Comparison of Astronaut Visual Color Observations With ASTP Photographs

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ABSTRACT

Visual observations of the color of both desert and ocean scenes, made by the U.S. astronauts on the Apollo-Soyuz mission, were analyzed and compared to photographs of the same regions. During the mission, use of Munsell color chips on a specially developed "color wheel" made the comparison possible. Colors on photographs never exactly match those observed from space; available films are less color sensitive than the human eye and do not capture the true Earth colors. Determination of a color correction factor for use with the photographs was not possible because of the inconsistent variations in measured colors and because of the meager statistical basis. It is recommended that additional observations be made from Earth orbit utilizing uniformly illuminated color chips. This would allow meaningful correlations between natural colors as seen from space and those depicted on orbital photographs.

INTRODUCTION

Astronauts of the Gemini, Apollo, and Skylab missions consistently reported that Earth colors observed from space were not captured accurately on film. As a result, visual color observations were planned as part of the Earth Observations and Photography Experiment (refs. 1 and 2) on the Apollo-Soyuz Test Project (ASTP). An attempt was made to quantify the color observations by the use of standard color chips. In addition to the knowledge of actual Earth color, it was hoped that astronaut visual color observations could be used to calibrate the colors on the photographs.

It was recently realized that color is an important parameter in studying orbital photographs. For example, in oceanography, measurements of water color are important in identifying distinct ocean currents, eddies, and areas of biological productivity (ref. 3). Also, in desert regions, a study of color variations could supply information on sand sources and the relative ages of sand seas (ref. 4).

WHAT IS COLOR?

Color is a phenomenon of light that depends on wavelength, specifically as seen by the eye. Light waves have different wavelengths; monochromatic light has its energy concentrated in a single wavelength, and white light or sunlight has an even distribution of energy throughout the visible spectrum (wavelength ranges from 380 to 720 nm). The latter is the band of light that develops when light passes through a prism and is broken down into its component colors composed of red, orange, yellow, green, blue, indigo, and violet. Red light has the longest wavelengths, and violet the shortest. When light falls on an object, some of the light is absorbed and some is reflected. An object observed in daylight appears in the color of the reflected waves.

The ability to discriminate light on the basis of its wavelength composition is called color vision. The eye is assumed to have visual receptors that

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respond differently to the various wavelengths of the visible light. As far as human vision is concerned, the commonly accepted view is that there are three or more types of receptors that possess pigments, which selectively absorb light from a particular region of the visible spectrum.

Colors in nature usually occur in an infinite number of mixtures; one seldom encounters a surface whose color is narrowly tuned to a single wavelength of light. The human eye is a very sensitive color sensor; it is more sensitive to subtle color variations than any instrument or film. Under laboratory conditions, the eye is estimated to be able to distinguish 7.5 million color surfaces, a precision that is two to three times better than most photoelectric spectrophotometers (ref. 5).

ASTP COLOR WHEEL

An important objective of the Earth Observations and Photography Experiment was to quantify desert and water colors observed by the astronauts during orbit. This was achieved through the use of a two-sided color wheel composed of carefully selected colors (fig. 1). Numerous versions of the color wheel were used by the crew during flyover exercises to obtain data on land and water colors. Actually, the colors of the wheel were selected on the basis of experience gained during the flyovers.

The color wheel, fabricated at NASA Lyndon B. Johnson Space Center (JSC),[1] was in a "doughnut" shape with a 20.3-cm (8 in.) diameter and a 12.7-cm (5 in.) central hole. It was constructed of 3-mm (1/8 in.) thick aluminum with double rows of Munsell standard color chips fastened to both sides. Each color chip was identified with a row identifier ("A" or "B") and a number that established its position in the row. A total of 108 different color chips were fastened onto the wheel; 54 color chips for desert colors on one side and an equal number for ocean colors on the other. The doughnut configuration allowed the crewmembers to conveniently hold the device and to rotate it until the proper color in either row "A" or "B" matched the scene on the Earth's surface.

Each color chip on the wheel corresponds to a color of the Munsell system (ref. 6). In this system, every color is identified by three basic attributes: hue, value, and chroma. These three properties form a three-dimensional balance, which the human eye perceives as a single color. Hue can be defined as the name of a color. It is that quality by which we distinguish one color family from another, as red from yellow, or green from blue (ref. 6, p. 15). There are five principal hues: red, yellow, green, blue, and purple. Five additional hues are formed by their intermediate combinations, YR, GY, BG, PB, RP, forming a continuous spectrum. Value is the lightness or darkness of a color. A light gray would have a high value, and black would have a very low value. Chroma is defined as the intensity, saturation, or strength of a color. A weak red has a lower chroma than a vibrant, strong red. Variation in either of these three attributes changes the exact color that is perceived.

Notation of color in the Munsell system takes the following form: Hue Value/ Chroma (H V/C). Hue is noted first by the initials of one of the 10 principal hues. A finer division of hue is obtained by dividing each hue into four subdivisions: 2.5, 5, 7.5, and 10. A 2.5YR is closer to the red end of the spectrum and a 10YR is closer to the yellow. However, both are yellow-red in hue. Value is noted next. It ranges from 1 (very dark, black) to 10 (very light, white). On the color wheel most chips range between values of 3 to 8. Chroma is the last color attribute to be noted. Each color chip on the wheel represents an even increment of chroma ranging between 4 and 12. Thus, any numbered chip on the color wheel can be put into Munsell notation; for example, color 16A on the wheel is 5YR 6/6 in the Munsell system (fig. 1).

VISUAL COLOR OBSERVATIONS

As previously stated, one of the principal objectives of the Earth Observations and Photography Experiment involved the use of a color wheel to quantify the visual observations of desert and ocean colors. During the mission, the ASTP

[1] Robert Wolfe of the Smithsonian Institution assisted James Regan of JSC in the preparation of the color wheel.

crewmembers held the color wheel up to the spacecraft window and noted the number of the Munsell color chip that best matched the color of the scene below. A total of 13 color comparisons were made in this manner.

Observations of desert areas included the Gran Desierto (16A); the Simpson Desert (6A); the Sahara Desert north of Lake Chad (25A); and Western Australia (9A). (For identification of desert colors see fig. 1(a).)

Ocean color observations were made over the Pacific Ocean northeast of New Zealand (47B); the Pacific Ocean east of Hawaii (47B); the Pacific Ocean off the coast of San Francisco (47B); the Mediterranean Sea between Tripoli and Sicily (36); the Caribbean Sea southeast of Jamaica (42A); current boundaries in the north Atlantic (37 to 41); and the Gulf of Mexico near the Mississippi coast (47B to 45B). (For identification of ocean colors see fig. 1(b).)

During some visual observation passes, viewing conditions were excellent, as clearly indicated by the following comments between the Apollo commander (ACDR), command module pilot (CMP), and capsule communicator (CAPCOM) (ref. 2, p. 149-150):

CMP — Hey, we're going over the Simpson Desert right now. And it's just fantastic. It's got dunes in it. It looks like they are very long, and they look like road tracks there are so many of them—like hundreds of parallel road tracks. And we'll comment on it in our usual fashion with the onboard tape recorder . . . .

ACDR — Yeah, and the long red streaks are matching about color 10, I would say, on Farouk's (color) wheel.

CAPCOM — Thanks a lot for the input; wish I could see it myself. Beano and I are whipping out our color chart and seeing what color it is ourselves.

CMP — This is one of those cases where there was light coming in the window, falling on the color chart. And that made it easy to use. Sometimes when it's in the shadow, it's hard.

CAPCOM — Roger. Understand. Incidentally if you ever do have a question about the chart or any comment on it, we've got one here at the console that's just about identical to yours, I think.

ACDR — And some of those long streaks, those long sand streaks, could have either gone between 9 and 10.

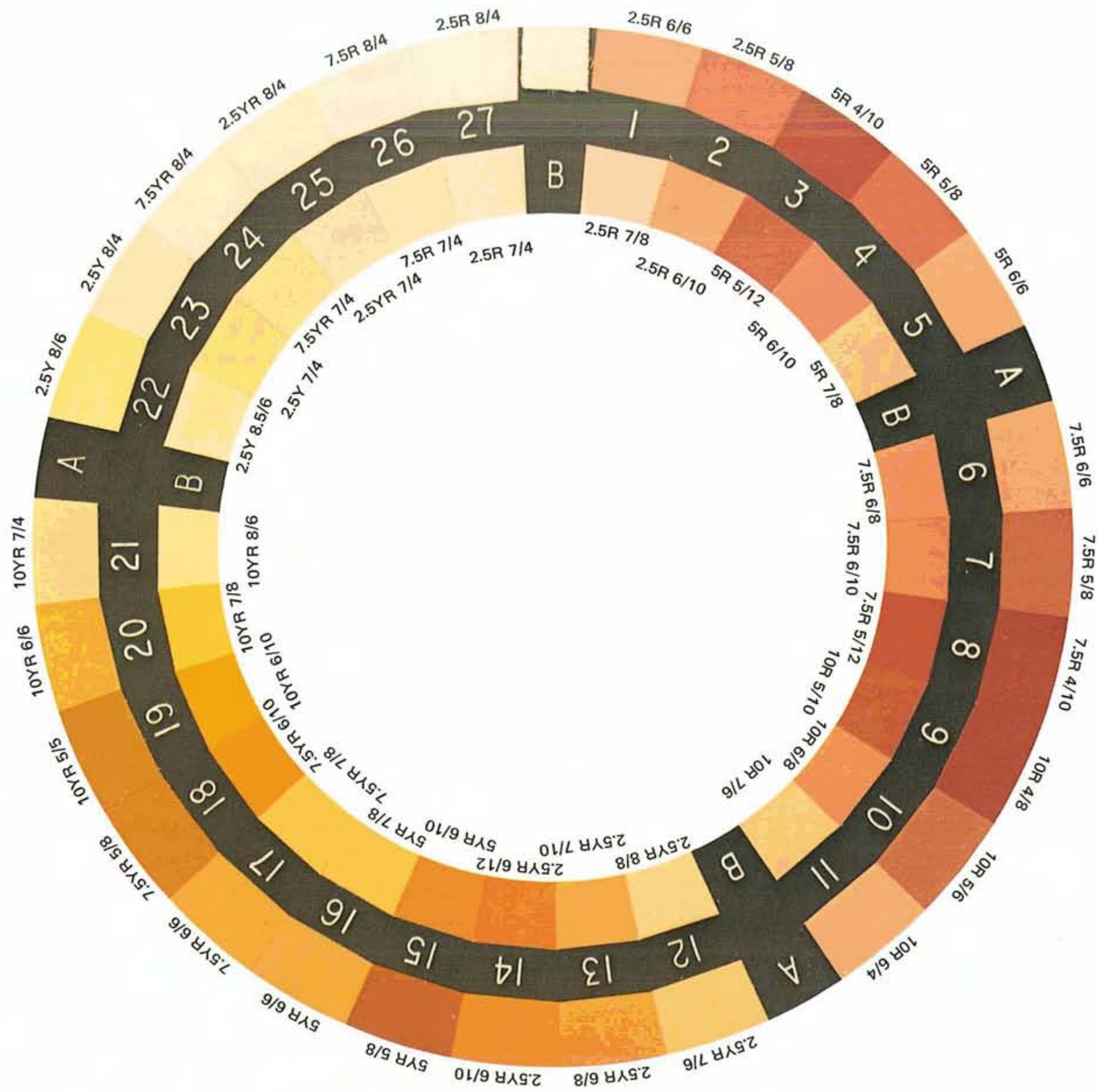
CAPCOM — Okay, thanks, Tom. Could you differentiate 9 or 10-A or B? Are they dark or light?

ACDR — Now that the sun gets on the wheel where I can see it, it was more like 9. Oh, I'm sorry. Okay. Be about like 9-A.

However, the ASTP color observations were not always made under the best possible viewing conditions. A number of factors, including spacecraft attitude, Sun angle, and atmospheric conditions, influenced the color comparisons and perhaps even affected their validity. The astronauts were aware of these problems, and early in the mission, they informed the Earth observations support team of the difficulties they sometimes encountered in using the color wheel.

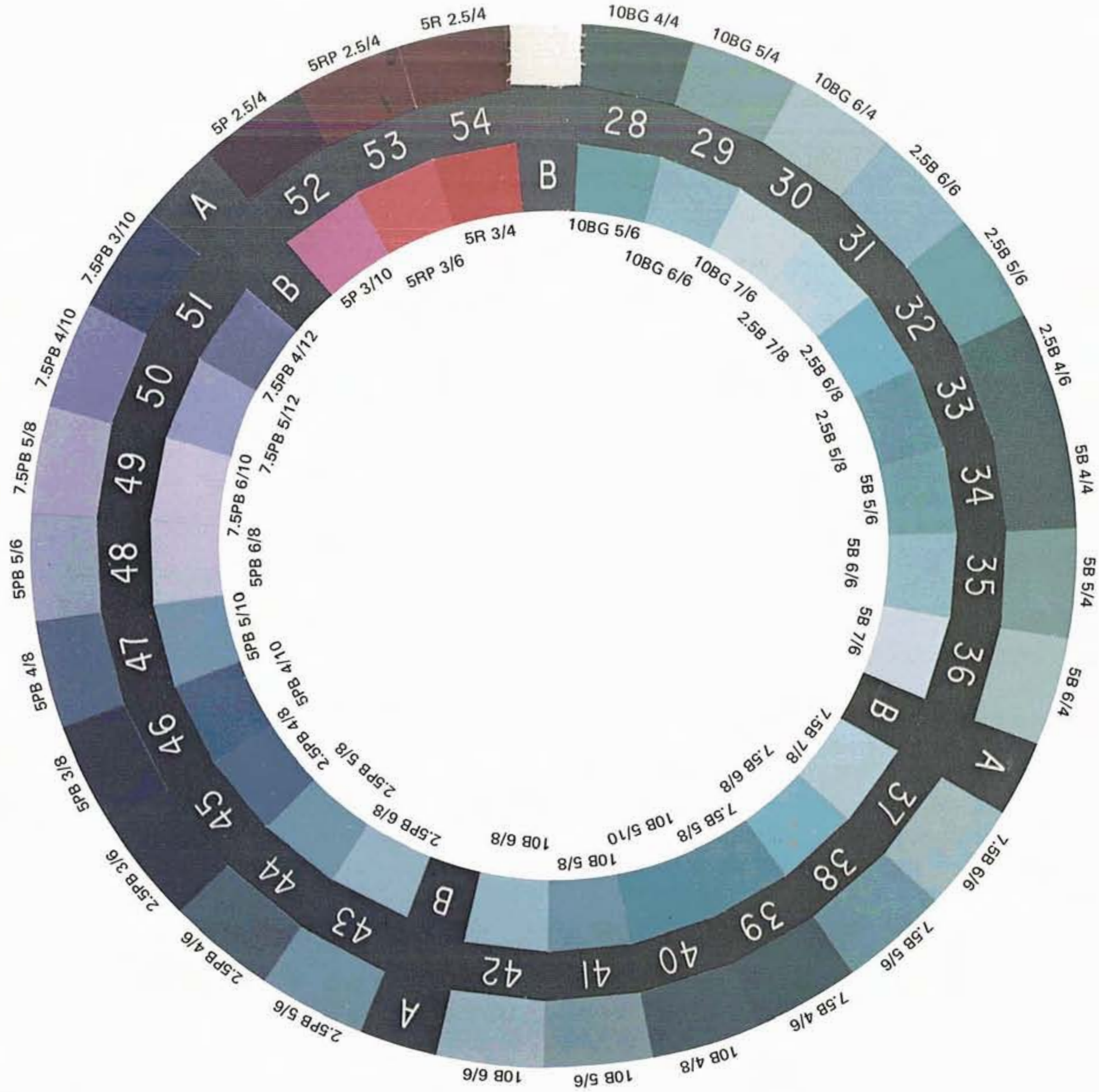
The main problem involved the varying lighting conditions within the spacecraft cabin. The astronauts found it difficult to compare the colors of a sunlit target with the Munsell color chips when the color wheel was shaded from the Sun. After the mission, this problem was discussed during the technical crew debriefings. The docking module pilot (DMP) and CMP commented as follows (ref. 2, p. 182):

DMP — But it (the color wheel) worked pretty good in the airplane where you get lighting behind it which corresponds with the lighting you're seeing on the ground. And in the spacecraft, you're always in the shade with the color wheel, but you are looking at (something) in the sunshine and trying to compare the two is like comparing apples with oranges. And the only way I could



(a)

FIGURE 1.—The two-sided color wheel used by Apollo astronauts for visual comparison with colors of observed Earth scenes. Color chips were given numbers arranged in two rows, "A" and "B." Munsell color notations are given near the corresponding chips. (a) Desert colors. (b) Ocean colors.



(b)

FIGURE 1.—Concluded.

DMP Concluded	come up with anything even close, I'd look out the window and then I'd come back in the cockpit and get the color wheel in the light, and look at that and say, I think that was close to what I was looking at.
CMP	My technique was to hold the color wheel sideways in the window and hope some light would shine on it.

Because of the viewing problems they encountered, the crew recommended the development of a handheld optical color comparator. If developed, this device would be about the size of a pair of binoculars. Through one half of the instrument the Earth could be viewed; the other half would "contain a uniformly lighted color screen, which could be varied to obtain ground/screen color comparisons" (ref. 2, p. 119).

COLOR OF ASTP PHOTOGRAPHS

The conventional interpretive procedures used with aerial photographs are different for Earth orbital photographs, largely because of the latter's greater regional coverage and frequent obliquity. For orbital photographs, photointerpreters find that color and texture are the most important recognition elements. Color is especially significant because natural colors are meaningful and are often important indicators of the identity of surface features. The human eye is able to distinguish significantly more color surfaces than gray tones. Because of this, most photointerpreters agree that color photographs are more useful and more informative than black-and-white photographs.

The geologist uses color variations to detect features such as boundaries between geological formations and to make gross lithological discriminations for thematic mapping. Studies of regional tectonic patterns, which include detection of faults, fractures, and folds, are also facilitated by the use of color orbital photographs.

Desert specialists use orbital photographs to study variations in the colors of desert sands. These color variations are meaningful and could provide information on the chemical makeup and relative ages of sand bodies. Desert sands often contain iron compounds, and the red color of many sand seas is due to the presence of iron oxide (hematite) coatings on individual grains. The degree of reddening in sands of uniform aridity, and derived from the same source, could be used to determine the relative ages of the sands (for example, ref. 4).

In the Western Sahara, the ASTP crewmembers noted the occurrence of reddened sands in a large expanse of the Algerian Desert (ref. 2, pp. 77 and 141) (fig. 2):

DMP	Oh, there's some really heavy clouds of sand blowing down there; some darker rock hills sticking out. . . . Some very red sand to the north. In fact, it looks almost like a massive parabolic sand dune, black with red sand behind it. And we're coming up on a large band of very black barren-looking hills with great red areas interspersed between them . . . .

The astronauts also noticed that in the Sahara the colors of desert sands were generally lighter along the Mediterranean coast. This sequence of the redder and presumably older sands accumulating inland away from the brighter and more yellow sands along the coastline is duplicated in the Namib Desert of southwestern Africa (refs. 2 and 7).

Color variations are also important to oceanographers, and accurate measurements of water color can help identify distinct ocean currents, eddies, and areas of biological productivity (ref. 3). On orbital photographs, a body of water may exhibit a wide variation in color, which could be a function of a number of factors such as Sun angle, water surface roughness, suspended sediments, and bottom topography (ref. 8, p. 1487). Theories concerning the optical properties of water suggest that a pure, deep body of water would be blue. Discoloration of water would occur as a result of the presence of (1) organic or nonorganic particles, such as suspended river sediments discharged into the ocean; (2) life forms such as red tide phytoplankton; and (3) bottom

FIGURE 2.—ASTP photograph showing various hues of reddened sands in part of the Algerian Desert (AST-17-1339).

topography in shallow water (ref. 8, p. 1488). For example, figure 3 illustrates the differences in water color between shallow and deep water bodies. In this ASTP photograph of Aitutaki Atoll in the Cook Islands, the triangular-shaped atoll is distinguished by the light blue color of the shallow lagoonal waters enclosed by a coral reef. The surrounding ocean waters are a deeper, darker blue.

It is difficult for a color film to reproduce a scene with total color fidelity, largely because available films are less color sensitive than the human eye and do not capture the true Earth colors. In addition, a number of other factors, such as Sun angle, atmospheric conditions, and film processing procedures, will influence the colors recorded on film. From the authors' own

FIGURE 3.—ASTP photograph of Aitutaki Atoll in the Cook Islands. Note the differences in water color between the shallow lagoonal waters and the surrounding deep ocean waters (AST-1-39).

experience they have found that the color prints made from the same negative can differ greatly if processing conditions are not strictly controlled.

The effects of Sun angle and atmospheric conditions are illustrated in figure 4. These three photographs were taken over different sections of the Great Barrier Reef, which extends more than 2000 km along the eastern coast of Australia. Figure 4(a) is overexposed, which darkens and deepens water color and suppresses the brighter hues of the shoals. Figure 4(b) was taken under haze conditions, which reduces contrast at the land/water interface and gives the whole photograph a blurry appearance. Figure 4(c) was taken at a low Sun-illumination angle, which drastically changes water color but, in the meantime, enhances water surface texture. This particular photograph was taken with a Sun azimuth angle which allowed direct reflection that simulated sunglint conditions. These three photographs clearly show how ocean colors can drastically vary with variation in Sun illumination conditions.

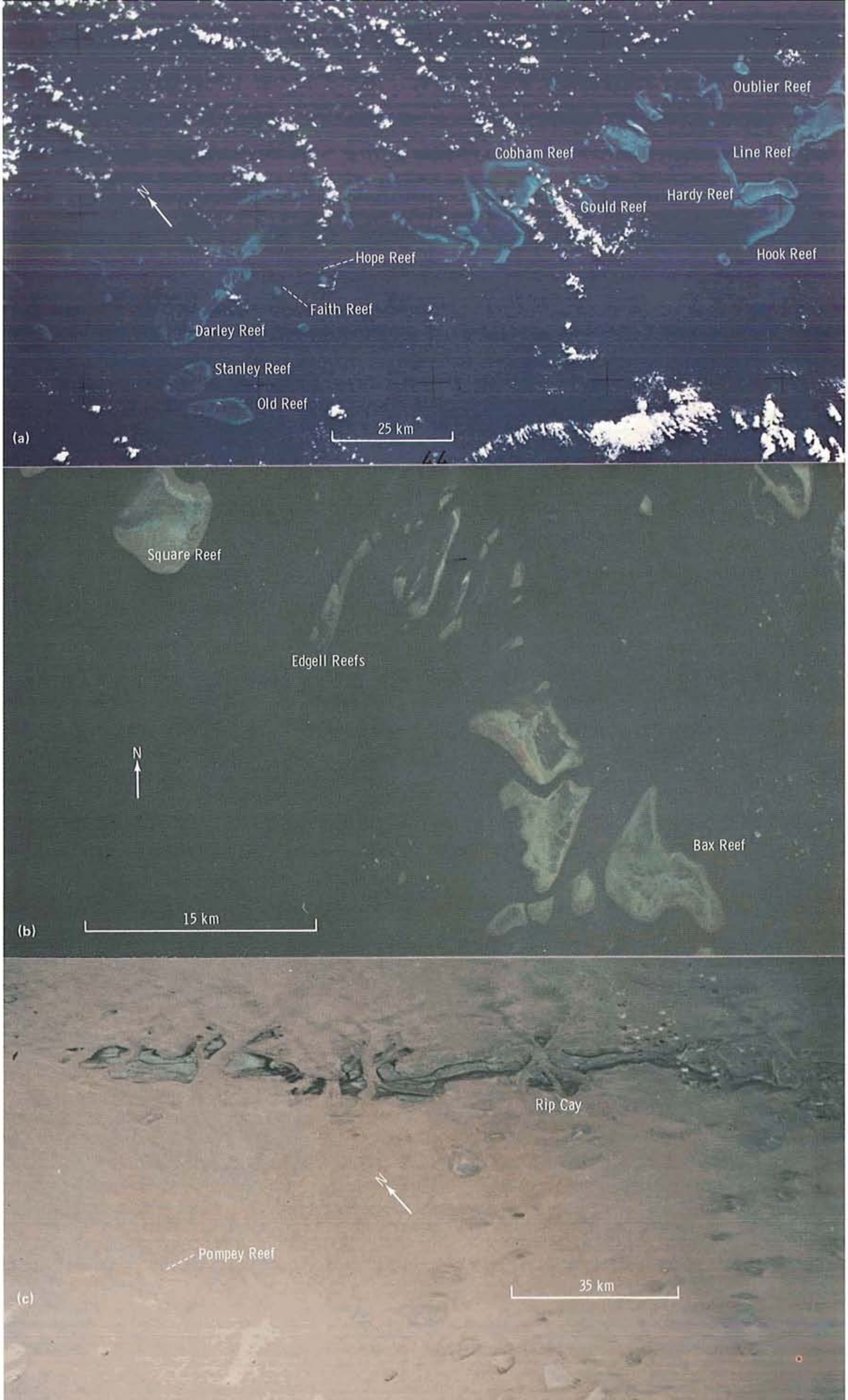
CONCLUSIONS

Visual color observations from Earth orbit complement photographic data. Color photographs, although they can depict subtle color changes in the photographed scene, do not faithfully capture natural colors. For this reason, the human eye can be efficiently used to add significant data in support of photointerpretation.

The observation aids used on ASTP fell short of achieving valid color comparisons. It is recommended that, for future space missions, particularly Shuttle flights, a better color-comparison aid be developed. This aid should have consistent internal lighting and should also permit the observer to mix various colors to achieve the best match.

Perhaps this type of observation aid could be achieved with a device resembling binoculars. Through one eyepiece the Earth could be viewed; the other half could contain an internally illuminated color screen. This device would provide a simultaneous view of the color screen and the target.

FIGURE 4.—Three ASTP photographs over parts of the Great Barrier Reef, Australia, illustrating how the ocean colors captured on film are affected by variations in Sun illumination conditions. (a) Overexposure (AST-16-1153). (b) Hazy atmospheric conditions (AST-2-103). (c) Low Sun-illumination angle (AST-1-46). →



Oublier Reef
Cobham Reef
Line Reef
Hardy Reef
Gould Reef
N
Hope Reef
Hook Reef
Faith Reef
Darley Reef
Stanley Reef
Old Reef
25 km
(a)
Square Reef
Edgell Reefs
N
Bax Reef
15 km
(b)
Rip Cay
N
Pompey Reef
35 km
(c)

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