Norris Geyser Basin's Dynamic Hydrothermal Features

Using Historical Aerial Photographs to Detect Change

David Shean

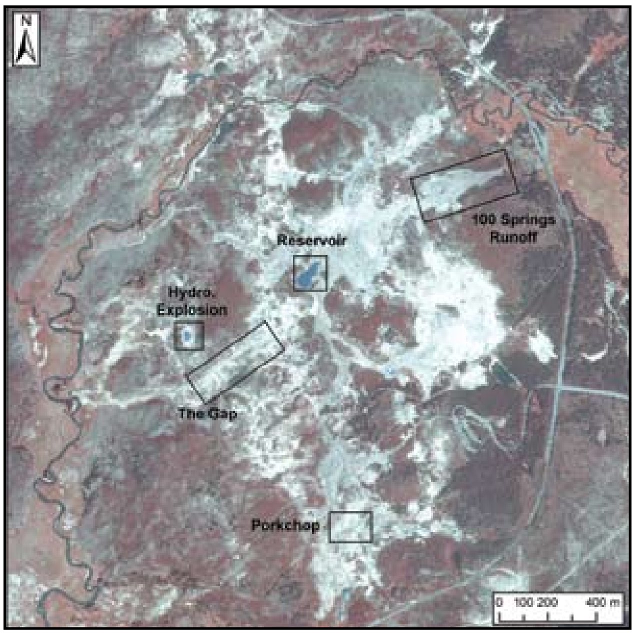

Figure 1. Context map for Norris Geyser Basin showing figure locations for preliminary change detection results over the 2001 color infrared digital orthophoto quarter quadrangle.

The spectacular hydrothermal features of Yellowstone National Park have captivated visitors and scientists alike since the late nineteenth century. While many efforts to monitor these geothermal features have been made, Yellowstone National Park implemented a scientific geothermal monitoring plan involving remote sensing during the last year. Among other efforts, the remote sensing portion of this geothermal monitoring plan calls for repeated airborne thermal surveys of high-priority hydrothermal areas in the park, including Norris, Upper, Midway, and Lower geyser basins.

The Norris Geyser Basin is one of the most remarkable and dynamic geyser basins in Yellowstone. It is home to Steamboat, the world's tallest active geyser, and is renowned for its basin-wide hydrothermal disturbances. These disturbances are poorly understood, but can involve relatively rapid changes in water temperature, changes in water sediment content, renewed activity of dormant features, development of new features, and changes in eruption intervals for regular geysers.

I spent the summer of 2006 working in Yellowstone through the Geological Society of America's GeoCorps America Program. The goal of my project was to obtain high-accuracy (sub-meter) global positioning system (GPS) ground control points for several high-priority geothermal areas, and to use these points to properly georectify presently available and future airborne thermal image data. GPS points were collected for the Mammoth, Old Faithful, and Norris areas, and the thermal image data for the Norris and Old Faithful areas were rectified. I also conducted a search for historical aerial photographs and maps of the Norris Geyser Basin that could be used to detect changes in the hydrothermal features. This search involved several sources, including Yellowstone's Fire Cache map room and Planning, Compliance, and Landscape Architecture files; the Yellowstone Heritage and Research Center (HRC) archives and historic photo collection; Denver National Park Service (NPS) Technical Information Center; Yellowstone Dataset Catalog; U.S. Geological Survey (USGS) Earth Resources Observation and Science; and other resources on the web. The products of this search were scanned, orthorectified (when camera calibration reports were available), and compiled in a GIS database for analysis. In addition, a database was produced for aerial photo flightline index maps, which can be used to identify available data for future projects.

Re-rectification of Existing Color Infrared Digital Orthophotographs

In order to accurately georectify airborne thermal data for Norris, it was necessary to collect GPS ground control points using a high-accuracy (±15 cm) mobile mapping system. In addition, lines and polygons were collected to outline easily identifiable shapes or curves that would be difficult to map with just one point (e.g., trails with curves, circular hydrothermal features, or an arc of vegetation within a road pullout). These points provided sufficient detail to properly map the features after differential correction of GPS data. Due to the wide range of data (thermal, black and white, and color infrared images) used for this study, it was also necessary to have an accurate basemap to which all digital data could be registered. The best available data for re-rectification is the CIRDOQQ (color infrared digital orthophoto quarter quadrangle) image data which was flown in 2001 and is publicly available on the web. Comparisons of the CIRDOQQs with high-accuracy GPS points collected for the Mammoth, Norris, and Old Faithful areas revealed that the true horizontal accuracy is typically a few meters for the color infrared digital orhtophotographs.

Historical Maps and Aerial Photos

As part of the search for historical data on Norris Geyser Basin, several geologic maps were located, digitized, georectified, and incorporated into a geographic information system (GIS) database. These maps allowed for identification of individual features and geological units within the basin. They may also be useful for change detection, however, the accuracy of the earlier maps is questionable, and the boundaries of thermal features may only be approximate. A thorough analysis of these maps has not yet been completed.

An extensive search was completed to determine the availability of aerial photos for Norris Geyser Basin and the entire park. This search revealed that aerial photos were collected for the park from 1954 through 2002, with varying intervals between flights. They include black and white, true color, and color infrared photos. Parkwide flights were conducted in at least 1954, 1969, 1988, 1991, 1994 (DOQQ), 2001 (CIR-DOQQ), and potentially 1978 and 1998. There were many additional flights with limited coverage but higher spatial resolution (1956, 1962, 1965, 1971, 1972, 1977, etc.).

Results

Comparisons of the clipped, orthorectified aerial photographs with the re-rectified 2001 CIRDOQQ basemap show that the orthorectification process was successful. Offsets of a few meters were observed in some regions of the images, while others were almost perfectly aligned. Due to the large amount of time required for scanning and orthorectification, less than a week was dedicated to analysis of the data. Obviously, a thorough scientific analysis is necessary, but the preliminary results are promising. Even with these time limitations, several obvious changes were noted for prominent features in Norris Geyser Basin.

During the initial analysis, efforts were made to identify changes in the color, clarity, outline (shorelines), absolute location, and runoff patterns of hydrothermal features, as well as vegetation/thermal barren boundaries. A context map is shown in Figure 1, and brief discussions of the observations are presented in the captions of Figures 2–6.

There are many possible causes for the changes identified in Figures 2–6. They might be related to large earthquakes (Husen et al. 2002), ground deformation potentially related to gas or magma injection (Wicks et al. 1998; Wicks et al. 2006), changes in fluid motion at depth, hydrothermal disturbance activity, changes in precipitation input to the hydrological system, or some combination of these causes.

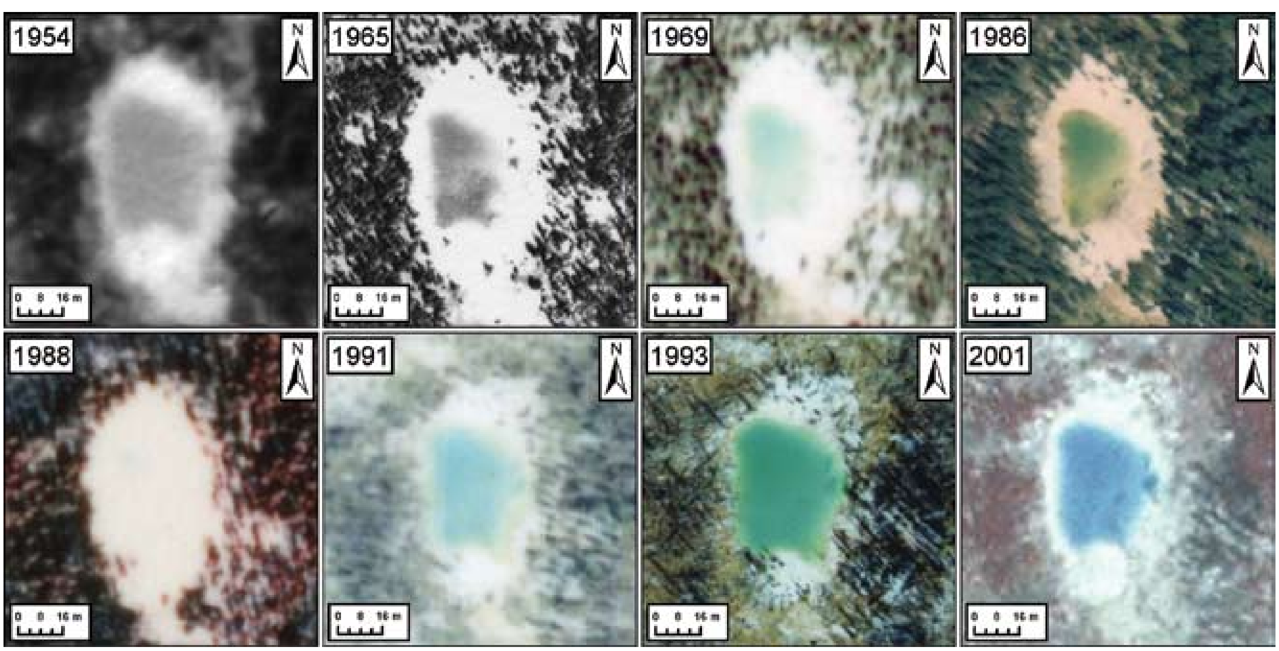

Figure 2. A relict hydrothermal explosion crater with central pool (White et al. 1988) ~200 m northwest of the Gap. Note the variations in water level, with highest apparent level in 1993.

A list of hydrothermal disturbance activity from 1926 to 1979 was obtained from the HRC library. The relevant hydrothermal disturbance dates from this list occurred on August 19, 1954 (18 days before the 1954 flight), September 25, 1965 (25 days after the 1965 flight), and September 9, 1978 (21 days before the 1978 flight). The 1978 hydrothermal disturbance may be related to the anomalous appearance of convective cells (attributed to boiling water) in the Reservoir (Figure 3). Cross-checking with ground-based observations of the Reservoir in 1978 should confirm or disprove this hypothesis. A comprehensive list of more recent hydrothermal disturbances has not yet been compiled.

In an attempt to understand some of the observed changes in the aerial photos, historical precipitation data was downloaded from the Western Regional Climate Center. Unfortunately, no data is available for the Norris area—the closest meteorological stations are located in Mammoth, Old Faithful, and West Yellowstone. Due to years with incomplete data and the large variation among these three stations, it is difficult to draw any conclusions about the influence of precipitation on individual hydrothermal features in Norris Geyser Basin. However, we do see that relatively dry periods were experienced around 1988 and 2001, when the runoff from the One Hundred Spring Plain appears to be minimal.

This technique appears to be a valuable tool for geothermal monitoring. However, it does have several limitations. It is apparent that the data type (color, black and white, color infrared) and resolution of the photographs are variable. This contributes two additional variables when attempting to isolate causes to explain any observed changes. The fact that the photos were taken at different times of the day and year also complicates interpretation. The shadows of trees and other features are of different lengths and extend in different directions for each photo. Finally, the features under study are active hydrothermal features, and thermal fog, steam plumes, and even erupting geysers can obscure the images. Despite these complications, the preliminary results presented here are promising, and many additional resources not yet investigated could provide important new data.

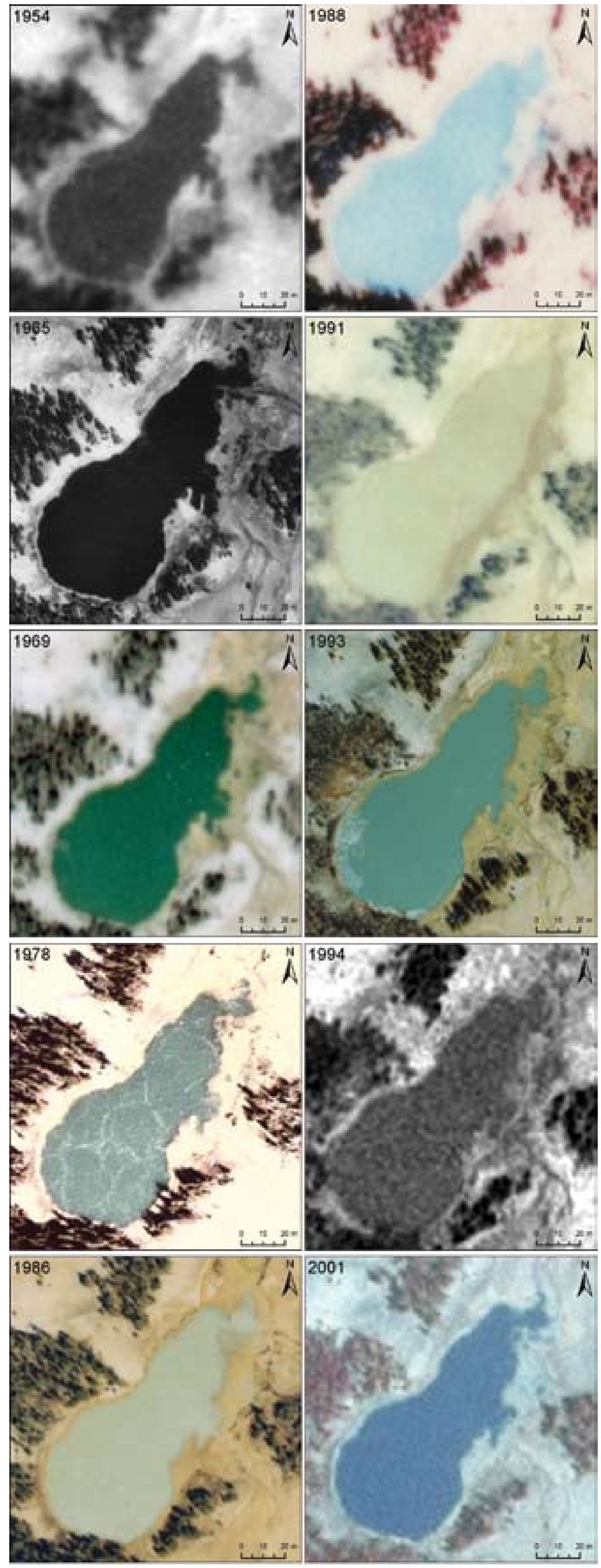

Figure 3. Aerial photos of the Reservoir. Note the remarkable stability of the borders since 1954. The 1991 photo shows a higher water level than any of the other photos, despite below-average precipitation levels during the period from 1990 to 1991. In addition, the 1978 photo shows what appear to be individual convective cells within the reservoir that are not seen in the other photos (despite similar resolution). This anomaly may be related to thermal disturbance activity that was recorded on September 9, 1978, just three weeks before the 1978 data were collected on September 30, 1978.

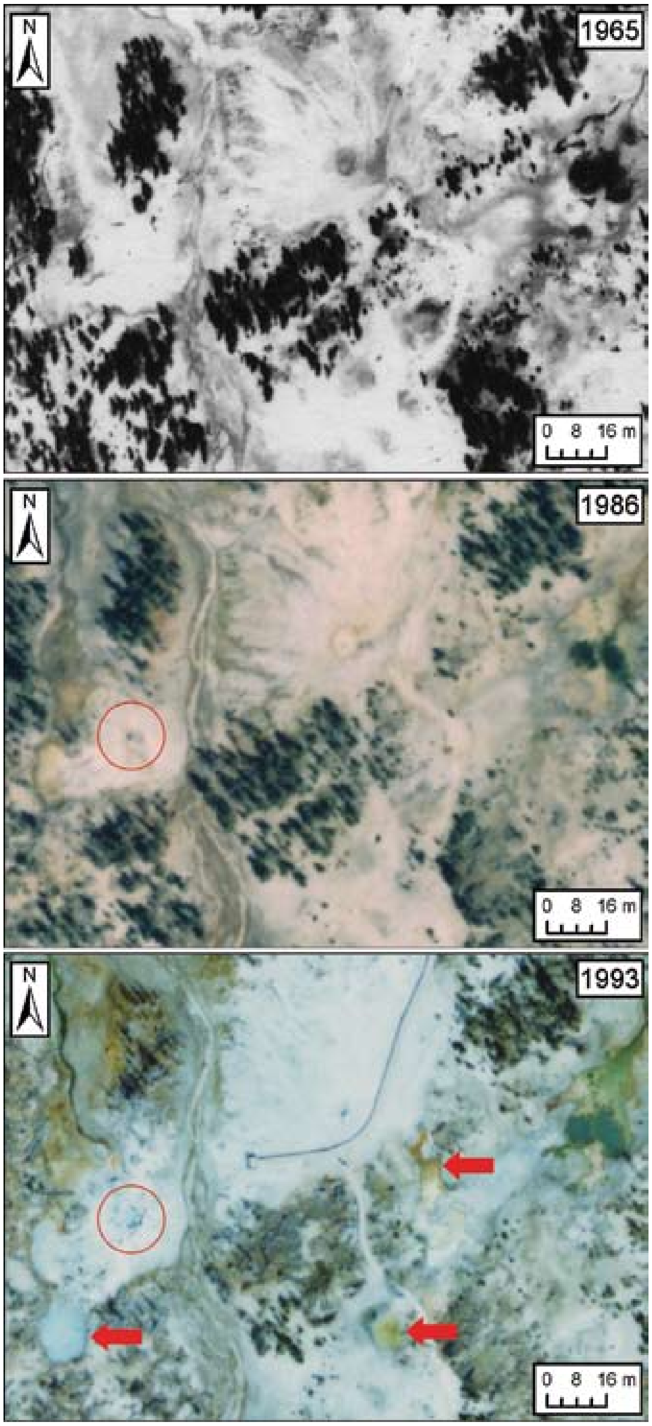

Figure 4. High-resolution aerial photos from 1965, 1989, and 1993 for the area near Porkchop Geyser. Red circles outline Porkchop, which underwent a hydrothermal explosion in 1989. Red arrows highlight new hydrothermal features observed in the 1993 photo. The large pool in the southwestern corner of the 1993 photo is not observed in 2001.

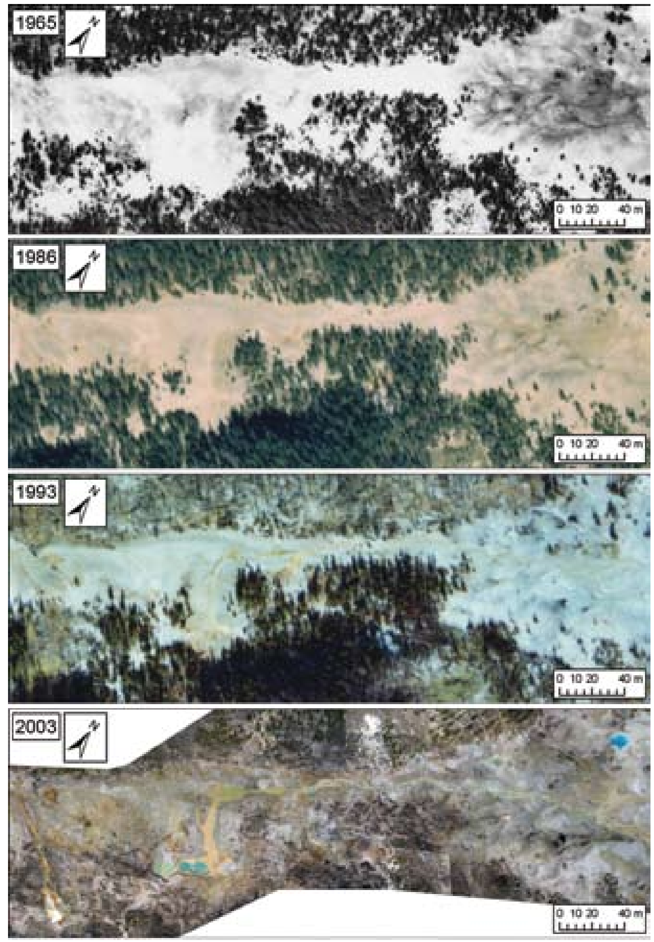

Figure 5. High-resolution aerial photos from 1965, 1986, 1993, and 2003 for the Ragged Hills area (the Gap). Note the apparent stability from 1965 to 1993, and the sudden appearance of several new hot springs between 1993–2003 (Ball et al. 2002; Planer-Friedrich et al. 2003), accompanied by notable changes in vegetation patterns.

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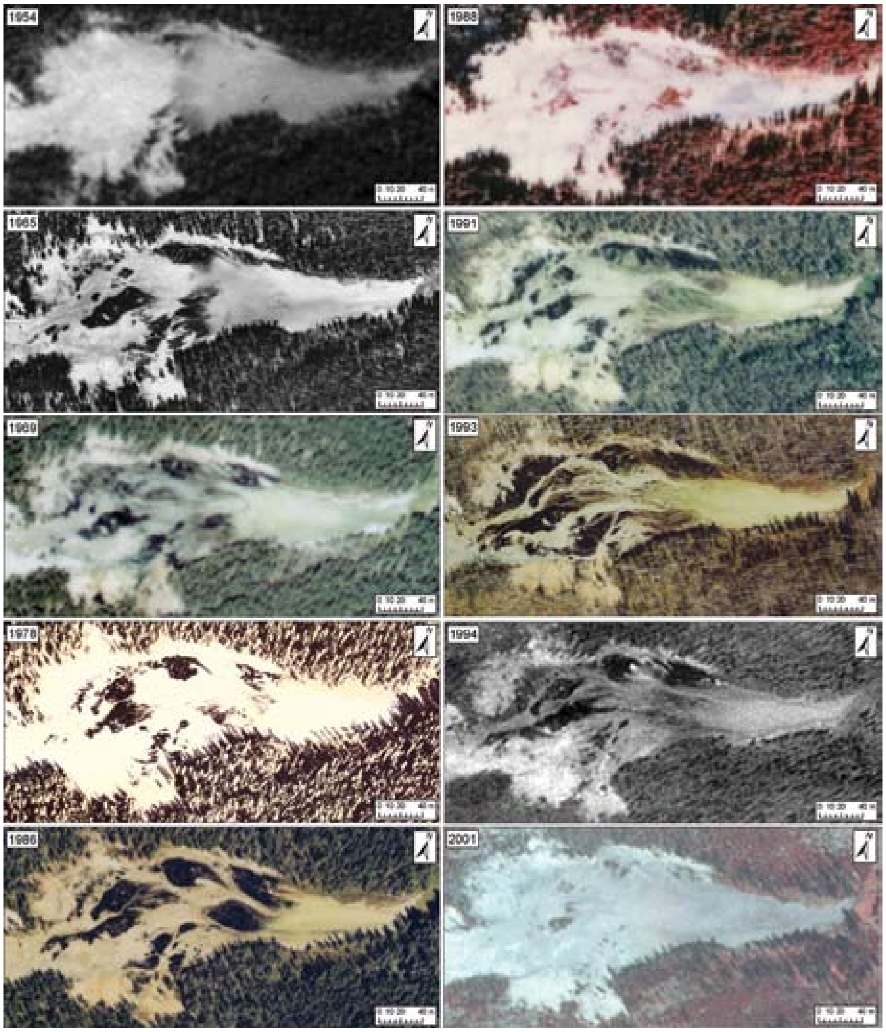

Figure 6. Aerial photos of the runoff from One Hundred Spring Plain. Note the apparent lack of bacterial/algal mats in 1988 and 2001, two years marked by below-average precipitation levels. While this apparent lack of mats may be partially related to the photo type (both of these flights are color infrared), we would expect the algal mats to be identifiable in the infrared band.

COURTESY OF AUTHOR

David Shean is a geologist who received his ScB/ScM in geology at Brown University. He has worked with faculty at Brown University and Boston University to investigate glaciers and climate change in Antarctica and on the planet Mars. As a Geological Society of America's GeoCorps volunteer, he worked as a Geothermal Resources Assistant in Yellowstone National Park during the summer of 2006. This article is adapted from his final report, "GPS Ground Control Point Collection and Rectification of Thermal Imagery for Geothermal Monitoring Efforts in Yellowstone National Park & Change Detection in Norris Geyser Basin using Historical Aerial Photographs," dated 8/25/2006.

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FROM THE ARCHIVES

NPS

Sapphire Pool, Biscuit Basin. Postcard by Detroit Photographic Co., ca. 1902.

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