

# Decorrelation stretch enhancement of Great Mural paintings of Baja California

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## **Abstract**

Decorrelation stretch, an image enhancement technique first used in remote sensing, can be usefully applied to rock art. In images from the Great Mural paintings of Baja California, I demonstrate its ability to bring out elements nearly invisible to the eye and to improve visualization of difficult panels. The technique is of particular interest to archaeologists who must document poorly preserved sites and to others desiring to study this fascinating body of art. A decorrelation stretch plugin to the imaging program ImageJ is available from the author, free for personal use.

## **Introduction**

The Great Mural paintings of the central Baja California peninsula constitute one of the premier rock art styles in the world (Figure 1). Many of the sites are beautifully preserved, but there are also many poorly preserved sites in which the ravages of times have all but erased the paintings that once were there. This paper describes a digital enhancement technique, called decorrelation stretch, which can make faded pictographs visible and help in the decipherment of densely painted panels.

Background information will be presented on the decorrelation stretch algorithm and on the DStretch program that implements it. Images from Great Mural sites are used to demonstrate the many uses of the technique.

The rock art enhancement techniques discussed in this paper are applied to digital images (Figure 2). The images and enhancements do not use infrared film or other special photographic techniques. Enhancement is possible since the human visual system misses many subtle color details in images.

Image enhancement brings out the subtle details our eyes miss and can make faint pictographs visible (Figure 3). Digital enhancement has been applied to rock art images with great success. Robert Mark and Evelyn Billo (2002), Steve Freers (2003) and others have pioneered in this field. The increasing use of digital cameras facilitates the enhancement process.

As another example of the possibilities of digital enhancement, consider the photo of a faded painting taken near Cueva Soledad (a Great Mural site near Cueva Pintada). Little can be seen in the photo except a faint red stain (Figure 4). Enhancement brings out a human figure, called a *mono*, in typical “arms up” pose with an arrow or spear in its shoulder (Figure 5).

## **Decorrelation stretch background**

The enhancement technique used on the previous figures is called decorrelation stretch. It was first developed in the field of remote sensing. Multispectral images had poor color contrast,



Figure 1. Great Mural area.



Figure 2. Original digital image (Cueva Soledad).

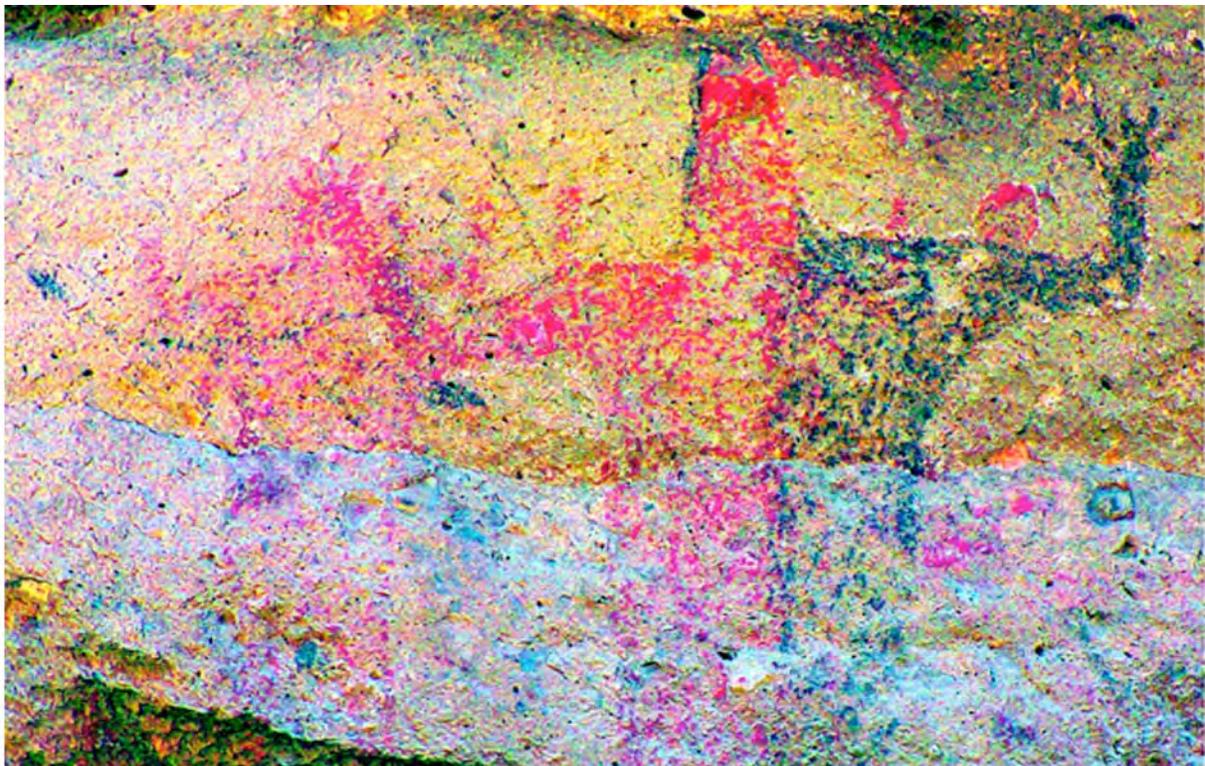


Figure 3. Enhanced image.



Figure 4. Original digital image (also from Cueva Soledad).

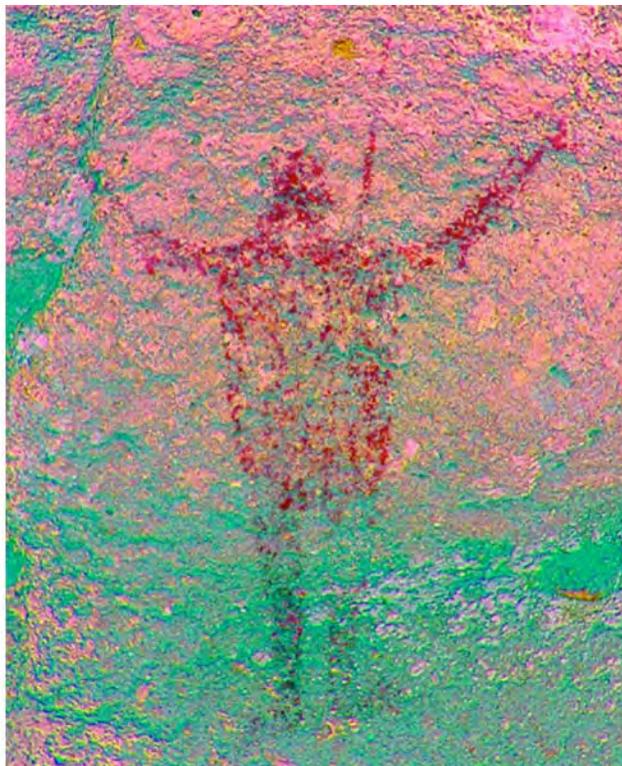


Figure 5. Enhanced version of Figure 4.

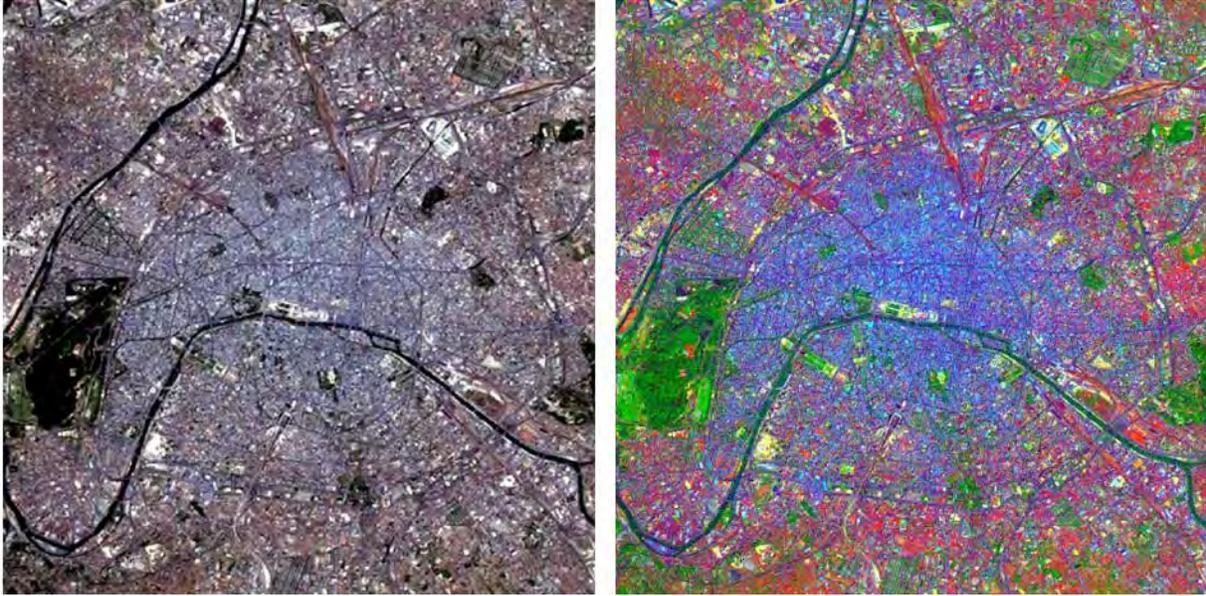


Figure 6. Aerial photo of Paris: (left) original; (right) enhanced with DStretch.

and a way was needed to enhance subtle color differences. The algorithm uses the Karhunen-Loève transform from probability theory. It produces an enhancement that is “false color,” in other words the color hues can be changed from the original. An example is a multispectral image of the city of Paris (Figure 6). The original is nearly colorless. The decorrelation stretch enhancement is much more colorful. This makes interpretation easier. For instance it makes the locations of natural (green) areas much easier to determine.

Commercially available photo editing software (such as Adobe Photoshop, the market leader) can be expensive and complicated. Achieving good results can require considerable expertise. The decorrelation stretch algorithm is not available in commercial photo editing software.

The idea of using decorrelation stretch for rock art enhancement was suggested to me by Robert Mark a year ago at the San Diego Rock Art Conference. As a base, I used ImageJ, an imaging program used by medical researchers. ImageJ has been developed at the U.S. National Institute of Health and is freely available. I created a “plugin” to ImageJ called DStretch. Both ImageJ and DStretch can run on PCs, Macs, and Linux computers. For more information visit [www.DStretch.com](http://www.DStretch.com).

### **Intuitive explanation of decorrelation stretch**

An intuitive explanation of how decorrelation stretch works can be gained by considering the histogram of an image. The histogram is the plot of the colors within the image in a three-dimensional colorspace. A simple example is the image of the moon rising against a dark hill (Figure 7). The histogram of a color image is a plot in some three-dimensional colorspace (in this case RGB) of the distribution of colors within the image. On the right of the image in Figure 7 are two views of the image histogram. Notice that most of the histogram of this image forms a blob near the origin in the dark blue part of the colorspace while the part from the moon falls in the bright yellow area of the colorspace.

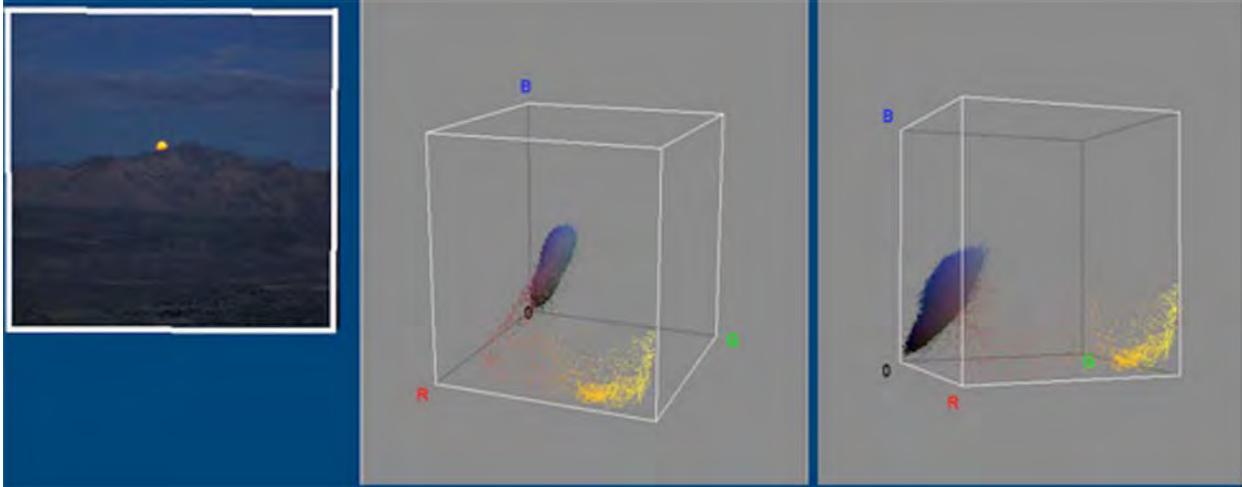


Figure 7. Moonrise photo with two views of histogram.

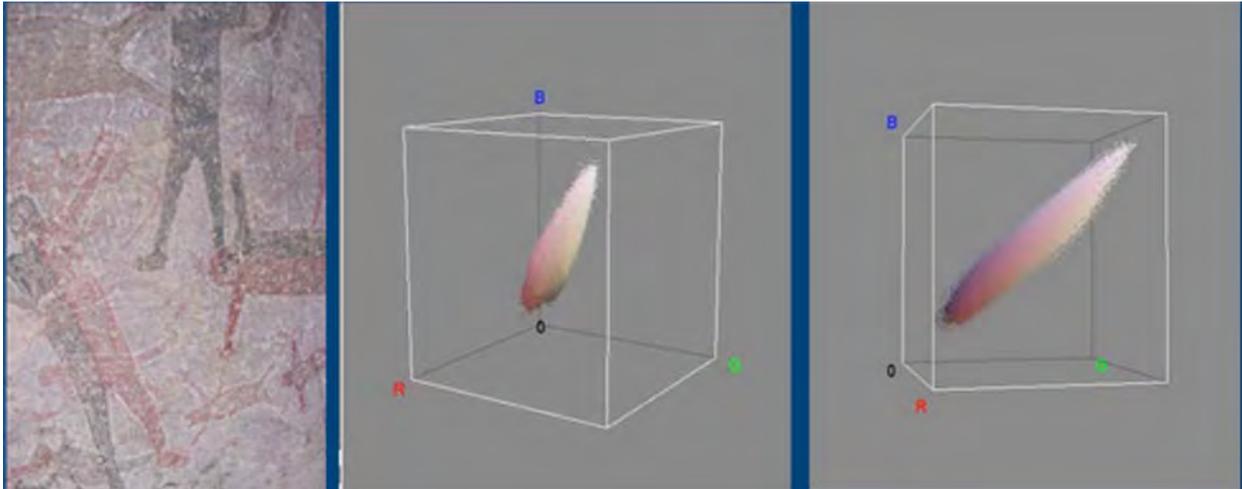


Figure 8. Original San Borjita image plus two histogram views.

The original image from San Borjita has a histogram that fills only a small portion of the colorspace (Figure 8). This is typical of rock art images. The color pallet is very restricted. The YDS enhancement has a histogram that fills the colorspace (Figure 9). The decorrelation stretch algorithm works by first transforming the image to decorrelate the colors, stretching the colors to equalize the variances, then transforming back. By expanding the colors in the image to use all the colors in the colorspace the algorithm enhances slight color differences. One can think of the decorrelation stretch process as taking the image into the “other” world, stretching it there, and then bringing it back (Figure 10). A stretch in the other world gives different results than one in this world, i.e. a simple contrast enhancement.

### The DStretch program

DStretch is written specifically for rock art enhancement. It performs decorrelation stretch automatically at the press of a button. Useful colorspace, special enhancements that

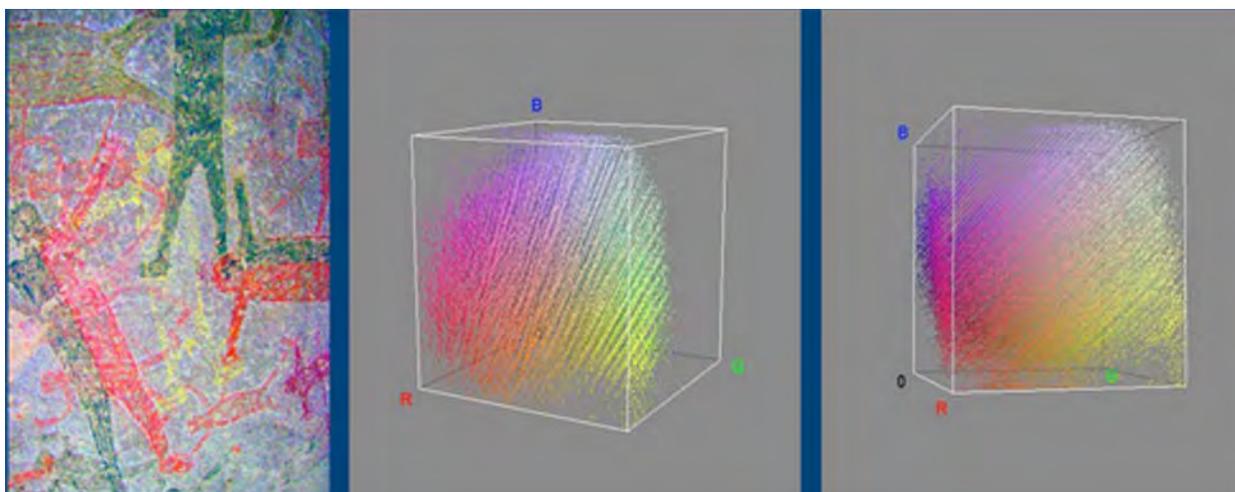


Figure 9. YDS decorrelation stretch image plus two histogram views.



Figure 10. Stretches of the image.

work well, and conventional enhancement tools are included.

DStretch requires a hue difference to work well. It works best on pictographs with red and yellow pigments. Blacks and whites are more difficult to enhance. I suggest trying three enhancements first: DStretch using the YDS colorspace, DStretch using the LAB colorspace, and the CRGB button. In the following example the three enhancements are shown for comparison.

An important feature of the DStretch program is its ease of use. The enhancements are automatic and require little expertise from the user. This allows DStretch to become a tool for quickly reviewing digital images from a site. It can bring out figures that might otherwise be missed and can clarify compositions. It becomes an extension of the eyes. It becomes routine to use it on all photos from a site just to check that nothing is missed.

Examples from Cueva La Trinidad near Mulegé, BCS will be used to demonstrate the DStretch user interface. In the upper left of the DStretch panel is a button labeled “DStretch” (Figure 11). Beneath that is a colorspace choice. Choose the colorspace (YDS) then hit the DStretch button. The result is shown in Figure 12. The YDS colorspace gives good enhancement

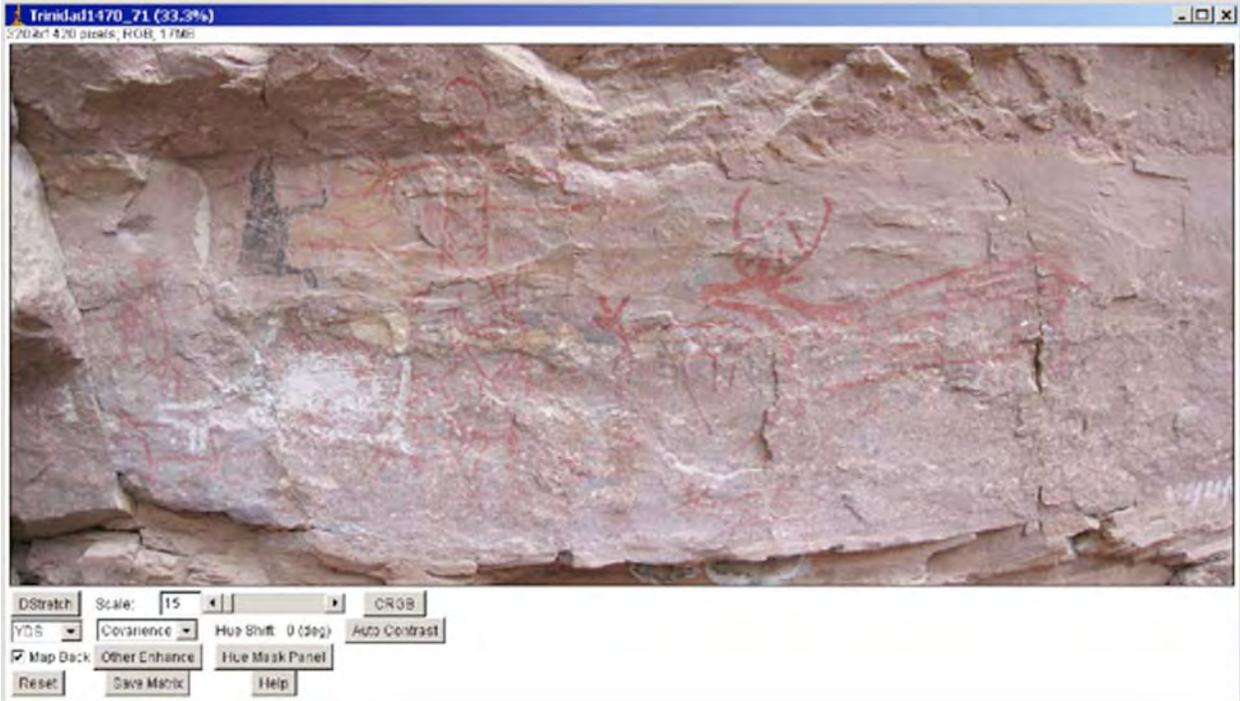


Figure 11. DStretch GUI.

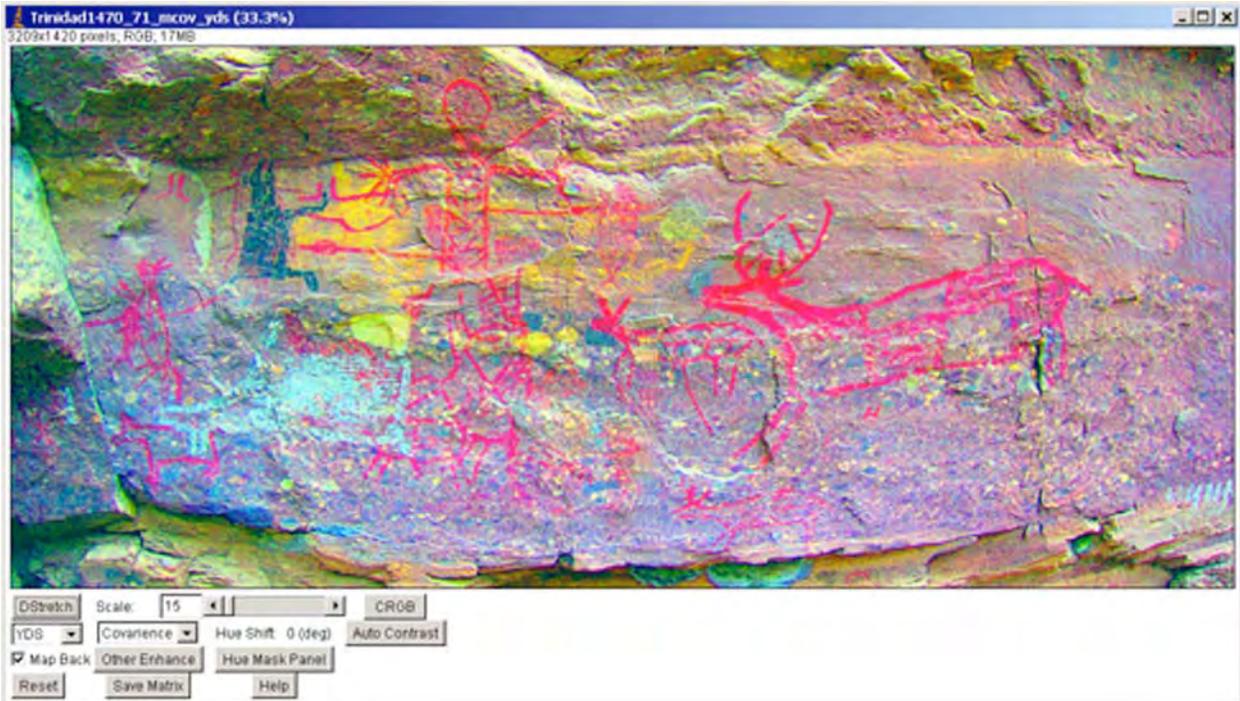


Figure 12. YDS enhancement.



Figure 13. LAB enhancement.

of red and yellow pigments. Press the reset button (bottom left), choose LAB colorspace then hit the DStretch button for another enhancement. This enhancement is shown in Figure 13. The LAB colorspace gives sharper images and is less affected by jpeg compression artifacts, but gives poorer enhancement of yellow pigments. Another button press (the CRGB button at right) gives an alternative enhancement that strikingly improves the visibility of the red pictographs (Figure 14).

Each DStretch enhancement calculates a matrix that transforms the colors in the image. Matrices that work well can be saved and used on other images. Also built into the program is one matrix for each colorspace that has proved to be useful. One particular matrix has shown great usefulness and has been given its own button on the panel. This is the CRGB enhancement. It gives a false color image. The enhancement used in the second Cueva Soledad image was also CRGB (Figure 5). Although the false colors of a CRGB enhancement can be very vivid, when converted to grayscale the result shows excellent contrast (Figure 15). This is very useful for publishing in cases when color cannot be used.

DStretch has several colorspace choices and other algorithm choices for enhancements. The following example shows just a few of the possibilities. A panel from Cueva La Trinidad is shown with three enhancements in Figure 16. The YDS enhancement does well on red and yellow pigments. It makes a yellow fish on the left and a turtle on the right visible. The LAB enhancement is sharpest and enhances black handprints well. The CRGB enhancement does especially well on red pigments, showing a large deer on the right that is nearly invisible in the original. Three more enhancements of the Trinidad panel use YCbCr, built-in LAB, and RGB colorspace (Figure 17). The many choices for enhancements give the DStretch user tools to tackle difficult problems.



Figure 14. CRGB enhancement.



Figure 15. Grayscale version of Figure 5.

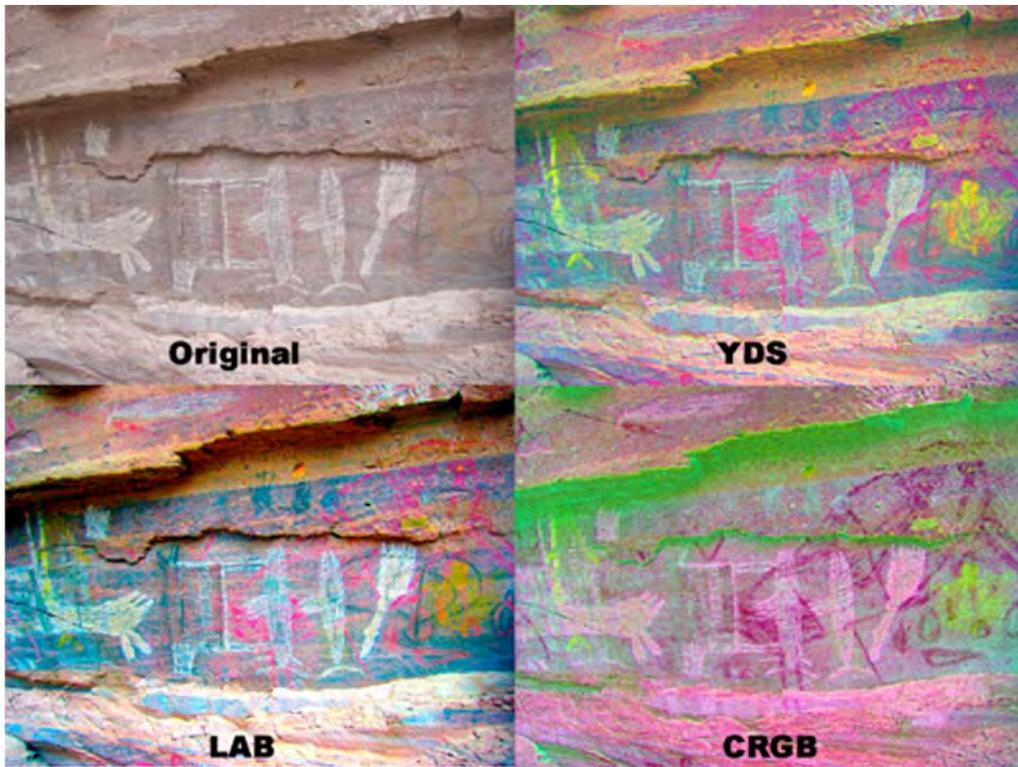


Figure 16. Enhancements using different colorspace.

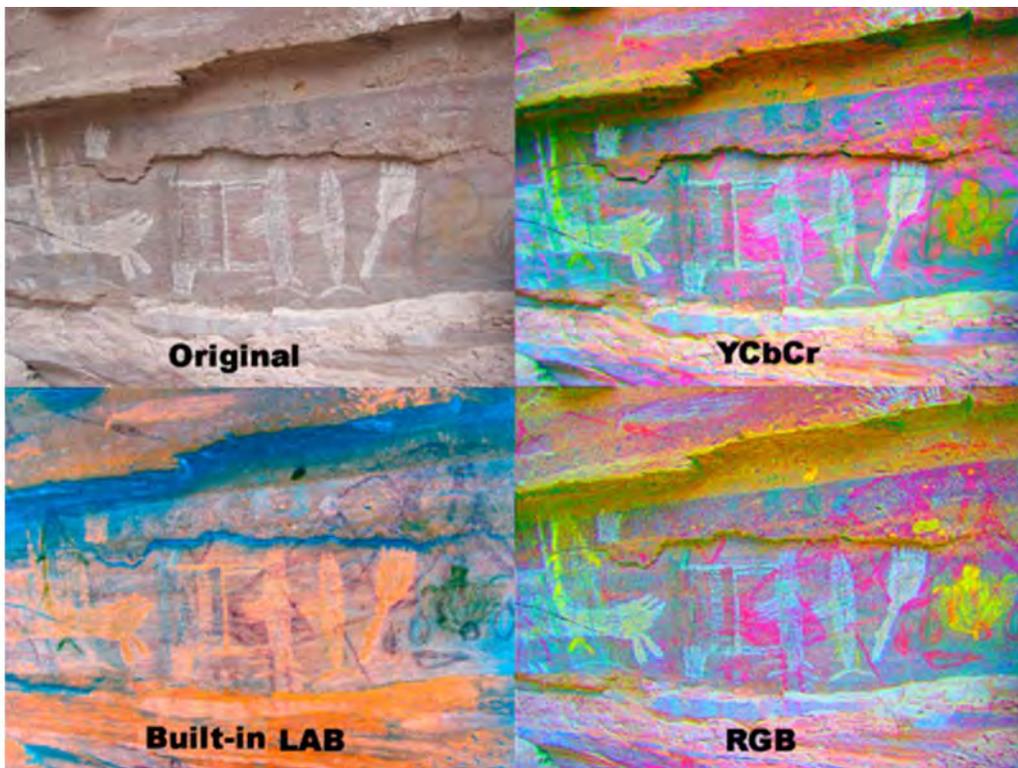


Figure 17. More colorspace enhancements.



Figure 18. Cueva San Borjita.



Figure 19. Cueva San Borjita, Diguet 1895.

### **Cueva San Borjita**

Cueva San Borjita is a well-known Great Mural site near Mulegé, Baja California Sur (Figure 18). Léon Diguet in 1895 (Figure 19) and Campbell Grant in 1974 have documented it. Campbell Grant included a masterful drawing of the entire painted surface (Figure 20). This fascinating cave continues to be studied today, as can be seen from a newspaper article that reports on new dates for the paintings (Figure 21).



Figure 20. Cueva San Borjita, Grant 1974.



Figure 21. Newspaper article posted at nearby rancho.



Figure 22. Detail from Grant's drawing (left) and my photo (right).



Figure 23. DStretch YDS (left) and LAB (right) enhancements.

Compare my photograph of a section of the cave wall with Campbell Grant's drawing (Figure 22). When decorrelation stretch is applied to the photo, a new figure appears that was missed by Grant. The YDS enhancement brings out the yellow figure nicely, while the LAB enhancement gives better contrast to the other figures (Figure 23). The yellow figure seems carefully positioned amongst the others. Overpainting and figure positioning in Great Mural art is a neglected subject that I will address a little in subsequent sections.

### **Cueva Pintada**

Cueva Pintada and nearby caves are the most famous Great Mural sites (Figure 24). They



Figure 24. Cueva Pintada.

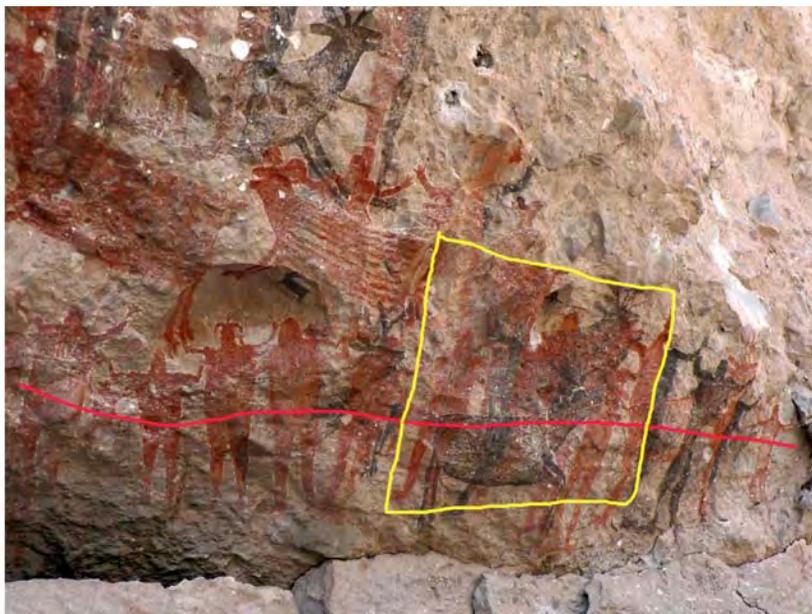


Figure 25. Cueva Pintada showing line of linked *monos*.

are located in the Sierra de San Francisco, Baja California Sur. Photos from these sites will be used to demonstrate the utility of DStretch in deciphering complicated or faded panels.

In studying overpainting in Great Mural art, I have become interested in examples of *monos* (and other Great Mural figures) that are linked together. The south gallery panel of Cueva Pintada has a line of linked *monos* (Figure 25). There is an area of dense painting in which the *monos* are obscured. A close-up of the densely painted area is hard to decipher (Figure 26). The CRGB enhancement does very well in bringing out the red parts of the figures and suppressing the black parts (figure 27). By studying the CRGB enhancement, it can be seen that the *monos* form an unbroken line linked by their arms.



Figure 26. Close-up of densely painted area.



Figure 27. CRGB enhancement.

## Cueva Soledad

Cueva Soledad is located near Cueva Pintada, but is not as well preserved. The main panel from Cueva Soledad is shown in Figure 28. As in Cueva Pintada, the panel contains many *monos*. A CRGB enhancement brings out the red parts of the figures and shows that there are two lines of linked *monos*, one above and one below (Figure 29).

A detail from the Soledad panel has hard-to-see red elements behind a black deer (Figure 30). The CRGB enhancement shows a red *mono* behind the deer that is linked to *monos* on either side (Figure 31). Other red figures appear, such as the deer on the left, which were nearly invisible in the original photograph. The central black deer can be emphasized by using one of the built-in matrices available in DStretch. Figure 32 uses the built-in LAB matrix.



Figure 28. Cueva Soledad.

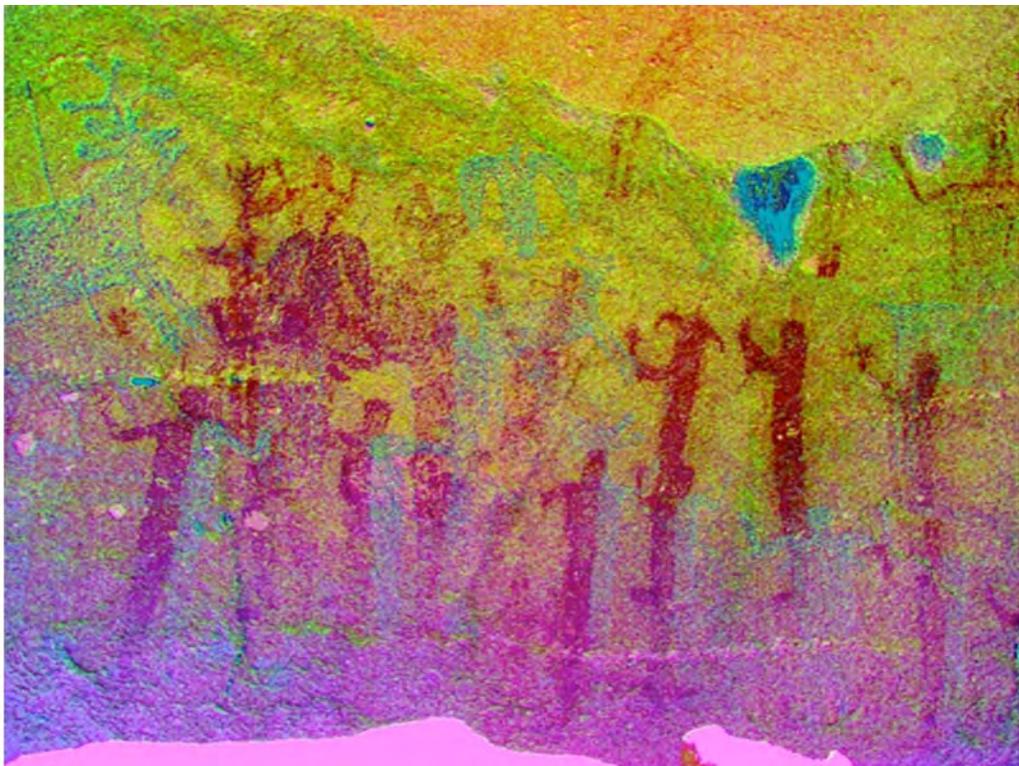


Figure 29. CRGB enhancement.



Figure 30. Detail of Cueva Soledad panel.

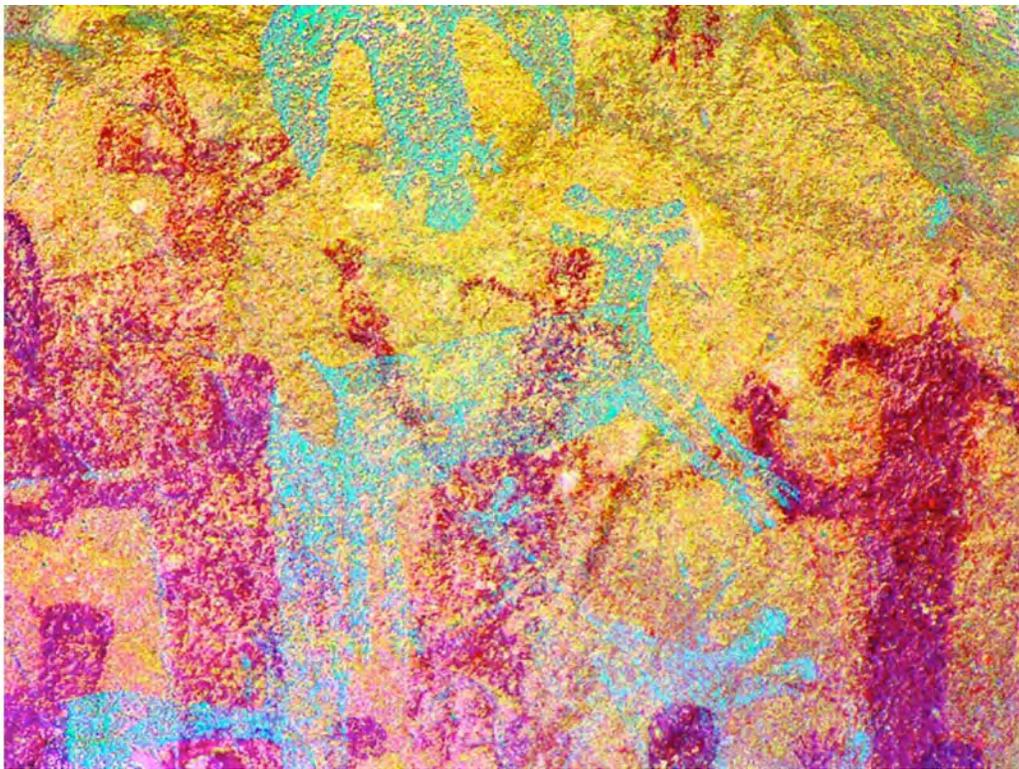


Figure 31. CRGB enhancement.



Figure 32. Built-in LAB enhancement.



Figure 33. Cueva Flechas, LAB enhancement.

### **Cueva Flechas**

Another cave near Pintada is Cueva Flechas. This cave has a beautifully preserved main panel as shown in a LAB enhancement (Figure 33), but it also contains less visible panels.

Often the utility of enhancement is not so much that it makes faint elements visible, but that it makes them stand out well enough so that it becomes easier to appreciate the panel



Figure 34. Faint deer from Cueva Flechas.



Figure 35. CRGB enhancement.

composition. For an example consider the outlined deer in Figure 34. CRGB improves the visibility (Figure 35). Converted to grayscale, the CRGB enhancement is also very good (Figure 36). The graceful composition of the running deer becomes much easier to appreciate.

### **Cueva Boca de San Julio**

Cueva Boca de San Julio is located about 1 mi. from Cueva Pintada. It contains beautifully painted deer, linked together, but few *monos* (Figure 37).

DStretch has a feature that allows the user to shift all the hues in an image. This can be used to increase the visibility of some features, as shown in the following example. A YDS



Figure 36. CRGB converted to grayscale.



Figure 37. Cueva Boca de San Julio.

enhancement somewhat improves the visibility of a *mono* behind a deer (Figure 38). Using the hue shift feature of DStretch, the *mono* is made even more visible in a striking false color image (Figure 39).

The final example also comes from Cueva Boca de San Julio. Figure 40 shows a close-up of the deer at the right in Figure 38. The built-in LAB enhancement shows details inside the deer, including two fish originally done in red. There seems to also be a fish on the right, originally in black, over the neck of the deer. The dotted lines, originally in red, appearing at the right of the deer, can be seen to cross the entire deer and connect with the small *mono* at left (Figure 41).



Figure 38. YDS enhancement.



Figure 39. YDS enhancement hue shifted by 254°.



Figure 40. Cueva Boca de San Julio.

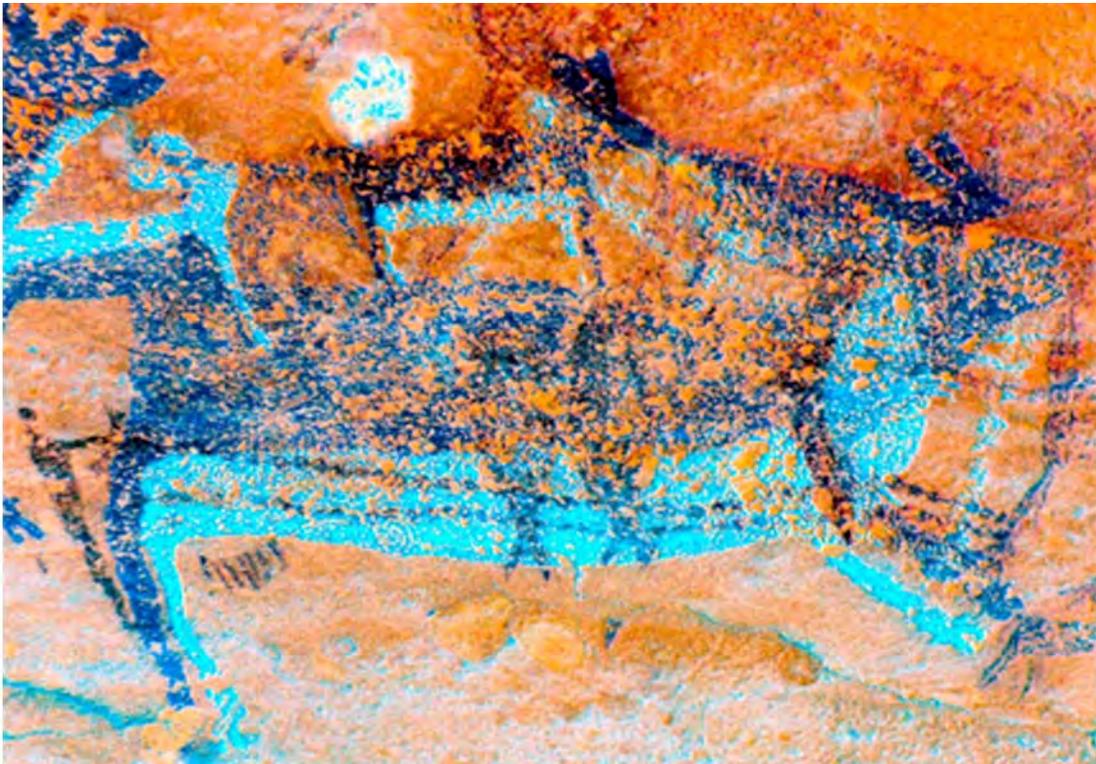


Figure 41. Built-in LAB enhancement.

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