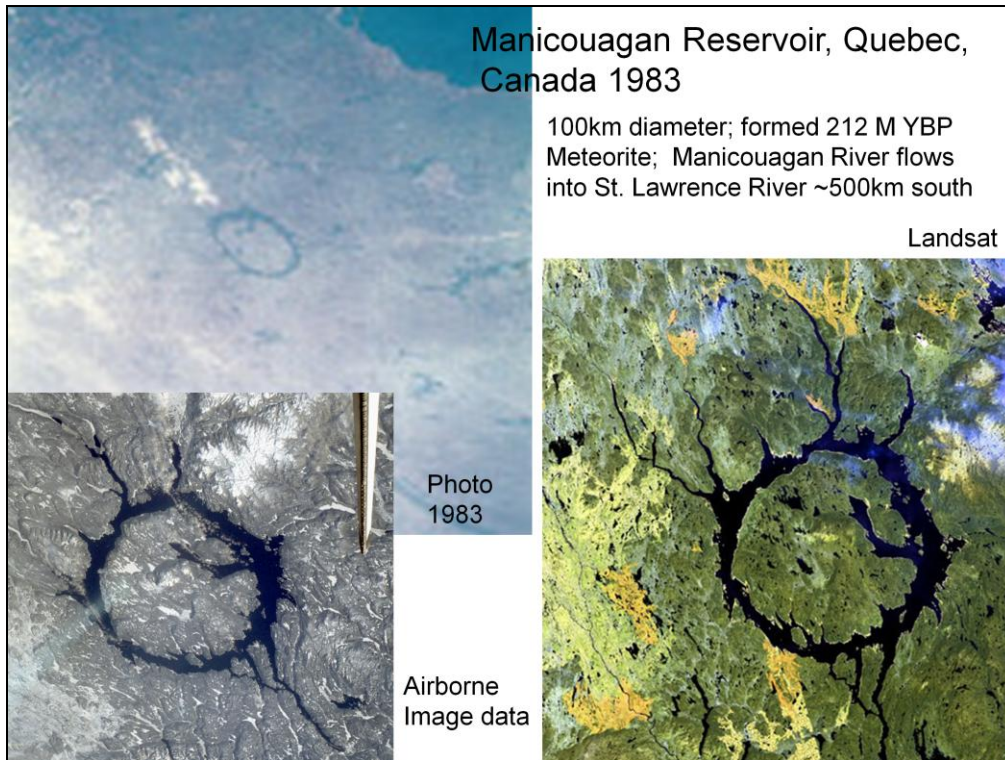
Note: This image was scanned from physical media.

Image courtesy Jet Propulsion Laboratory [Planetary Photojournal](#)

The iron mass that smashed into Arizona some 49,000 years ago to create Meteor Crater was just the crumbled remains of a far larger rock body. What is more, this shower of debris was moving much slower than researchers had previously thought. Most researchers agree that the iron projectile that collided with the top of the Earth’s atmosphere was about 40m across, and past estimates of the speed at which the mass was traveling when it hit the ground range from 9.4 to 20km/s - with the faster estimates recently considered more likely. It still leads to a violent event, however - releasing the equivalent force of 2.5 Megatonnes of TNT, or more than 150 Hiroshima atom bombs - but even more energy was dissipated in an atmospheric blast.



49,000 years ago, a large meteor created
[Barringer Meteor Crater](#) in Arizona



Manicouagan Reservoir, Canada December 1983

Located in a rugged, heavily timbered area of the Canadian Shield in Quebec Province, Manicouagan Reservoir is impressive in this low-oblique, west-looking photograph (upper left). The reservoir, a large annular lake, marks the site of an impact crater 100 kilometers wide. Formed almost 212 million years ago when a large meteorite hit Earth, the crater has been worn down by many advances and retreats of glaciers and other processes of erosion. The reservoir is drained at its south end by the Manicouagan River, which flows from the reservoir and empties into the Saint Lawrence River nearly 483 kilometers south. Photo courtesy of NASA

Cretaceous-Tertiary Boundary Impact Crater

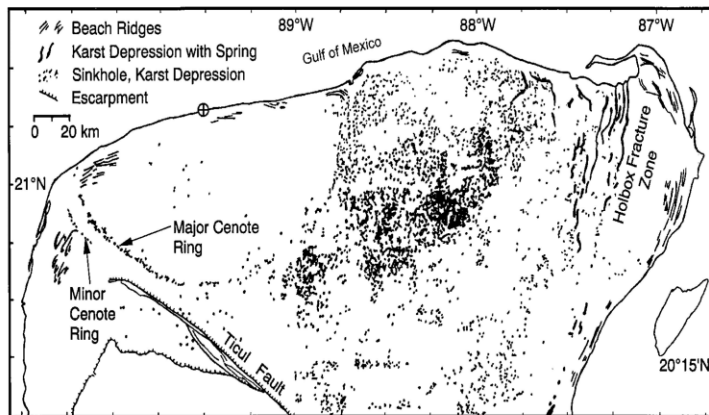
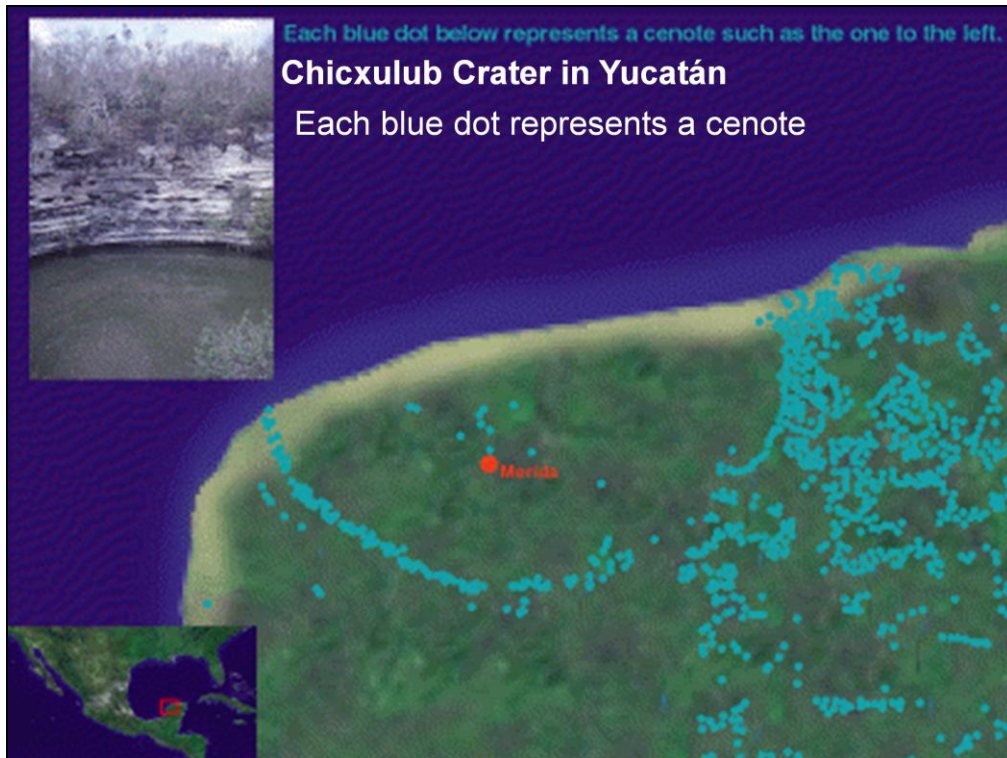


Figure 1. Geomorphology of northern Yucatán Peninsula. Distribution of beach ridges and springs (Holbox fracture zone only) based on photo interpretation of Landsat TM and SIR-C/X-SAR spaceborne imagery. Distribution of sinkholes and karst depressions from Hildebrand et al. (1994) with slight modification from SIR-C/X-SAR imagery (minor Cenote ring and Holbox fracture zone). Linear features between escarpments of Ticul fault are ridges of unknown origin. Cross marks center of major Cenote ring and inferred center of crater (Pope et al., 1993).

Kevin Pope, *Geology* 1996



end of the Cretaceous era (135-65 myr) Cretaceous-Tertiary boundary impact caused the environmental changes that led to dinosaurs becoming extinct.

Aorounga Impact Crater, Chad



Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR)

April 18 and 19, 1994 red is L-band HH; green is C-band HH; and blue is C-band, HV

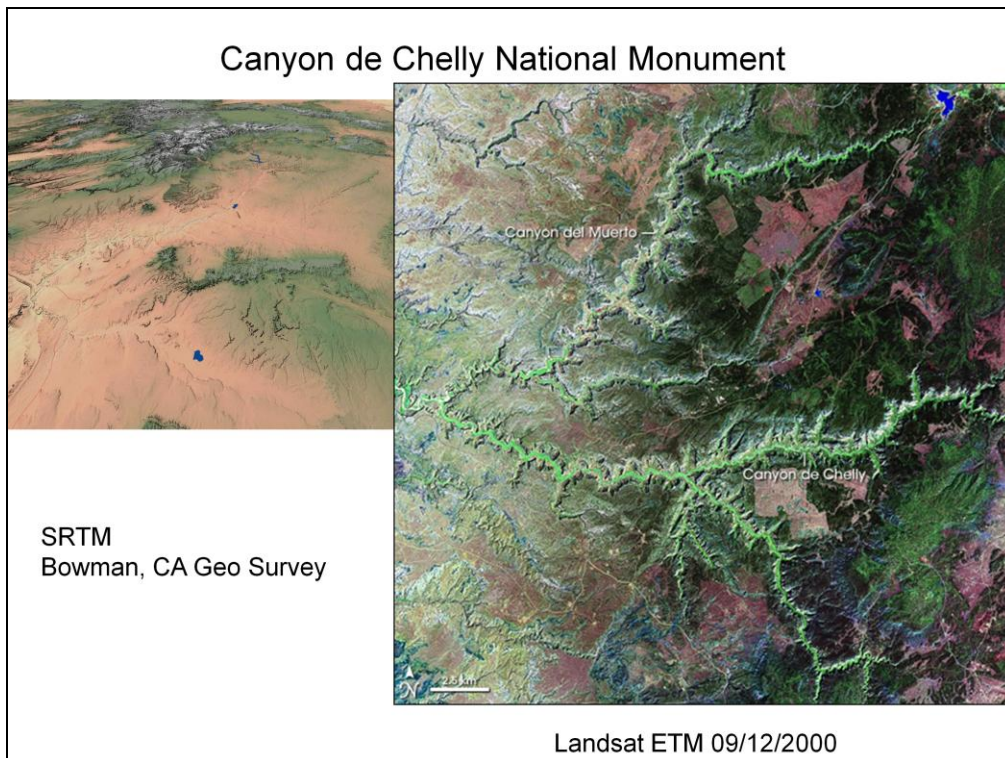
Aorounga Impact Crater, Chad

Photo ID: P-46712

March 20, 1996

The impact of an asteroid or comet several hundred million years ago left scars in the landscape that are still visible in this spaceborne radar image of an area in the Sahara Desert of northern Chad. The concentric ring structure is the Aorounga impact crater, with a diameter of about 17 kilometers (10.5 miles). The original crater was buried by sediments, which were then partially eroded to reveal the current ring-like appearance. The dark streaks are deposits of windblown sand that migrate along valleys cut by thousands of years of wind erosion. The dark band in the upper right of the image is a portion of a proposed second crater. Radar images are used to investigate the possibility that Aorounga is one of a string of impact craters formed by multiple impacts. Radar imaging is a valuable tool for the study of desert regions because the radar waves can penetrate thin layers of dry sand to reveal details of geologic structure that are invisible to other sensors. The image was acquired by the Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) on April 18 and 19, 1994, onboard the space shuttle Endeavour. The area shown is 22 kilometers by 28 kilometers (14 miles by 17 miles) and is centered at 19.1 degrees north latitude, 19.3 degrees east longitude. North is toward the upper right. The colors are assigned to different radar frequencies and polarizations as follows: red is L-band, horizontally transmitted and received; green is C-band, horizontally transmitted and received; and blue is C-band, horizontally transmitted, vertically received. SIR-C/X-SAR, a joint mission of the German, Italian and United States space agencies, is part of NASA's Mission to Planet Earth program.

Remote Sensing of Fluvial Landforms

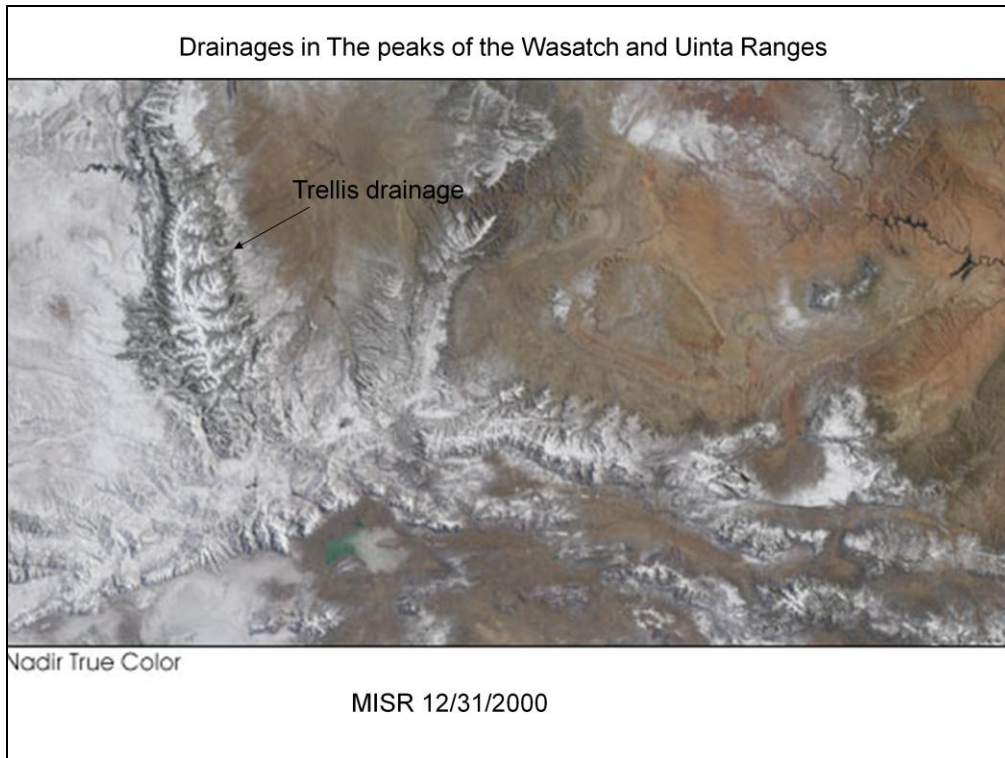


Canyon de Chelly National Monument was created in 1931 to protect the cultural heritage of the canyon lands of Arizona. The monument is unique in the U.S. National Park system because it lies entirely on Navajo Tribal Trust Land. Members of the Navajo Nation still live in the rugged, harsh, and beautiful landscape, which is located in the Four Corners region of the American Southwest. The monument, located in northeastern Arizona right near the border with New Mexico, is managed jointly by the National Park Service and the Navajo Nation.

This false-color image (right) was created using data obtained by Landsat 7's Enhanced Thematic Mapper Plus (ETM+) instrument on September 12, 2000. In this image, healthy vegetation shows up as verdant green, filling the floors of the canyons. The patchwork of deep greens and deep pinks above the canyons is a mixture of forested hillsides and open grazing lands on Defiance Plateau. The small, brilliant blue patch at the top of Canyon del Muerto is Tsaile Lake, which supplies the nearby town of Tsaile with water. The monument extends down the canyon below this lake, encompassing Canyon del Muerto to the point where it joins Canyon de Chelly, Canyon de Chelly itself, and the small canyons that feed into each of these two larger canyons. The plateau area above the canyon rims is Tribal Trust Land outside the monument's boundaries.

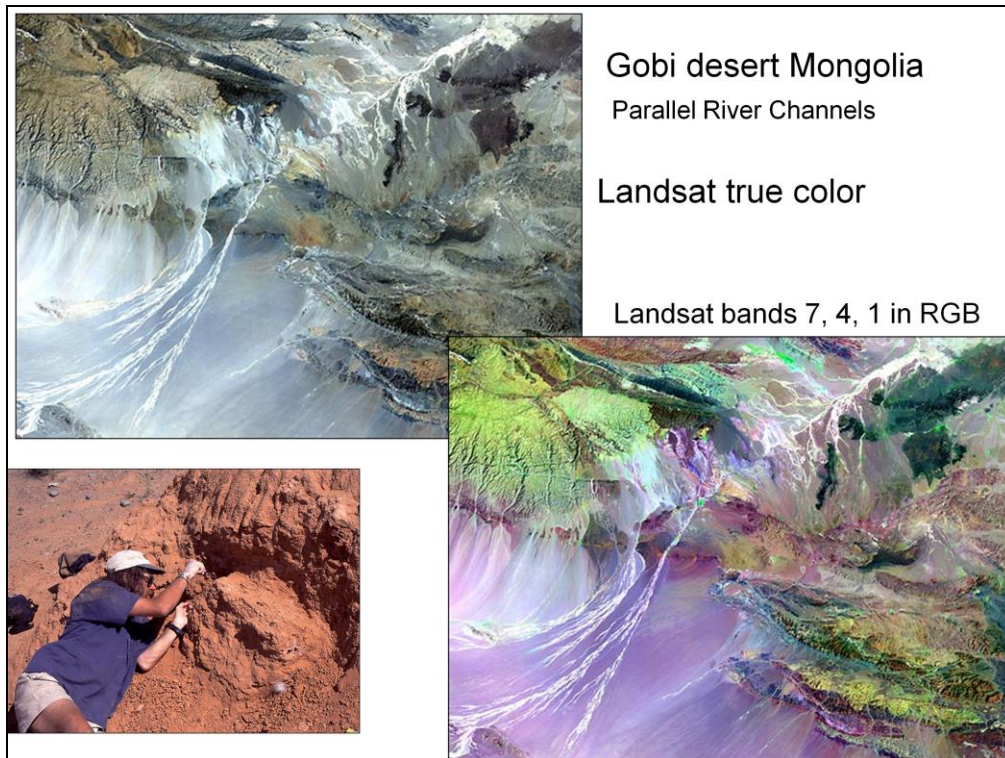
According to the National Park Service Website on [Canyon de Chelly](#), the area is one of the oldest continuously inhabited regions of North America. The first evidence of human habitation in the area dates from around A.D. 300, and it has been almost continuously occupied since. The most dramatic of the archaeological remains in the area come from the [Anasazi](#), whose buildings were tucked under overhangs in the canyons. The Navajo arrived in the area around 1600 and became semi-nomadic farmers. The canyon lands provided shelter from their enemies as well as a suitable place in the valleys to raise crops and tend sheep, which they still do in the valley floor to this day. The ruins and living communities in the monument are its main attractions, though the scenery is also stunning. Visitors are able to explore the tops of the canyons on their own, but because of the cultural sensitivity of the land (both past and present), visitors must have a local guide to enter the depths of the actual canyons.

NASA image created by Laura Rocchio, Landsat Project Science Office.



The peaks of the Wasatch and Uinta Ranges provide spectacular backdrops for the 2002 Winter Olympics, to be held in Salt Lake City, Utah. The mountains surrounding Salt Lake City are renowned for the dry, powdery snow that results from the arid climate and location at the western edge of the Rocky Mountains and eastern rim of the Great Basin.

This early-winter image was acquired by the Multi-angle Imaging SpectroRadiometer (MISR) on December 31, 2000. The image is a natural-color view from MISR's nadir (downward-looking) camera.



Gobi desert Mongolia

Parallel River Channels

Landsat true color

Landsat bands 7, 4, 1 in RGB

This image uses Landsat band 7 (shortwave infrared) for red, band 4 (near infrared) for green, and band 1 (blue) for blue. Vegetation and different types of rock and soil stand out clearly in this image, enabling fossil hunters to find likely fossil sites. (Images by Barbara Summey, NASA GSFC Visualization Analysis Lab, based on Landsat 5 data provided by the Laboratory for Terrestrial Physics)

This true color Landsat 5 image of the Gobi desert covers an area between Ukhaa Tolgod and the Flaming Cliffs, two of Mongolia's most famous fossil sites. Landsat data are more accurate than existing maps of the region, so they are extremely helpful in the search for fossils. Unfortunately, there is no simple combination of bands that will immediately pinpoint the fossil sites in the Gobi. Novacek explains that the best they can do is combine blue, near-infrared, and thermal radiation bands on the images of the desert. Together these bands show the rock formations of the Gobi in the most detail. "We then look for the outcrops types of rock formations will yield fossils and how to spot them on an image. Though there are no hard and fast rules for identifying fossil-bearing rocks with the right features and contours," he says. After years of dealing with the geology of the Gobi, Novacek and his team have developed a sense for what outcrops have fossils, he explains they are usually found at the base of the larger mountains that run through the Gobi. These outcrops also contain layers of sedimentary rock, and they are well-weathered, low-lying, and sparsely vegetated. All of these aspects can be detected in the satellite images. So far, Novacek says they have had some success using these Landsat images. Last year, in fact, they tracked down one such site northeast of Ukhaa Tolgod and visited it on their yearly campaign. While it was nothing like Ukhaa Tolgod, he says they did find a few well-preserved, fossilized mammal skulls as well as some partial fossils of dinosaurs. The find gives him confidence that in the future the maps will be useful in tracking down both new sites as well as confirming sites shown on the questionable older maps of the Gobi. "And more than anything they will save us many days of driving across the desert," he says. **References**

Loope, D. B., L. Dingus, C. C. Swisher, and C. Minjin, 1998: Life and death in a late Cretaceous dune field, Nemegt Basin, Mongolia, *Geology*, 26(1), pp. 27-30. Norell, M. A., J. M. Clark, L. M. Chiappe, and D. Dashzeveg, 1995: A Nesting Dinosaur, *Nature*, 378, 21/28 December, pp. 774-776. Webster, D., 1997: Dinosaurs of the Gobi: Unearthing a fossil trove, *National Geographic*, July 1996, pp. 73-89. **Links**

[The American Museum of Natural History . A Layered Past](#)

China's Songhua River flows north out of the Changbai Mountains and cuts across the Manchurian Plain



ASTER 04/01/2002

Northeastern China's Songhua River flows northward out of the Changbai Mountains and cuts across the Manchurian Plain before emptying into the Amur River, which separates northeastern China from Russia's Far East. As China's northernmost river system, the Songhua is an important artery for transporting agricultural products grown on the plain. On its way, the river flows past Harbin, the capital of China's Heilongjiang Province, where it is the source of drinking water for several million people. In November 2005, the city faced a water crisis when an explosion at a chemical factory spilled toxic levels of benzene into the Songhua. In late December, the spill reached the Russian city of Khabarovsk.

This image from the Advanced Spaceborne Thermal Emission and Reflection Radiometer ([ASTER](#)) on NASA's [Terra](#) satellite shows the Songhua River just downstream (east) of the city of Harbin on April 1, 2002. The mainstem of the river and its myriad channels appear deep blue, winding from bottom left toward center right. To the west of the river, shallow lakes appear electric blue. The surrounding landscape reveals the Manchurian Plain in shades of brown, crossed by pale lines (roads) and spots (villages and towns).

The extreme flatness of the Manchurian Plain has caused the river to meander widely over time. The result of the meandering is that the river is surrounded by a wide plain that is filled with swirls and curves, showing paths the river once took. The plain includes classic features of meandering rivers, such as ox-bow lakes—semi-circular lakes formed when a meander (a wide bend in the river) is cut off from the main channel by river-deposited sediment. Meandering rivers shift their positions across the valley bottom by depositing sediment on the inside of bends while simultaneously eroding the outer banks of the meander bends.

The high-resolution image covers an area of 31.9 kilometers by 41.0 kilometers, and is centered near 45.4 degrees North latitude, 126.9 degrees East longitude.

Image courtesy NASA/GSFC/METI/ERSDAC/JAROS, and the U.S./Japan ASTER Science Team

Brahmaputra River (braided)

Located between the Tibetan Plateau to the north and the Himalaya Mountains to the south; about 35km south of Lhasa



Space Shuttle Photograph

On October 13, 2000, the Expedition 3 crew of the International Space Station, high over Tibet, took this interesting photo of the Brahmaputra River. This mighty Asian river carves a narrow west-east valley between the Tibetan Plateau to the north and the Himalaya Mountains to the south, as it rushes eastward for more than 1500 km in southwestern China. This 15-km stretch is situated about 35 km south of the ancient Tibetan capital of Lhasa where the river flow becomes intricately braided as it works and reworks its way through extensive deposits of erosional material. This pattern is indicative of a combination heavy sediment discharge from tributaries and reduction of the river's flow from either a change in gradient or perhaps even climate conditions over the watershed.

The light color of the deposits and the milky color of the water is attributed to presence of glacial "flour," the fine material created by erosion from glaciers. Besides erosion by water and ice, this scene also depicts features created by wind. Note the delicate field of dunes on the alluvial fan toward the right edge of the image. The riverbed here is at an elevation of over 3,500 m, and with the long west-east extent of this barren valley, strong, persistent westerly winds also move and shape these deposits. Photos such as this one bring immediate visual understanding and appreciation of natural processes in some of the most remote locations on Earth.

Image [ISS003-E-6632](#), was provided by the [Earth Sciences and Image Analysis Laboratory](#) at Johnson Space Center. Additional images taken by astronauts and cosmonauts can be viewed at the NASA-JSC [Gateway to Astronaut Photography of Earth](#).

Remote Sensing of Delta Landforms

Ural River empties into the northern coast of the Caspian Sea

High
sediment
deposition,
Low wave
erosion



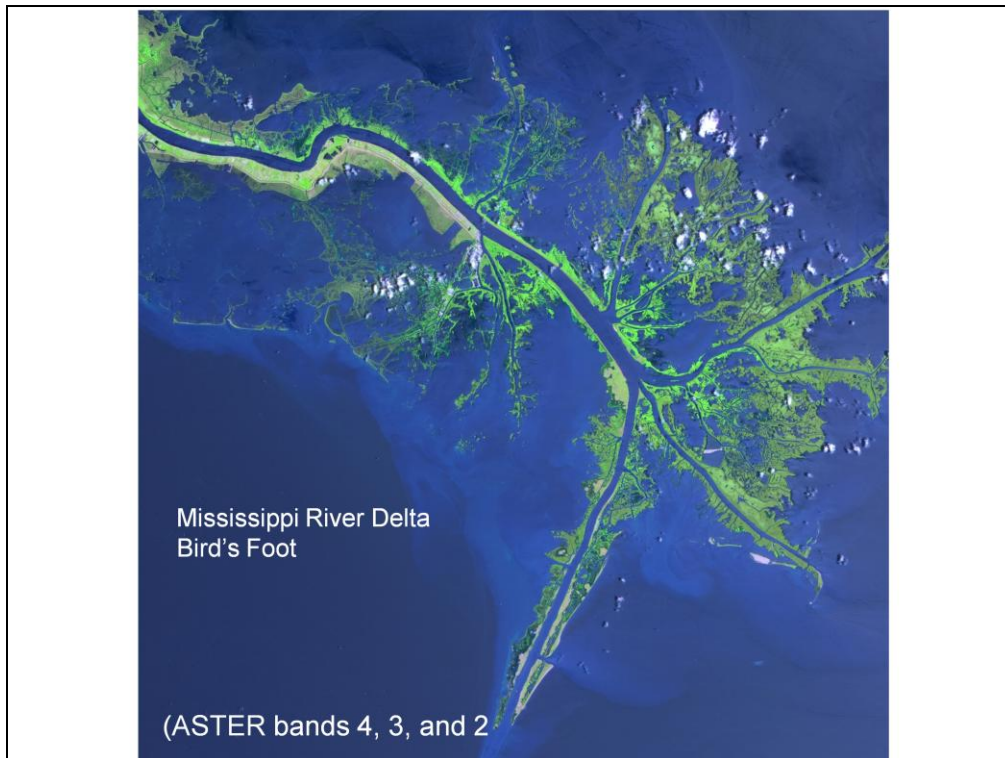
Astronaut photograph

The Ural River is one of the two major rivers (the other is the Volga) that empty into the northern coast of the Caspian Sea, creating extensive wetlands. This image shows details of the Ural's tree-like (or "digitate") delta. This type of delta forms naturally when wave action is low, and sediment content in the river is high. New distributary channels form in the delta when the river breaches natural levees formed by sediment deposition. The long main channel of the river in this image and several of the distributary channels are too regular to be entirely natural, however. Like the famous Mississippi River delta in the United States, the Ural River delta has been significantly modified to reduce flooding and divert water.

The dark regions running along the coast are the wetlands, which support high biodiversity due to the unique environment and relative isolation of the Caspian Sea. The coastal wetlands are especially important to migrating birds as an important stop-over along the Asian flyway.

The Ural River's trek to the Caspian is long —roughly 2,400 kilometers (1,500 miles) southward from the Ural Mountains in Russia to empty into the northern Caspian Sea in Kazakhstan. Although the current sea level of the Caspian is more than 26 meters below global mean sea level, the water levels have risen roughly 2 meters since 1980. This increase has caused flooding of much of the coastal region, including the Ural Delta, and it endangers these coastal wetland environments. The coastal flooding has also impacted the oil exploration infrastructure bordering the Caspian coastline.

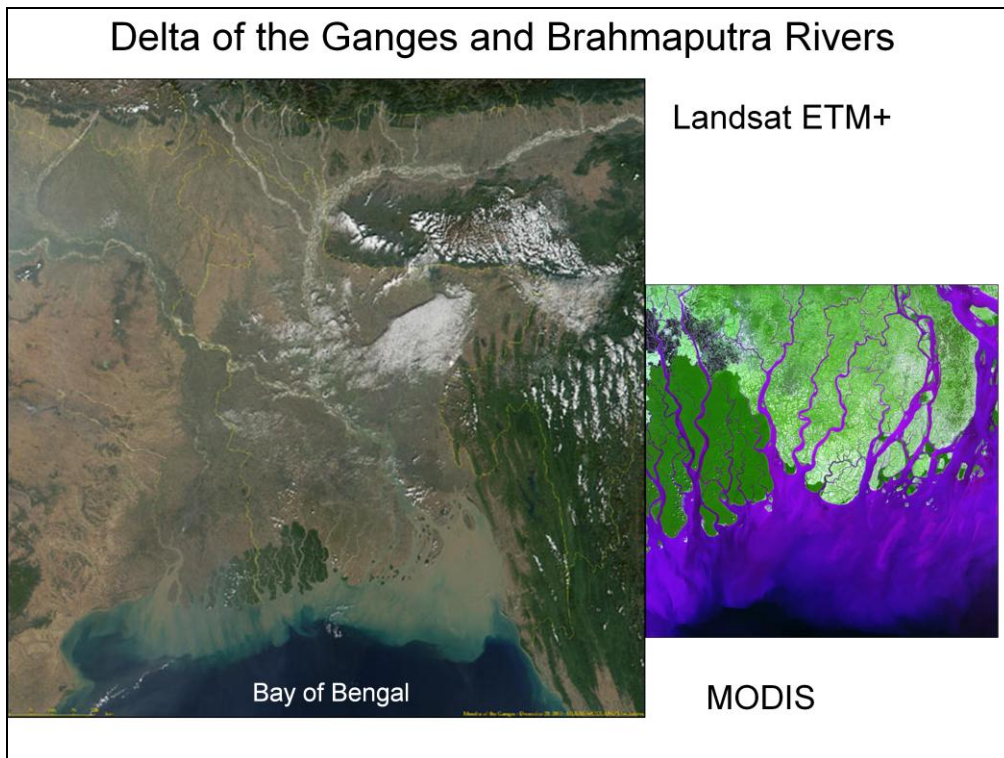
Astronaut photograph [ISS009-E-18679](#) was acquired August 17, 2004 with a Kodak 760C digital camera with an 400 mm lens. The image is provided by the ISS Crew Earth Observations experiment and the Image Science & Analysis Group at the Johnson Space Center. The [International Space Station Program](#) supports the laboratory to help astronauts take pictures of Earth that will be of the greatest value to scientists and the public, and to make those images freely available on the Internet. Additional images taken by astronauts and cosmonauts can be viewed at the NASA/JSC [Gateway to Astronaut Photography of Earth](#).



Turbid waters spill out into the Gulf of Mexico where their suspended sediment is deposited to form the Mississippi River Delta. Like the webbing on a duck's foot, marshes and mudflats prevail between the shipping channels that have been cut into the delta.

This scene was acquired by the ASTER instrument on NASA's Terra satellite on May 24, 2001. This false-color composite was created by combining shortwave infrared, infrared, and near-infrared wavelengths (ASTER bands 4, 3, and 2).

Image provided by the [USGS EROS Data Center](https://eros.usgs.gov/) Satellite Systems Branch as part of the Earth as Art II image series



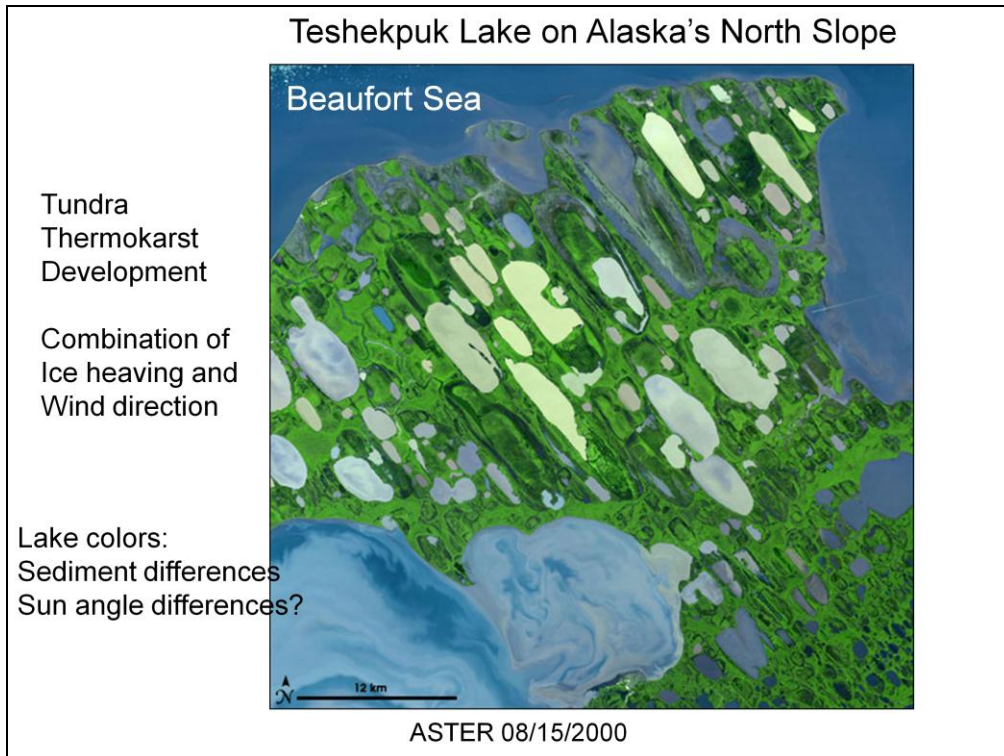
The combined delta of the Ganges and Brahmaputra Rivers is the largest in the world. This true-color image from the [Moderate-resolution Imaging Spectroradiometer](#) (MODIS) shows both the delta and sediment flowing into the Bay of Bengal. Fed by monsoon rains and Himalayan snowmelt, the rivers often flood. These floods often cause catastrophic damage, but also enrich the soil.

The Ganges River forms an extensive delta where it empties into the Bay of Bengal. The delta is largely covered with a swamp forest known as the Sunderbans, which is home to the Royal Bengal Tiger. It is also home to most of Bangladesh, one of the world's most densely populated countries. Roughly 120 million people live on the Ganges Delta under threat of repeated catastrophic floods due to heavy runoff of meltwater from the Himalayas, and due to the intense rainfall during the monsoon season.

This image was acquired by [Landsat 7's](#) Enhanced Thematic Mapper plus (ETM+) sensor on February 28, 2000. This is a false-color composite image made using green, infrared, and blue wavelengths.

Image provided by the [USGS EROS Data Center](#) Satellite Systems Branch

Remote Sensing of Glacial Landforms

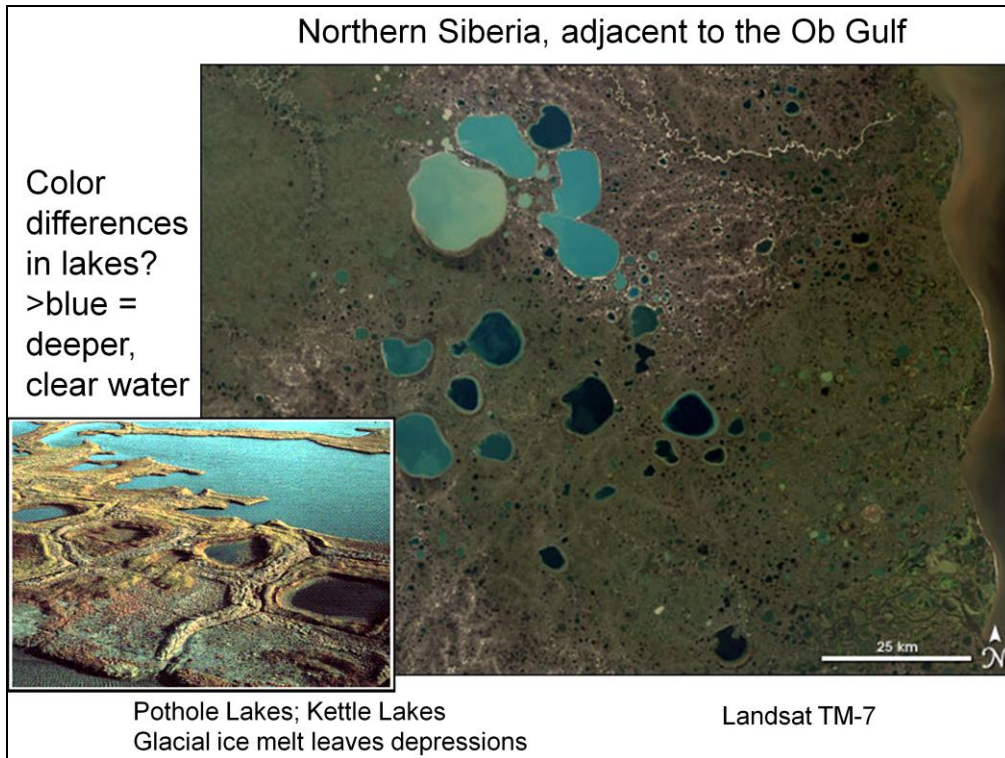


On January 11, 2006, the U.S. Department of the Interior (DOI) approved oil and gas drilling on approximately 500,000 acres of land in and around Teshkepuk Lake on Alaska's North Slope within the National Petroleum Reserve. Up to 90,000 geese nest in this area in the summertime, and up to 46,000 caribou use the area for both calving and migration. Some environmental groups contested the DOI decision to allow drilling. The DOI decision stipulated that no surface drilling would be allowed on land considered crucial for molting geese or caribou, and a maximum of 2,100 acres in seven different zones could be permanently disturbed on the surface.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer ([ASTER](#)) on NASA's [Terra](#) satellite took this picture on August 15, 2000. In this image, green indicates vegetation and blue indicates water. Some bodies of water also appear in off-white or yellowish, probably due to different amounts of sediment in the water and/or the sun angle. The Beaufort Sea is at the top of the scene, while Teshkepuk Lake is at lower left. The land here is a lacy, lake-dotted expanse of tundra.

The large image covers an area of 58.7 by 89.9 kilometers, and is centered near 70.4 degrees North latitude, 153 degrees West longitude.

Image courtesy NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team



When the Pleistocene Ice Age reached its peak around 22,000 years ago, continent-spanning glaciers covered large sections of North America and Eurasia like a sheet. As the Ice Age waned, the glaciers retreated. Occasionally large chunks of ice broke off from the glacier and became surrounded or even buried by soil and rock debris deposited by the melting ice sheet. Eventually, the blocks of ice also melted, leaving behind a depression in the ground. These depressions are called kettles; when they are filled with water, they are called kettle lakes, or pothole lakes.

This natural-color Landsat 7 image shows blue and green pothole lakes in northern Siberia, adjacent to the Ob Gulf. The different colors of the lakes reflect different amounts of sediment or depth; the deeper or clearer the water, the bluer the lake. The arctic tundra in this area is permafrost: the top levels of the soil melt and warm in the summer, but the ground below is frozen solid year round. Rivers cut only shallowly into the hard, frozen ground, and they meander across the image like golden threads (upper right and lower left). The landscape is dominated by spongy peat bog, covered in shallow-growing vegetation such as moss that can survive the harsh winters.

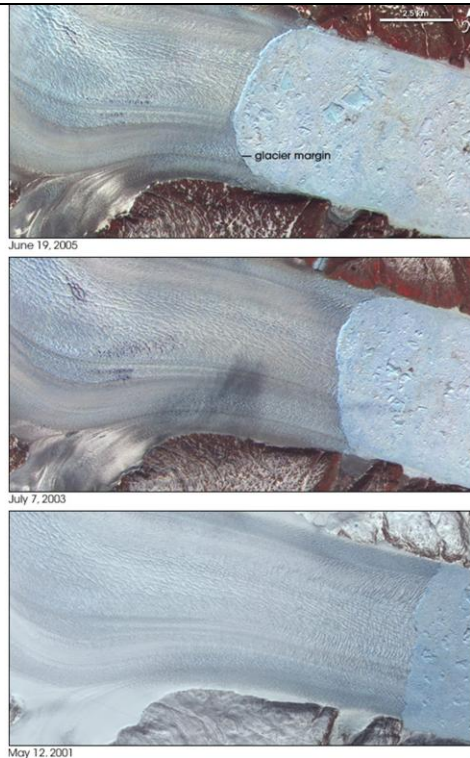
Pothole lakes dot the landscape of the Northern Hemisphere in the American and Canadian prairies, the Russian steppes, and throughout northern Siberia. Scientists use satellite images of these glacial kettle lakes to [measure water clarity](#) and to make environmental assessments. These lakes are far from agricultural land and settled areas, so they have fairly clear and unpolluted waters. Scientists also monitor these lakes to study climate change. Researchers reported in *Science* that some glacial kettle lakes in northern Siberia [have drained](#) over the past 30 years as the region has warmed and the permafrost beneath the lakes has “cracked,” allowing lake water to drain out.

NASA image created by Jesse Allen, Earth Observatory, using data obtained courtesy of the University of Maryland’s [Global Land Cover Facility](#).

Glacial Retreat Rate of retreat

Helheim glacier (outlet from
Greenland Ice Sheet)

June 2005 (top),
July 2003 (middle),
and May 2001 (bottom).



Along the margin of the Greenland Ice Sheet, outlet glaciers flow as icy rivers through narrow fjords and out to sea. As long as the thickness of the glacier and the depth of the water allow the ice to remain grounded, it stays intact. Where the ice becomes too thin or the water too deep, the edge floats and rapidly crumbles into icebergs. Satellite observations of eastern Greenland's Helheim Glacier show that the position of the iceberg's calving front, or margin, has undergone rapid and dramatic change since 2001, and the glacier's flow to the sea has sped up as well.

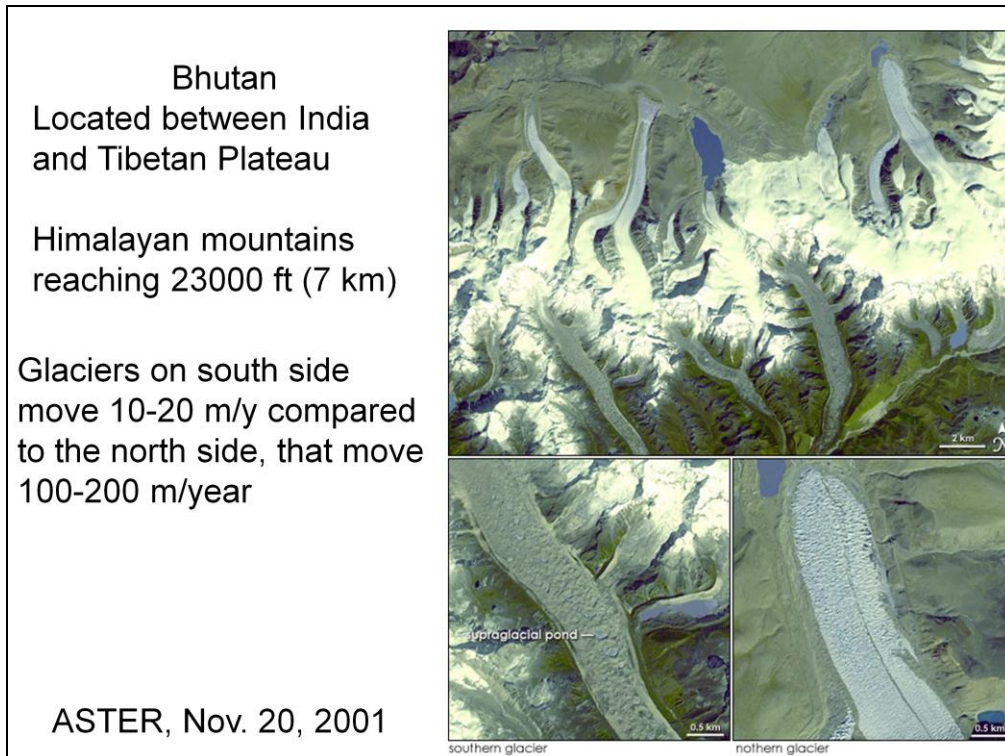
These images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer ([ASTER](#)) on NASA's [Terra](#) satellite show the Helheim glacier in June 2005 (top), July 2003 (middle), and May 2001 (bottom). The glacier occupies the left part of the images, while large and small icebergs pack the narrow fjord in the right part of the images. Bare ground appears brown or tan, while vegetation appears in shades of red.

From the 1970s until about 2001, the position of the glacier's margin changed little. But between 2001 and 2005, the margin retreated landward about 7.5 kilometers (4.7 miles), and its speed increased from 8 to 11 kilometers per year. Between 2001 and 2003, the glacier also thinned by up to 40 meters (about 131 feet). Scientists believe the retreat of the ice margin plays a big role in the glacier's acceleration. As the margin of the glacier retreats back toward land, the mass of grounded ice that once acted like a brake on the glacier's speed is released, allowing the glacier to speed up.

Overall, the margins of the Greenland Ice Sheet have been thinning by tens of meters over the last decade. At least part of the thinning is because warmer temperatures are causing the ice sheet to melt. But the other part of the thinning may be due to changes such as glacier acceleration like that seen at Helheim. Initial melting due to warming may set up a chain reaction that leads to further thinning: the edge of the glacier melts and thins, becomes ungrounded and rapidly disintegrates. The ice margin retreats, the glacier speeds up, and increased calving causes additional thinning. Understanding the dynamic interactions between temperature, glacier flow rates, and ice thickness is crucial for scientists trying to predict how the Greenland Ice Sheet will respond to continued climate change.

Reference

Howat, I. M., I. Joughin, S. Tulaczyk, and S. Gogineni (2005). Rapid retreat and acceleration of Helheim Glacier, east Greenland. *Geophysical Research Letters*, 32, L22502, doi:10.1029/2005GL024737.



One of the highest mountain relief on Earth can be found in the tiny country of Bhutan. Sandwiched between eastern India and the Tibetan plateau, Bhutan hosts peaks that reach between 5,000 and 7,000 meters (16,000-23,000 feet) in height. These mountains are neighbors to Mount Everest, Earth's highest peak at 8,850 meters (29,035 feet). The impressive Bhutan Himalayas are permanently capped with snow, which extends down valleys in long glacier tongues. Because of weather patterns on each side of the Himalaya and differences in topography, the glaciers on each side of the mountain are distinctly different from one another and are likely to react very differently to climate change.

This image, taken by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on November 20, 2001, is one of a series of images used to study the glaciers of the Bhutan Himalayas. By tracking the movement of surface features like crevasses and debris patterns, Andreas Kaab of the University of Zurich measures the speed at which glaciers flow down the mountain. He found that glaciers on the north side of the range move as much as ten times faster than glaciers on the south side.

Glaciers move under their own weight. As more and more snow piles on the glacier, the ice compresses, deforms, and eventually begins to slide. One of the reasons the glaciers on the south side of the Bhutan Himalaya are moving so slowly—10-20 meters per year compared to 100-200 meters per year on the north — may be that their supply of ice is dwindling. Without new weight pressing on the glaciers, they are stagnating.

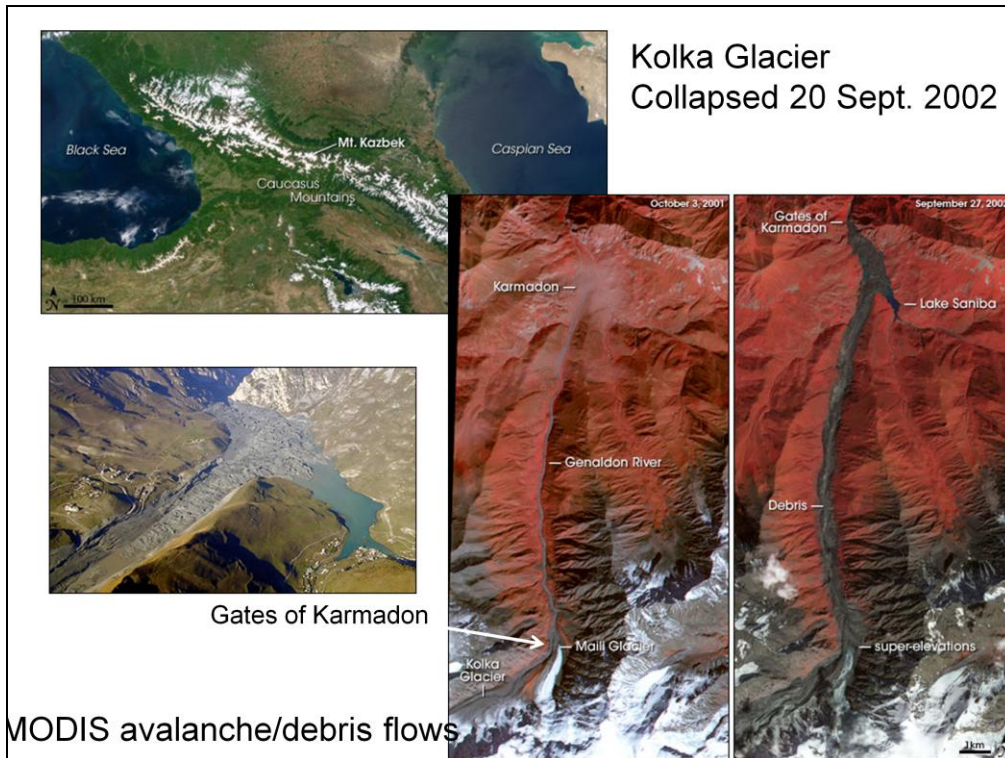
One reason the southern glaciers may be losing weight is the rock and gravel that rests on top of them. As this image clearly shows, the northern glaciers form in plateaus as high as 7,000 meters in elevation. The glaciers slide from the plateaus down the steep mountain side in long glacier tongues, which are white, tinted blue-gray where the snow is very compressed. The mountains are no less steep on the south side, but the glaciers have no plateaus on which to form. Instead, the glaciers cling to steep rock walls, which shower the glaciers with debris. The glaciers on the south are tinted gray-brown in this image because of the debris. Because the dark-colored debris absorbs energy from the Sun, the surface of the glacier is more susceptible to melting than it would be if its surface remained a reflective white. Indeed, the close view of a southern glacier, shown in the lower left image, shows pale blue ponds of liquid water, "supraglacial ponds" on the glacier's surface. The northern glacier, lower right, is free of both debris and ponds.

The difference between the glaciers on each side of the mountain could become more pronounced as global warming sets in. Eighty to ninety percent of new snow falls on the southern glaciers between March and October during the summer monsoon. As temperatures warm, not only will more snow melt, but precipitation will tend to fall as rain instead of snow. Without fresh snow to maintain their mass and movement, the glaciers will shrink in place, a process called "down wasting." By contrast, the northern glaciers are fed mostly by winter snow. Because temperatures are already cooler in the winter, the northern glaciers are more likely to get fresh snow every year, making them less sensitive to climate change. As temperatures warm, the fast-moving northern glaciers are most likely to adjust by retreating—shortening the length of the tongues that extend down into the valleys.

Understanding how glaciers may evolve is important because mountain glaciers are the proverbial "canary in the coal mine" when it comes to tracking global warming. Along with polar ice, they are the things most sensitive to warming temperatures. On top of being harbingers for climate change, melting glaciers can cause catastrophic floods, making it essential to monitor them regularly. Since most glaciers are remote and hard to get to, remote sensing is crucial to ongoing monitoring.

References:

Kaab, A. (2005). "Combination of SRTM3 and repeat ASTER data for deriving alpine glacier flow velocities in the Bhutan Himalaya" *Remote Sensing of Environment*. 94 (4), 463-474.



MODIS avalanche/debris flows

Between the Black and Caspian Seas, the Caucasus Mountains separate Russia (north) from Georgia (southwest) and Azerbaijan (southeast). Elevations reach 5,642 meters (18,511 feet), and glaciers accumulate from heavy snowfall in the steep mountain valleys. Around Mount Kazbek, a dormant volcano, glaciers intermittently collapse, burying the landscape below under rock and ice. (NASA Image by Jesse Allen and Robert Simmon based on [MODIS](#) data)

At the northern end of the depression, the churning mass of debris reached a choke point: the Gates of Karmadon, the narrow entrance to a steep-walled gorge. Gigantic blocks of ice and rock jammed into the narrow slot, and water and mud sluiced through. Trapped by the blockage, avalanche debris crashed like waves against the mountains and then finally cemented into a towering dam of dirty ice and rock. At least 125 people were lost beneath the ice.

When the Kolka Glacier collapsed in September 2002, ice, mud, and rocks partially filled the Karmadon Depression, destroying much of the village of Karmadon. The debris swept in through the Genaldon River Valley (lower left) and backed up at the entrance to a narrow gorge (top center). The debris acted as a dam, creating lakes upstream. This aerial photograph (looking north) was taken only 16 days after the disaster. (Photograph courtesy Igor Galushkin)

This pair of satellite images, taken before and after the collapse, shows the vast extent of the disaster. Debris and ice filled the Genaldon Valley from the Kolka Glacier Cirque to the Gates of Karmadon—a distance of about 18 kilometers (11 miles). (Images by Robert Simmon based on [ASTER](#) data)

Avalanche

Running east to west across the narrow isthmus of land between the Caspian Sea to the east and the Black Sea to the west, the Caucasus Mountains make a physical barricade between southern Russia to the north and the countries of Georgia and Azerbaijan to the south. In their center, a series of 5,000-meter-plus summits (16,000-plus feet) stretch between two extinct volcanic giants: Mt. Elbrus at the western limit and Mt. Kazbek at the eastern. Volcanism fuels hot springs that steam in the alpine air. On the lower slopes, snow disappears in July and returns again in October. On the summit, winter is permanent. Glaciers cover peaks and steep-walled basins called cirques. The remote, sparsely populated area is popular with tourists and backpackers.

On the evening of September 20, 2002, in a cirque just west of Mt. Kazbek, chunks of rock and hanging glacier on the north face of Mt. Dzhimarai-Khokh tumbled onto the Kolka glacier below. Kolka shattered, setting off a massive avalanche of ice, snow, and rocks that poured into the Genaldon River valley. Hurling downriver nearly 8 miles, the avalanche exploded into the Karmadon Depression, a small bowl of land between two mountain ridges, and swallowed the village of Nizhny Karmadon and several other settlements.

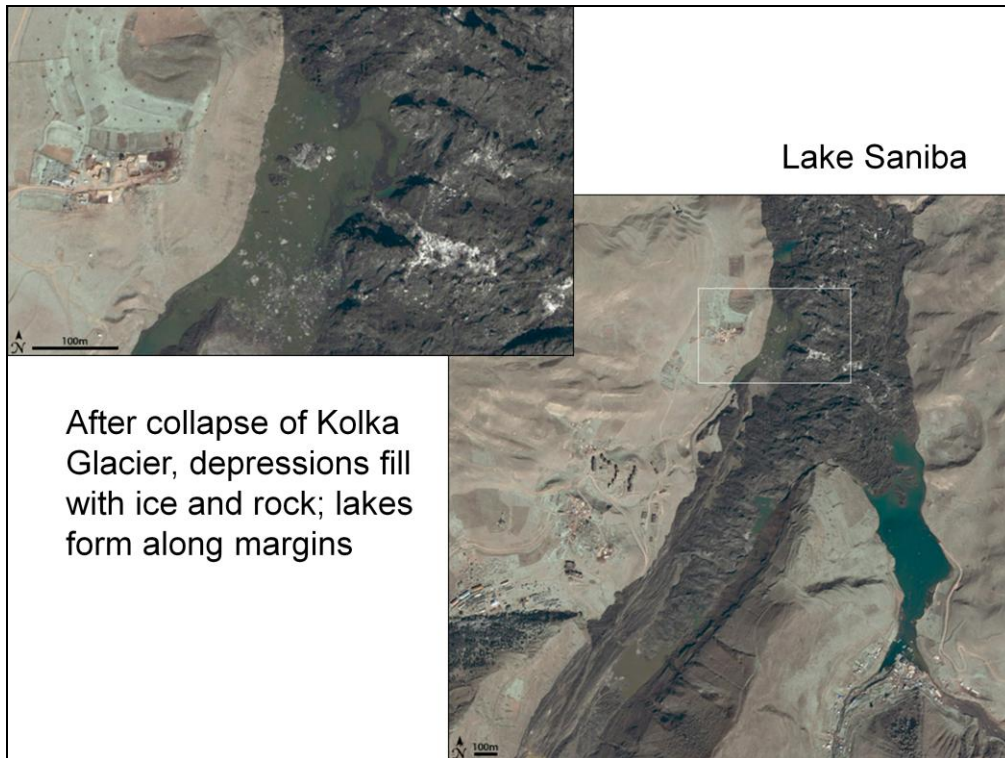
At the northern end of the depression, the churning mass of debris reached a choke point: the Gates of Karmadon, the narrow entrance to a steep-walled gorge. Gigantic blocks of ice and rock jammed into the narrow slot, and water and mud sluiced through. Trapped by the blockage, avalanche debris crashed like waves against the mountains and then finally cemented into a towering dam of dirty ice and rock. At least 125 people were lost beneath the ice.

Dmitry Petrakov, Sergey Chernomorets, and Olga Tutubalina have been returning to the site since the disaster. The three have been friends and colleagues for several years. Tutubalina and Petrakov are members of the Faculty of Geography at Moscow State University. She teaches and researches in the Laboratory of Aerospace Methods for the Department of Cartography and Geoinformatics, and he is a researcher in the Department of Cryolithology and Glaciology. Chernomorets is the General Director of the University Centre for Engineering Geodynamics and Monitoring in Moscow. The combination of backgrounds made the team uniquely qualified to study the Kolka disaster. In the year following the event, they made five trips to the Russian Republic of Ossetia in the central Caucasus. They wanted to figure out exactly what had happened that day and to forecast what might happen in coming weeks, months, and years at the site. [A Dangerous Past](#)

This pair of satellite images, taken before and after the collapse, shows the vast extent of the disaster. Debris and ice filled the Genaldon Valley from the Kolka Glacier Cirque to the Gates of Karmadon—a distance of about 18 kilometers (11 miles). (Images by Robert Simmon based on [ASTER](#) data)

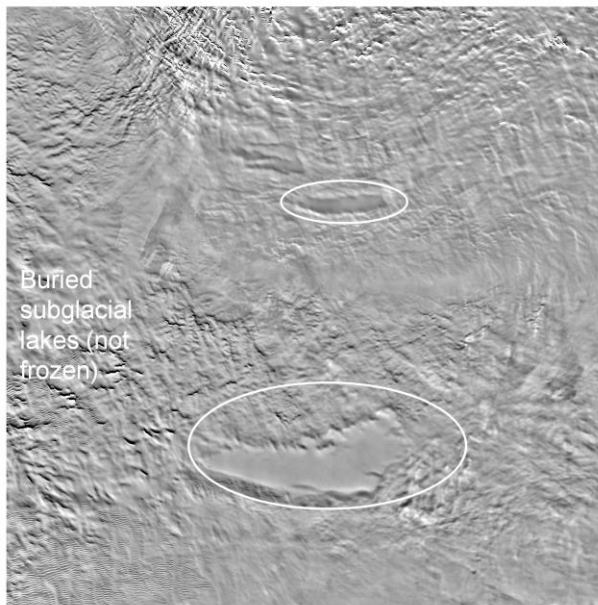
A Dangerous Past

After the collapse, people speculated that something called a glacial surge had triggered the Kolka collapse. “In a surge,” explained Petrakov, “the leading edge of a glacier might slip a few hundred meters down slope very rapidly—perhaps in a day. A similar event happened at Kolka in 1969.” In 1902, a more significant collapse at Kolka Glacier had killed 32 people. Despite a history of disasters there, routine monitoring of the Kolka Glacier cirque ended shortly before the Soviet Union collapsed in 1991.



After the Kolka Glacier collapsed, the Karmadon Depression filled with ice covered by black, pulverized rock. Water from dammed streams and melting ice formed lakes along the margins. The rapidly rising water was a continuing danger, threatening a sudden outburst that would cause flooding downstream. (Image copyright [Digital Globe](#))

East Antarctic Ice Sheet



In the coldest spot on the earth's coldest continent, Russian scientists have reached a freshwater lake the size of Lake Ontario after spending a decade drilling through more than two miles of solid ice, the scientists said Wednesday Feb. 8, 2012 (New York Times).

Water had been sealed for 15-34 M yrs

MODIS Terra and Aqua composite 11/20/2003 - 29/2004

Across the rippling, crevassed whitescape of the East Antarctic Ice Sheet, two unusual shapes appear in this grayscale satellite image of the frozen continent. The smooth, dark gray oval shapes are slight depressions in the surface of the ice sheet that trace out the shorelines of two lakes that are buried several thousand meters (more than 2 miles) deep in ice. Scientists recently published the first thorough description of the size, depth, and origin of these two large lakes, called 90° East Lake (for its longitude) and Sovetskaya Lake (for the Russian research station that was unknowingly built over top it many years ago).

The two lakes are close to Lake Vostok, thought to be the largest of Antarctica's 70 or more subglacial lakes. The water in the lakes is kept from freezing by warmth from the surface of the Earth and the insulation provided by the thick covering of ice. Scientists believe Vostok and the new lakes may contain unique ecosystems isolated from the outside world for tens of millions of years. The survival of life in these buried lakes could provide corroboration for the idea that life could exist in an ice-covered ocean that some scientists believe exists on Jupiter's moon Europa.

The image above is part of the satellite image collection called the "MODIS Mosaic of Antarctica," a map of the continent's surface made from 260 images acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on NASA's [Terra](#) and [Aqua](#) satellites between November 20, 2003, and February 29, 2004.

Reference

Bell, R. E., M. Studinger, M. A. Fahnestock, and C. A. Shuman. (2006). Tectonically controlled subglacial lakes on the flanks of the Gamburtsev Subglacial Mountains, East Antarctica. *Geophysical Research Letters*, 33, L02504, doi:10.1029/2005GL025207.

Further Reading:

[Two New Lakes Found Beneath Antarctic Ice Sheet](#), from the Earth Institute at Columbia University

[Lake Vostok Fact Sheet](#) from the National Science Foundation

[Europa](#) article entry in Wikipedia online encyclopedia

[MODIS mosaic of Antarctica](#) courtesy National Snow and Ice Data Center

New York Times Feb. 9, 2012. A statement by the chief of the Vostok Research

Station, A. M. Yelagin, released by the director of the Russian Antarctic Expedition, Valery Lukin, said the drill made contact with the lake water at a depth of 12,366 feet. As planned, lake water under pressure rushed up the bore hole 100 to 130 feet pushing drilling fluid up and away from the pristine water, Mr. Yelagin said, and forming a frozen plug that will prevent contamination. Next Antarctic season, the scientists will return to take samples of the water.

The first hint of contact with the lake was on Saturday, but it was not until Sunday that pressure sensors showed that the drill had fully entered the lake. Lake Vostok, named after the Russian research station above it, is the largest of more than 280 lakes under the miles-thick ice that covers most of the Antarctic continent, and the first one to have a drill bit break through to liquid water from the ice that has kept it sealed off from light and air for somewhere between 15 million and 34 million years.

There have been much-disputed hints that life might still exist there. If so, that would give a great boost to hopes of finding life in similar conditions in icy water on one of the moons of [Jupiter](#).

Dr. Lukin said it was a momentous, pioneering moment. “For me, the discovery of this lake is comparable with the first flight into space,” he told the Interfax news agency. “By technological complexity, by importance, by uniqueness. After reaching the water, the research team gathered by the drilling site for a [photograph](#).

John Priscu, a geologist specializing in Antarctica at Montana State University, who has kept in contact with scientists in Antarctica and in [Russia](#) as the drilling has progressed, said that the anticipation had grown in the past two weeks as the drilling team finally came close to the lake surface just as the Antarctic summer was ending and the weather worsening.

“It has been a suspenseful two weeks for me,” Dr. Priscu said. He is headed for Antarctica next season to drill to another buried lake, and he said he was delighted with the Russian achievement. “I applaud them,” he said. “I think they have done a great job.” Russian officials said the timing of the announcement was fitting because on Wednesday, Russia celebrated “Science Day,” commemorating the occasion in 1724 when Peter the Great signed an order establishing the St. Petersburg Academy of Sciences. And the drilling saga, like the expeditions of early explorers, has been years in the making and involves both scientific inquiry and national pride. In the early 1990s, an international team of researchers were drilling at the Vostok research station to obtain cores to study clues to past climate in ice that has been accumulating for millions of years. At a depth of more than two miles they reached a kind of ice different from the ice sheet and realized they had frozen lake water.

That a lake existed there was not a surprise, although its size and shape were not then known. What did raise scientific eyebrows was evidence that the lake ice contained microbes, said Robin Bell, of the Lamont-Doherty Earth Observatory at Columbia University, who has studied the lake extensively. But Dr. Bell said a consensus had never been reached on whether the evidence resulted from contamination from the drilling fluid.

Dr. Bell, who studies the behavior of ice sheets, designed surveys of the lake conducted in 2000 and 2001, using radar and other techniques, which showed its shape and location. Because it is such an unusual environment, there is always the possibility that it will provide other geological insights, she said, adding, "We could learn something absolutely unique."

The drilling project has been Russian, not international. And the difficulties of drilling through more than two miles of ice and keeping the roughly five-inch bore hole from freezing over have been extraordinary. The bore hole has had to be filled with kerosene to keep it from freezing over, and the researchers have had to work in what are difficult conditions, to say the least.

Dr. Priscu said the drillers, led by Dr. Lukin, had been racing against time to complete the project before the Antarctic summer ended and flights became impossible. Temperatures have dropped to lower than minus 45 already, and at minus 50 the difficulties for aircraft become extreme.

Nowhere does it get colder than at Vostok, in the middle of the East Antarctic ice sheet about 800 miles from the South Pole. The coldest documented temperature on earth was recorded at Vostok in July 1983, minus 128.6. Some environmentalists have raised objections to drilling to subglacial lakes because of the possibility of contamination. The Russian plan to prevent the drilling fluid from reaching the pristine lake water was to plug the bottom of the bore hole with an inert fluid, Freon, and to drill the final distance with a heated drill tip instead of a motorized drill. Enough kerosene would be removed to lessen the pressure in the bore hole so that when the lake was reached, lake water would flow up the bore hole, then freezing and forming an icy plug. That is exactly what happened, Russian scientists confirmed.

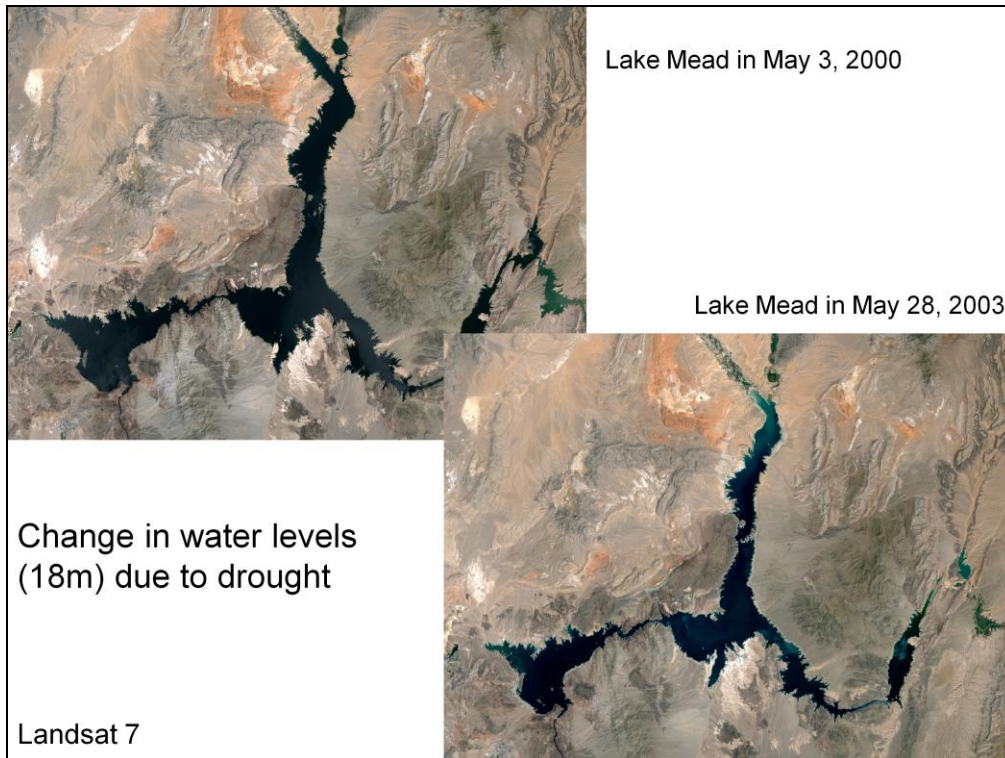
The need to prevent even the slightest contamination of the lake is acute. Its environment is comparable to conditions on the moons of Jupiter, which are among the candidates for extraterrestrial life. If life exists in Vostok, it may well exist on Europa, one of the moons of Jupiter, which has subsurface icy water. The water in Vostok stays liquid because of the pressure and the warmth of the earth below it.

Next season American and British expeditions will try to drill to other buried lakes, Dr. Priscu said. He is part of the American expedition that has targeted a lake in West Antarctica.

The specially designed drill that the American team will use, Dr. Priscu said, is being sent down to Antarctica by ship, and that journey has already begun. "The drill," he said, "is on its way to the ice."

David M. Herszenhorn reported from Moscow, and James Gorman from New York.

**Remote Sensing of
Lake and Dune
Landforms**



The image above, acquired by the Landsat satellite, shows the shoreline of Lake Mead in May 3, 2000. Place your cursor over the image to see the shoreline in May 28, 2003. Dramatic changes are quite evident in the three-year span between these images. Water levels in the lake between these images **dropped 18 meters**.

In the space of just three years, water levels in Lake Mead fell more than sixty feet due to sustained drought. Move your cursor over the image to compare the shoreline in 2000 to 2003. (Image by Jesse Allen, based on data provided by the [Landsat 7 Science Team](#))

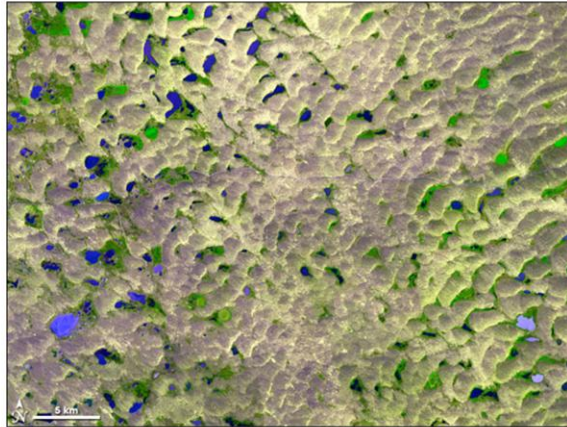


May 3, 2000



May 28, 2003

Sand Hills cover about 25% of Nebraska



Ancient (Pleistocene) Sand Dunes

Natural Color ASTER, 09/12/2001

The Sand Hills cover about a quarter of the U.S. Great Plains state Nebraska. These ancient sand dunes are from the Pleistocene Epoch (the geologic time period spanning about 1.8 to about 10,000 years ago). They are made of sediment eroded from the Rocky Mountains by the monumental Pleistocene glaciers, washed out into the plains, and now mostly stabilized by grassland vegetation. Covering an area of about 60,000 square kilometers in western Nebraska, the Sand Hills are the largest sand dune formation in America.

This simulated natural-color image from the Advanced Spaceborne Thermal Emission and Reflection Radiometer ([ASTER](#)) on NASA's [Terra](#) satellite shows a portion of the Sand Hills region, the landscape rippled by crowded yellow-tan and lavender-brown dunes. The area doesn't drain water very well, and so the hollows at the bases of dunes are filled with brilliantly blue lakes. In the large image it is easy to see that some of the emerald green vegetation is being cultivated, rather than growing naturally. Perfect circles of vegetation resulting from center-pivot irrigation appear in the scene, as well as fields with sharp angles and straight lines.

According to a [report on the Sand Hills](#) by the World Wildlife Fund, the soils of the Sand Hills aren't like any other soils in the Great Plains, and unique grasses and plants live there. The sandy soils were not attractive to farmers, and so the area was left largely unplowed by European settlers. As such, the area is one of the least disturbed remnants of the vast prairies that once filled the central United States. The area is an important habitat for migratory birds, such as the sandhill crane, one of only two species of crane native to North America.

This ASTER image was acquired September 10, 2001, and the [large image](#) covers an area of about 57.9 by 61.6 kilometers. It is centered near 42.1 degrees North latitude, 102.2 degrees West longitude.

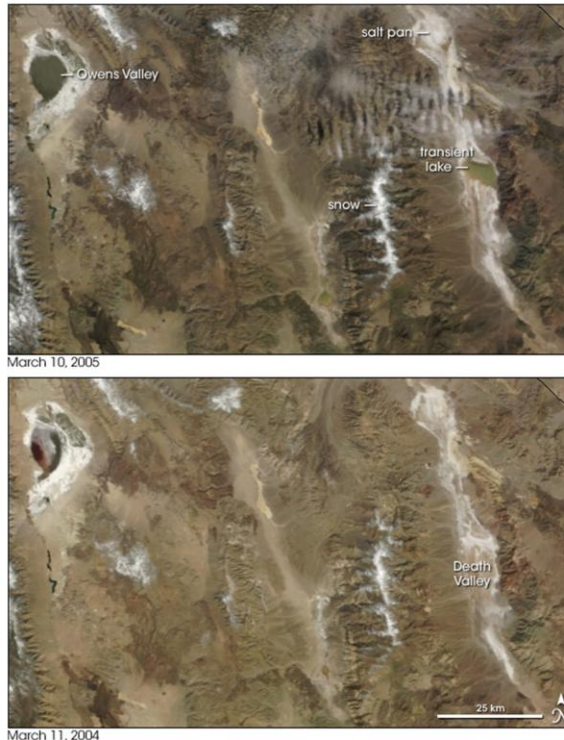
Image courtesy NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan [ASTER Science Team](#)

Death Valley:
Driest place in North
America

Ruminant of
Pleistocene Lake
Manly (transient lake)
100mi long and 600 ft
thick)
Owens valley –also
ruminant Lake

Salt pans

MODIS



Now the driest place in North America, Death Valley was once a verdant, water-filled haven. Between 128,000 and 186,000 years ago, ice covered the Sierra Nevada and rivers flowed into the long valley, feeding Lake Manly. At nearly 100 miles long and 600 feet deep, this massive lake filled Death Valley. To the west, on the other side of the Panamint Range (capped with snow in the top image), was the slightly smaller Panamint Lake. Though the lake and rivers dried as the ice retreated and the climate warmed, water has left its mark on the landscape. Evaporating water left a white salt pan in its place, so the beds of both lakes are clearly visible in these images, acquired by the Moderate Resolution Imaging Spectroradiometer ([MODIS](#)) on NASA's [Terra](#) satellite on March 10, 2005, (top) and March 11, 2004 (bottom).

Driven by a mild El Niño, winter 2005 was wet. Southern California was inundated with heavy rain from December through late February. The effects on the landscape hearken back to an earlier age when water was more prevalent. On March 10, 2005, water had pooled in the former Lake Manly and, less noticeably, in Lake Panamint. To the northwest, Owens Valley—another remnant of the last ice age—is also filling with water.

Aside from darkening the dry salt pans with water, the winter weather had another effect on the landscape. The mountains are darker and slightly greener with growing vegetation. On average, Death Valley receives less than two inches of rain per year. When the rain does fall, the desert springs to life, blossoming with flowers. This year, Death Valley National Park received over six inches of rain, and the result is a rainbow of wildflowers—one of the best blooms in modern history, the National Park Service reports. For daily wildflower updates, visit the [Death Valley National Park](#) home page.

NASA images created by Jesse Allen, Earth Observatory, using data obtained courtesy of the [MODIS Rapid Response](#) team and the Goddard Earth Sciences DAAC.

Lecture 10: Remote Sensing of Geomorphology, What you should know. Lots of examples & review text examples. Be able to give examples of how different types of RS data would or would not be useful in mapping these geologic features. Consider what information you need to identify these structures.

Various terms/ideas to know:

1. 3 types of rock formation and examples of each
2. 3 types of ways rocks respond to deformation and stress.
3. Types of folding and what they look like
4. Major types of faulting and how faults are described
5. What are the characteristics of impact craters and how do (if) they differ from volcanoes?
6. How are fluvial, delta, dune landscapes observed in RS data?
7. Thermokarst and kettle lakes? Glacial landscapes?