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INTRODUCTION

In two companion papers (Simonett and Henderson, 1969; Schwarz et. al., 1969) we have discussed the problems of thematic mapping from space by focusing attention on line and point phenomena, namely, detection of roads on a space photograph of the Dallas-Fort Worth area, and categorization of land use in Eastern Kansas on the basis of 40-acre decision cells. In this paper we are concerned primarily with a third problem, namely that of boundary delineation as a precursor to area typing.

The example now to be discussed concerns resource mapping of a natural environment near Alice Springs, Central Australia, where both boundary detection and categorization are complicated by the inherent complexity of landscape elements. In this environment we are not dealing with the same degree of patterned regularity found in cultural landscapes; nor are we dealing with more or less discrete entities such as crop types and roads, or cultural vs. natural phenomena. Instead nature has provided in this region a continuous variation in space of the several elements: terrain, soil surface, and vegetation. We know from principles of geography and ecology that such variation is not random, and were we to study it on (or near) the ground, we could eventually decipher all the intricacies of the patterns. When viewed from space, however, the very meaning and composition of boundaries, to say nothing of the "things" they separate, become increasingly ambiguous.

Two themes will be pursued in the Central Australian study to illustrate some advantages and disadvantages of using space photography in world resource inventories. The first concerns itself with the detection and meaning of boundaries, the second with sources of confusion during categorization.

In the discussion to follow we will demonstrate that space detected boundaries, regardless of their apparent obscurity, derive substantially from ground information. Direct comparison of boundaries in the field with those on the space photograph, as well as indirect line by line comparisons using low altitude obliques and photo mosaics, have



Figure 1. Location Map for the region northwest of Alice Springs, Central Australia. The numbers give the locations of air photo mosaics in Figures 13 and 14.

shown without question that even the smallest pin pricks of space data relate to qualitative changes in the landscape. Moreover, space boundaries are often easier to detect than are identical boundaries on photo mosaics.

Detecting a boundary and knowing that the landscape is somehow different either side of it is not the same as knowing either the nature or magnitude of that difference, nor is it to be presumed that the boundaries lie all at the same hierarchical level in a classification. Since generalizing is unavoidable in space photography due to current resolution limitations, boundaries may result from changes in one or several features of the environment, none or all of which may be significant in a particular resource inventory. While the boundary has meaning, therefore, it may not be one we wish to map.

Categorization is also related to this problem of generalization. Image discrimination functions such as texture, height etc. have restricted values in space photo interpretation. Tone is the most versatile of the image qualities but its limitation should be appreciated. Disjunct shades of similar color on the space photo sometimes relate to dissimilar combinations of elements in the landscape. Equally serious, dissimilar colors sometimes contain a similar combination of elements but in different proportions or under different illumination. In both cases substantial errors of interpretation arise, even among experienced interpreters.

The Alice Springs area was photographed with Ektachrome MS Aerographic 70 MM film in August 1965 by the crew of Gemini V. Figure 1 is a photo enlargement on which the main geographic features have been identified. This photo was selected for study because it is representative of the mapping problems to be encountered in very large regions of the semi-arid and arid tropics. In addition, the original photograph is of acceptable to good quality despite a substantial haze scattering in the blue and to a lesser degree even the green sensitive layers (Figure 7). Three of the investigators (Simonett, Cochrane, Morain) have been to the Alice Springs area on separate occasions and between us we have spent seven weeks in the field studying the soils, vegetation and topo-

graphy.¹ This is immensely important from the point of view of categorizing areas delineated on the photo. In addition, one of us (Simonett) has conducted aerial and ground reconnaissance of the region with space-photo-in-hand for purposes of comparing boundaries, and obtaining low altitude aerial oblique and ground photos for laboratory comparisons. Finally, although the area is remote, the natural environment is fairly well known thanks to the efforts of R. A. Perry and his colleagues at CSIRO Division of Land Research. Perry's (1961) pasture map of the area is particularly valuable as a source of information and comparison.

NATURAL FEATURES OF THE ALICE SPRINGS AREA

The Alice Springs study area (Figure 1) covers almost 21,000 square miles of country in semi-arid central Australia. It stretches from the James and Krichauff ranges in the south, and includes most of Missionary Plain, a large part of the Macdonnell and Chewings Ranges, all of Napperby Lake and Stuart Bluff Range and terminates at Mt. Denison in the north. Alice Springs itself is located on the lower right margin of the photo. The following brief discussion of landscape types draws heavily from the works of Perry (1960) and Perry et. al. (1962).

Physiographically four major landscape divisions are delimited on the Perry Pasture Map. These are:

1. Folded Ranges: represented on the photo by the James, Waterhouse, Macdonnell, Hann and Stuart Bluff Ranges.
2. Crystalline Uplands: Reynolds ranges, Crown Hill, Pine Hill.
3. Crystalline Ranges: Strangways Range, Mt. Chapple, Mt. Hay, Mt. Zeil, Mt. Heughlin, Redbank Hill.

¹At the time of writing of this report G. R. Cochrane is engaged in an additional 5 weeks of field work and low altitude aerial photographic studies in the area.

LANDSCAPES NORTHWEST OF ALICE SPRINGS, CENTRAL AUSTRALIA

Base: C.S.I.R.O. Pasture Land Map, 1961

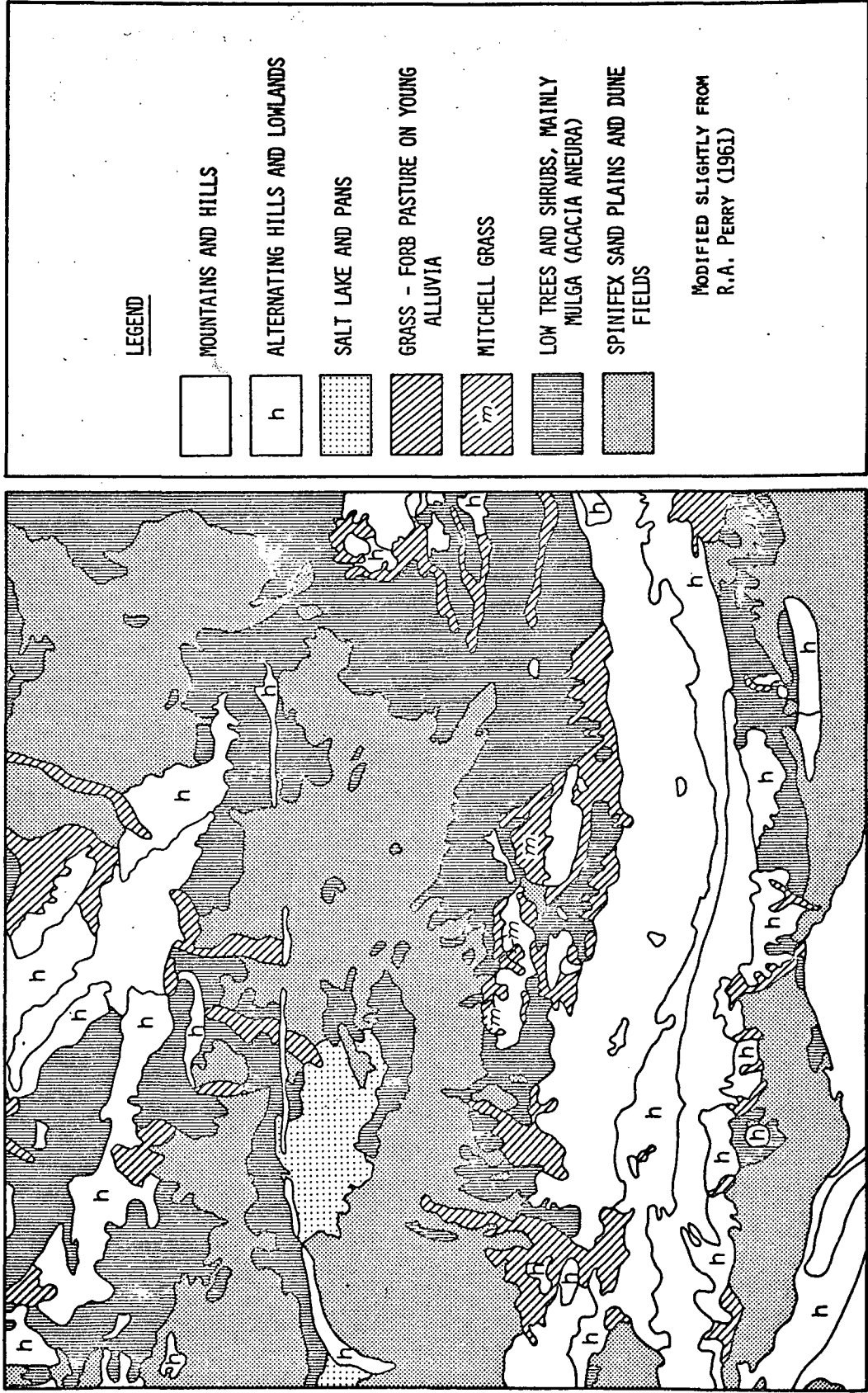


Figure 2. Landscapes northwest of Alice Springs, Central Australia. Modified slightly from R. A. Perry (1961), Pasture Land Map.

4. Northern Plains: Burt Plain, Everard Scrub, Missionary Plain (the last is not included by Perry as part of this category).

All of the ranges and uplands have large bare-rock outcrops and skeletal or shallow, stony soils. In the plains areas, soils are generally characterized as red sands, red clayey sands and red earths. Saline soils and unconsolidated sands are usually found along drainage lines and at Napperby Lake.

When vegetation types are superimposed on the physiographic and soil patterns, seven broad landscape types may be recognized. Figure 2 illustrates the distribution of these environments as mapped by Perry et al. (1962). Where possible the broad categories are defined in terms of vegetation even though in most circumstances the plant cover is open or very sparse. What is actually recorded on the space photograph is the spectral reflectance not only of vegetation but of rock and soil surface as well.

The seven landscape types delineated on Figure 2 are:

1. Mountains and Hills 2. Alternating Hills and Lowlands
3. Salt Lake and Pans 4. Grass-Forb Pasture on Young Alluvia
5. Mitchell Grass 6. Low Trees and Shrubs, Mainly
7. Spinifex Sand Plains Mulga (Acacia Anuera)
and Dune Fields

Of these landscape units the Mountains and Hills and Alternating Hills and Lowlands categories have intricate mixtures of the other five categories recognized. The scale of these mixtures is far too small to detect or map on the space photo. Some discrimination of the larger entities may be feasible on say 10 X enlargements but uncertainties arising from shadowing and highlighting will prevent even modestly reliable categorization.

Salt Pans and Salt Lakes are largely bare of vegetation themselves (see photo 13 in Figure 10 and photo 19 in Figure 11) but are surrounded by a complex of spinifex, salt grasses, and other salt tolerant plants. Most species in this category are extremely sensitive to small changes

Figure 3 (Following page)

1. Spinifex (Triodia basedowii) with scattered wicketty bush (Acacia kempeana), blue mallee (Eucalyptus gamophylla), Hakea divaricata, and Petalostylis cassinoides, near Connors Well 60 miles north of Alice Springs; 2. Typical mulga (Acacia aneura) community with a ground cover of kerosene grass (Aristida browniana), at seventeen mile experiment site north of Alice Springs; 3. Forb-field plains with a variety of both perennial and annual chenopods, particularly Bassia spp., and composites including Brachyscome spp., and grasses mostly Aristida spp., Panicum decompositum, and Chloris scariosa, near Harry's Creek north of Alice Springs; 4. Short grass-forb pastures on Hamilton Downs station. Mount Hay is in background. Forbs increase in response to heavy grazing; 5. Kerosene grass (Aristida browniana) forb-field on young alluvium flanking the Macdonnell ranges west of Alice Springs; 6. Kerosene grass (Aristida browniana) on Napperby Creek alluvials. Low trees are of Eucalyptus suberia, Hakea divericata and iron wood (A. estrophiolata) and Atalaya hemiglauc.

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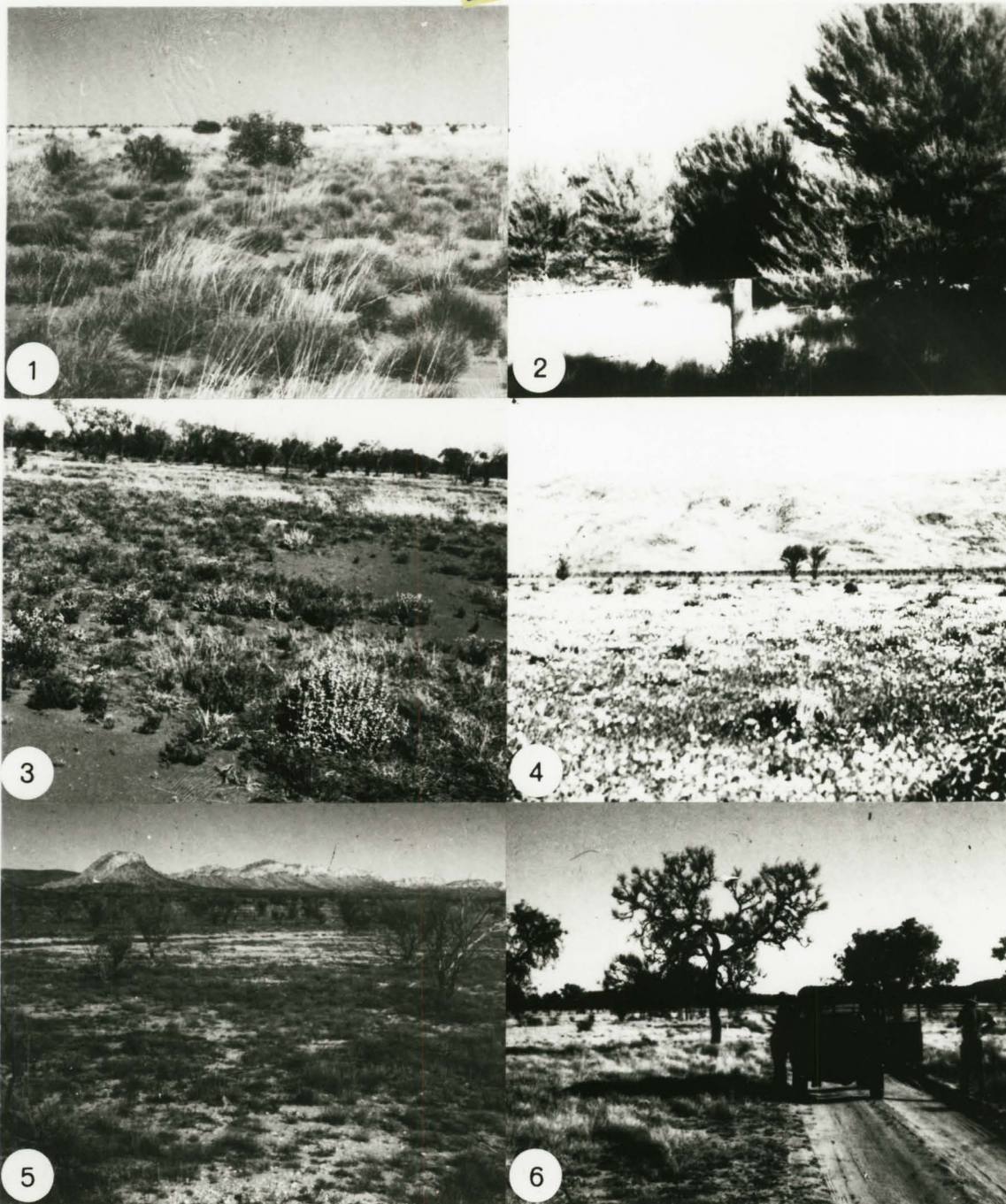


Figure 3

in salt content, soil texture and drainage and for this reason distinct belts of vegetation develop around the individual pans. As with the Mountain and Hill category most of these changes occur at scales too small to map and too small to be detected on the space photograph.

Mitchell Grass country is the most restricted spatially of the grass categories recognized. The type carries mainly Mitchell grass (Astrebla pectinata) as well as the other drought-evading perennial grasses, blue bush (Chenopodium auricomum) and salt bush (Atriplex vesicarium) (see photo 4 in Figure 3). It is generally restricted to flat or gently sloping treeless plains with heavy calcareous clay soils on Tertiary or recent alluvia.

On his original map Perry recognized two types of Short Grass-Forb pasture, one type occurring on young alluvia and the other on flat or undulating country. In this report the young alluvia type is retained as a predominantly grass category, but the more extensive variety on flat or undulating country is reclassified as Low Tree and Shrub.

In alluvial areas ephemeral short grasses and forbs form the predominant ground cover with scattered low trees overhead (see photos 5 and 6 in Figure 3). Kerosene grass (Aristida browniana) is the species most commonly encountered in the footslope zone of the ranges between Hamilton Downs and Dashwood Creek. Along Gidyea, Napperby and Day Creeks northeast of Napperby Lake sparse low trees occur together with kerosene grass. The main species involved are mulga (Acacia aneura), witchetty bush (A. kempeana), gidgee (A. georginae), coolibah (E. microtheca), and ghost gum (E. papuana).

The Low Tree and Shrub category is overwhelmingly dominated by mulga (Acacia aneura) and is found on flat to undulating topography (see photo 2 in Figure 3) and on the flanks of mountain ranges (see photo 11 in Figure 4) on all rock types and on a wide range of soils. Associated with the mulga are: gidgee (Acacia georginae), southern ironwood (A. estrophiolata), myall (A. calicola) and witchetty bush (A. kempeana). In all of these, height, density and vigor are highly variable due mainly to the effects of drought.

Figure 4 (Following page)

Ground Photographs of representative vegetation types and landscapes near Alice Springs: 7 River red gum (Eucalyptus camaldulensis) along Napperby Creek. 8 Soft spinipex (Triodia pogens) with Coolibah (E. microtheca) near Rembrandt Rock southeast of Napperby Salt Lake. 9 Interbedded sedimentaries (limestone, sandstones and conglomerates) in the Macdonnell ranges. 10 Melalenca spp., swamp scrub on the Yuendumu road 7 miles southeast of Napperby Salt Lake. 11 Mulga-spinifex slopes of the Heavitree Range near Ellery Gorge in the Macdonnell Ranges. 12 Bare areas and mulga on Missionary Plain, located as site 12 in Figure 12.

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Figure 4

to the effects of drought. As a consequence an endless variety of structural subtypes exists, most of which have ill-defined boundaries.

Spinifex Sand Plains and Dune Fields occupy most of the central portion of the photo. Hard spinifex (Triodia basedowii) (see photo 1 in Figure 3) is the dominant species on flat sandy plains with smaller areas of soft spinifex (T. pungens) (see photo 8 in Figure 4) and feathertop (Plectrachne schinzii). Trees and shrubs are widely scattered except in local low spots where mulga and coolibah (E. microtheca) congregate. In dune fields hard spinifex occupies the flanks with mulga in the swales. Dune relief frequently approaches 20 feet or more from swale to crest with troughs 400 yards wide and dune flanks 150-300 yards long depending on orientation. The parallelism and linearity of these dunes give rise to alternating zones of spinifex and mulga vegetation which are easily distinguishable even from orbital altitudes.

IMAGE CHARACTER AND TRANSFORMATIONS

The basic requirement for photo interpretation is that the photo in question have differences in tone, texture, shape and size between entities. Ordinarily the photo-interpreter works with high resolutions such that texture, shape and size convey most of the information, and differences in tone are of relatively modest importance. Air photos commonly show quite different tones for objects or aggregates of objects which we know to be the same, depending on lighting conditions and other variables; conversely, similar tones may be noted for unlike objects.

With the resolution in the space photograph between relatively low contrast entities (300 to 450 feet, areal weighted average resolution) several features should be mentioned: 1) detailed texture, shape and size clues are completely missing, though textures, shapes and sizes at a much gross level of generalization may appear for the first time; 2) tone is retained as the major clue, but because of the modest resolution many entities are mixed in resolution cells thus seriously diluting dis-

crimination power; 3) as many as 8 discrete categories of landscape in the Alice Springs area have much the same light tone on the space photograph, yet all are worthy of separate categorization: neither man nor machine (IDECS) can make such separation rationally on this color photo, partly because the phenomena may be truly unseparable and partly because of the haze noise in the blue and green-sensitive layers in the film; 4) as Schwarz et. al. (1969) have shown, at the 400 foot resolution level there are few environments which do not have a majority of cells containing two or more categories; 5) when unknown proportions of well-, moderately-, poorly-, and totally-unknown entities are mixed in a cell, who can understand the "information" such mixtures convey; and 6) the gross the resolution the more one obtains an average of the landscape.

Image Transformations

The more important image transformations performed on the Alice Springs photo are described in the following pages in order to give insights into the general complexity of photo content.

Most color film, including Ektachrome MS film, consists of three separate recording dyes (layers of the emulsion) each sensitive to a different region of the visible spectrum. The sensitivity (S) of each layer to light of a given wavelength (λ) is defined as:

$$S(\lambda) = E(\lambda)^{-1}$$

where

E is the energy of monochromatic radiation of wavelength (λ) required to produce a given dye density in the individual layers when the film is developed. Figure 5 shows spectral sensitivity as a function of wavelength for each dye-type of Ektachrome MS film. As seen in this illustration each dye has a peak sensitivity at a different wavelength; thus, even though there is considerable overlap in their combined sensitivity, it is feasible to distinguish them in terms of general spectral

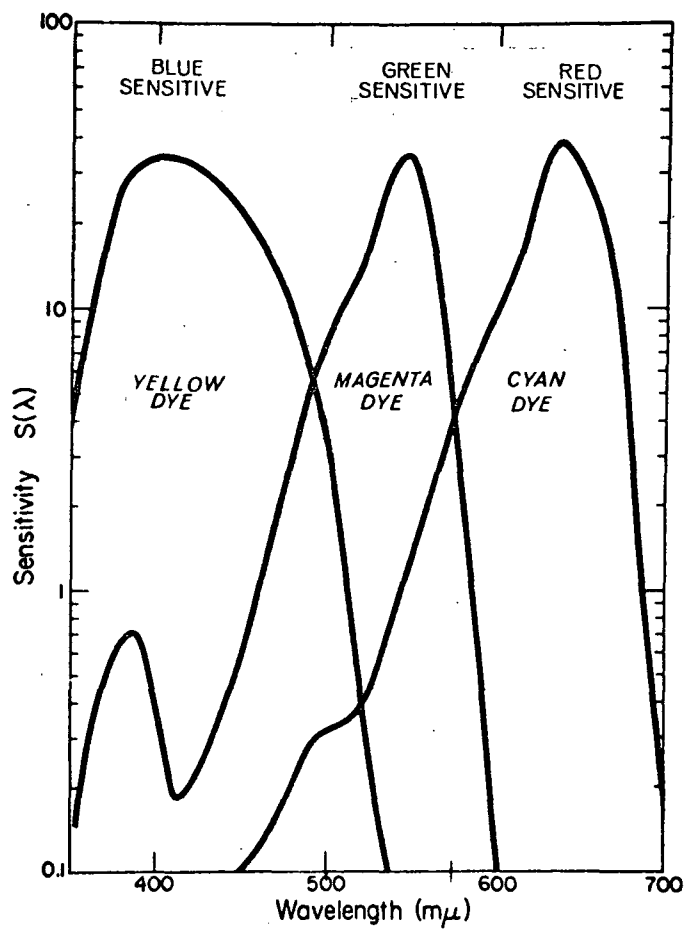


Figure 5. Spectral sensitivity of Kodak Ektachrome MS Aerographic Film (Estar Base), Type SO-151.

response regions. This approximation permits us to think in terms of three colors (blue, green, red) each corresponding to a particular wavelength band.

The limits of the respective wavelength bands occur at points where the sensitivity of each given dye decreases to about 10% of its peak sensitivity. This is an arbitrary choice that results in blue being defined as wavelengths from 350 nanometers to 490 nm; green 490 nm to 590 nm; and red 590 nm to 690 nm. Figure 5 is a conceptual model in which the energy received by the film is lumped into three wavelength bands each corresponding to one of the primary colors. The actual error introduced by such lumping is small, because color photographs by their nature record only color, not the actual spectral reflectance of the original scene. The lumped model provides the necessary generalizing concept for analyzing the amount of information contained on a color photograph in each of the three bands.

One manipulation the lumped model permits us to carry out is that of separating the color photograph into three images each containing the information present in one of the wavelength bands. This procedure is a standard one involving: 1) masking to correct for overlapping skirts of the three dye density curves (Figure 6); and 2) preparation of black and white negatives from the color photo using blue, green and red filters. The particular filters used on the Alice Springs photograph, Wratten numbers 47B, 58, and 29, are illustrated in Figure 7, photos 1, 3, and 5. Masking is essential to insure that the content of each separation plate is crudely spectrally limited. Each of the separation plates is a rough record of the amount of energy received by the camera in the corresponding wavelength band (Figure 6); thus, variations in density on any of the separation plates represent approximate relative increase or decrease in reflectance in that wavelength region and in a general way simulate the way three true multi-band photographs would appear. It is important to emphasize, however, that these separation plates are not quantitative, nor are they multiband; they are approximations.

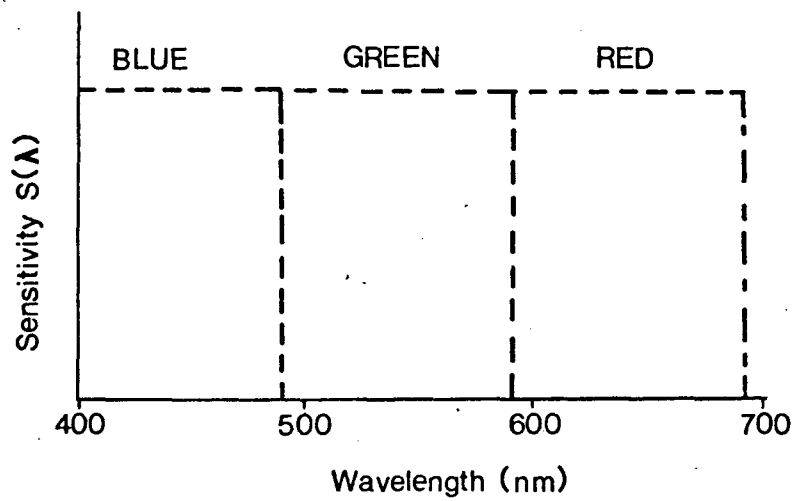
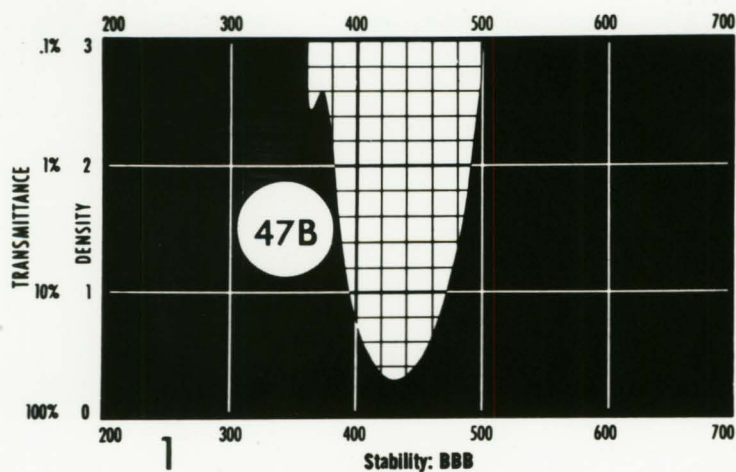


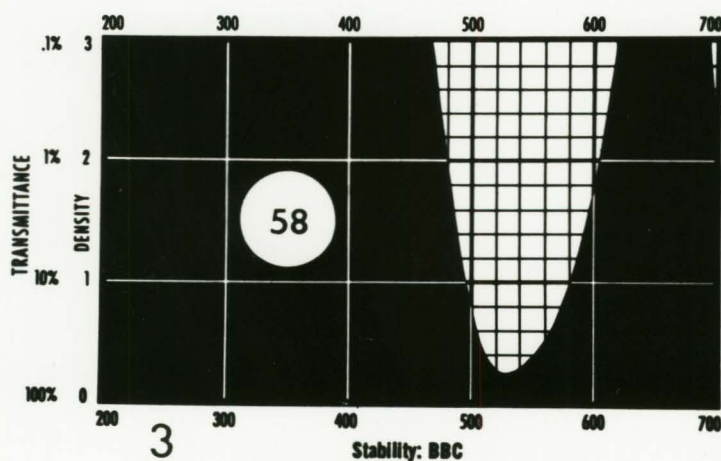
Figure 6. Crude lumped model for the blue, green and red sensitive layers of Ektachrome MS Aerographic Film after color separation and masking.

The separation plates give a visual account of the amount of information recorded in a given wavelength band and are therefore a valuable asset in deciphering some of the tonal ambiguity present in the original color photograph. This approach to the study of image content as a function of wavelength is useful in evaluating spacecraft photography, since atmospheric attenuation is a function of wavelength. Figure 8 -constructed from data in Elterman (1964) - shows the theoretical trend of atmospheric attenuation versus wavelength for Rayleigh, aerosol, and ozone attenuation factors in a "clear standard atmosphere". Actual atmospheric attenuation however, is a function of local weather conditions and dust content and the "clear standard atmosphere" never occurs in nature. Consequently, Figure 8 illustrates the best possible conditions ever available for spacecraft photography.

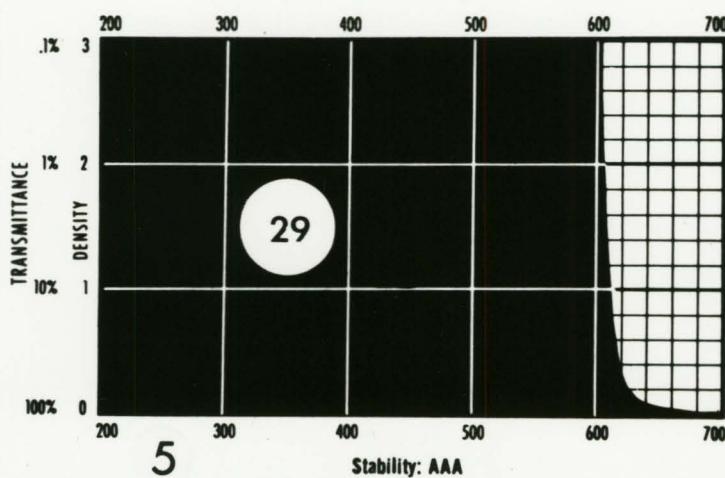
Comparison of Figures 7, photos 2, 4, and 6, with Figures 8 and 9 reveals, as expected, that attenuation is most severe in the shorter wavelengths. The blue band has very little terrain detail and is practically useless for mapping purposes. The green-sensitive layer contains considerably more terrain detail in the form of boundaries and discrimination of areas visible on the color photograph. In effect this means that the blue band merely adds noise to the color photograph, and the same is true to some degree of the green band. The red-sensitive layer has, as expected, more contrast with clear vegetation and soil boundaries. Figure 9 is particularly interesting in this respect. It shows the blue, green and red separation plates of aerial obliques located as marked on Figure 1. The blue separation plate shows the effect, even with short passage through the atmosphere, both of inherent low contrast (few blues occur in arid regions; only whites have high reflectance in the blue region), and contrast reduction from scattering, and consequent weak boundary discrimination. The improved level of boundary delineation possible with the green and red plates is consistent with the amount of detail recorded on the space photograph, indicating that this procedure does give a reliable guide to where information lies in the latter.



2



4



6

Figure 7.

Reproduction of the blue, green and red separation plates of the Alice Springs space photo with the filters used for the separations.

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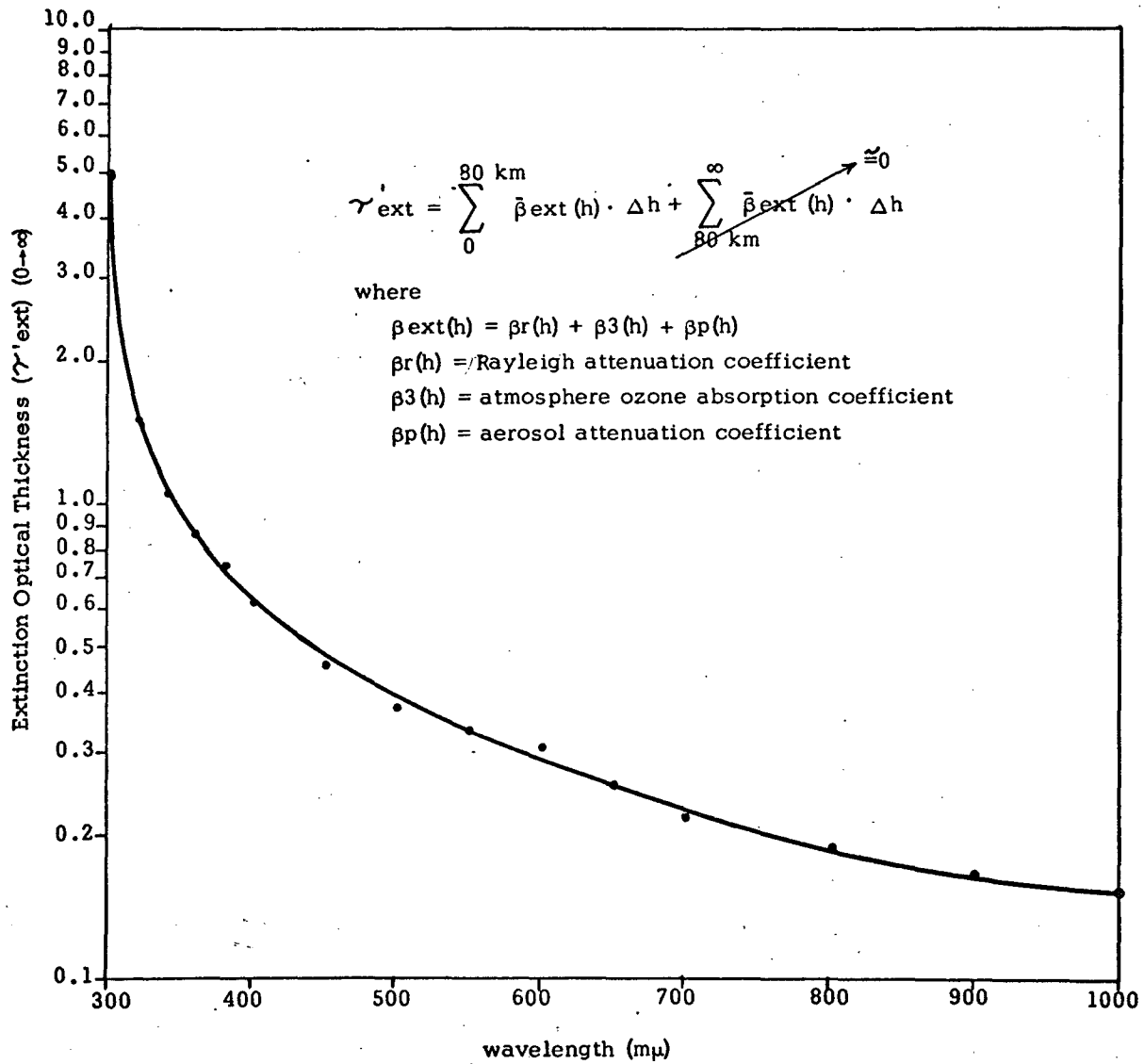


Figure 8. Theoretical trend of extinction optical thickness for a clear standard atmosphere (after Elterman 1964).

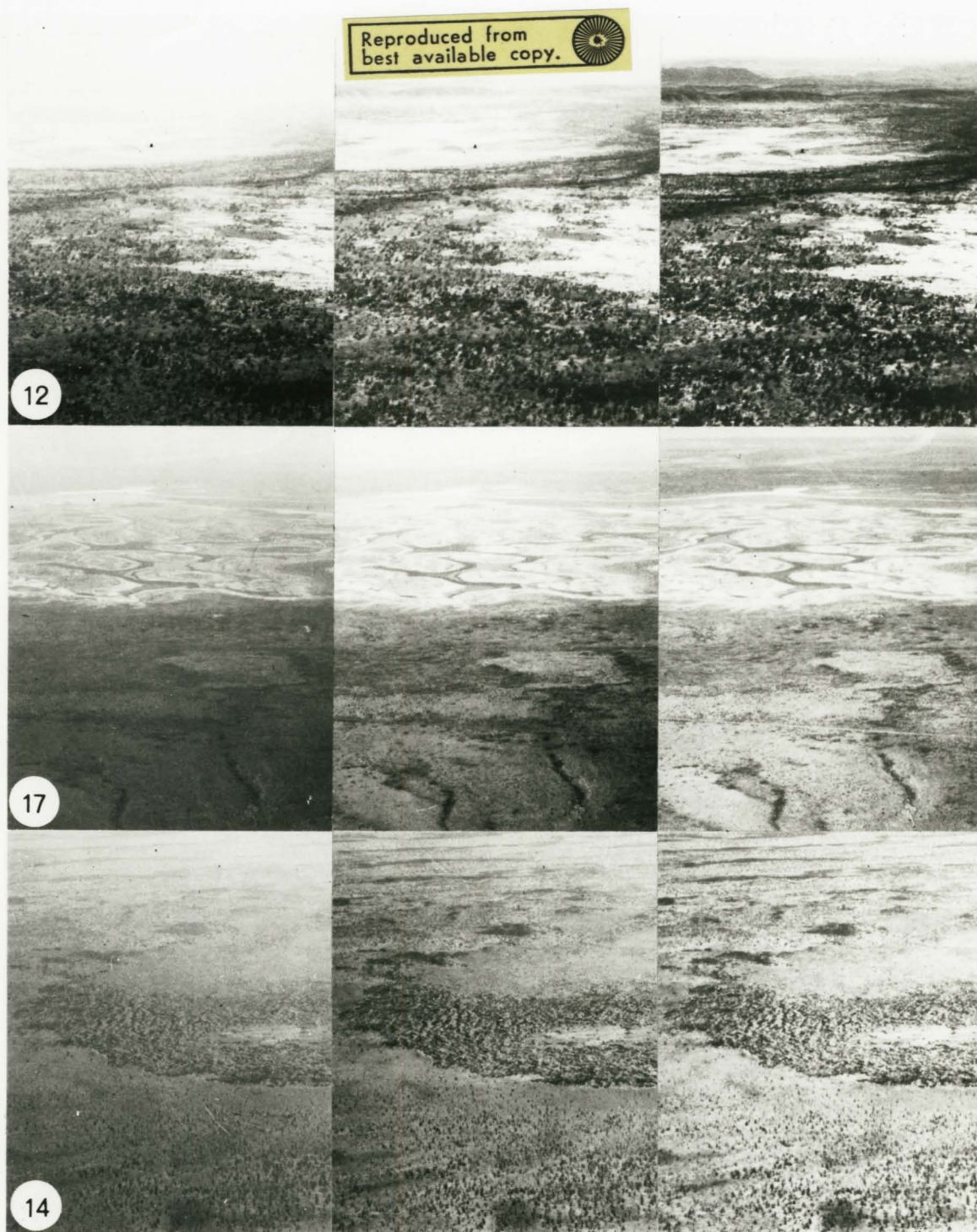


Figure 9 .

Blue , green and red separation plates of three aerial color oblique photographs obtained August 1968 . The location of these areas is shown on Figure 12 , sites 14 , 17 and 12 , respectively located west and north of Napperby Salt Lake , and southwest of Alice Springs on Missionary Plain .

Edge Enhancement and Differentiation

Another possible transformation of space photographs consists of edge enhancement and differentiation. Edge enhanced images may be produced photographically by the Kodak tone line process. This process consists of stacking a positive and negative transparency in an exact registry sandwich which appears as an almost uniform grey surface at normal incidence, but at all other viewing angles lines can be seen wherever abrupt density gradients occur. Now, in order to obtain a photographic record of all the lines from all viewing angles the sandwich is placed over a sheet of unexposed film on a rotating vacuum board. The film is then exposed by a point light source offset from the axis of rotation, and at all points where a sharp density gradient exists a line will appear on the enhanced image. The resulting image in effect clips out a band of similar gradients along boundaries; i.e. it is a range of certain slopes in the first derivative of the original.

Edge enhanced images of the Alice Springs photo have been made on an experimental basis but a further rather massive investment of time would be required to optimize them and conduct an interpretation. One of the major difficulties is that all density changes on the original image—whether representing true large scale boundaries or merely scratches, image texture, or a fine mosaic of terrain types — appear as edge-enhanced features. It is therefore not possible for all edge enhanced boundaries to separate meaningful landscape changes. On the other hand very subtle but meaningful differences not detectable by eye will also be enhanced, and for this reason the technique is potentially valuable (Wingert, 1967).

Other Manipulations

Other manipulations one can perform on the photographs include all those with the IDECS system. Since these are fully reported and illustrated in Peterson et al. (1969) we will not add to the bulk of this report by detailing them here. Furthermore, since the IDECS combinations of the Alice Springs area are currently being evaluated in the field (May-

June, 1969 by Professor G. R. Cochrane) we cannot report on them at this time. They will be included in the later published version of the report.

BOUNDARY DELINEATION AND VERIFICATION

Boundary Delineation

The delineation of boundaries and categorization of areas presented here are based on interpretation of 6 X enlargements of both the original color photograph of the Alice Springs area and its red and green separation plates. The initial interpretation consisted of tracing all boundaries observable on the unaltered color enlargement. Three types of boundaries were mapped; those representing obvious, sharp, color differences separating grossly dissimilar entities; those representing less obvious but nevertheless distinct differences in color and density; and those differences in tone and density regarded as dubious or conjectural. The same procedure was applied to the red and green separation plates.

Following boundary delineation, the three resulting maps (original color photo, red separation, and green separation) were compared qualitatively by superposition. They were found to display remarkable similarity in their total boundary content although some differences were observed.

1. An approximately equal number of first category boundaries were drawn on both color photograph and red and green separation plates and these were strongly coincident as to location.
2. The second category of boundaries, those defined by moderate contrast ratios across adjacent entities, demonstrated less agreement of the color photo and red and green separations. Grassland boundaries seem to be easier to detect on the color photo and green separation, whereas the darker tone of wooded areas are better defined on the red separation.

3. Numerous differences in both the number and placing of third category boundaries occurred. Since these boundaries are defined by low contrast ratios between adjacent entities, a much higher degree of subjectivity is involved in their mapping. The exact placement of any particular boundary on a separation plate is bound to shift slightly from its placement on the original color photo, especially when dealing in minor changes in entity characteristics. A subtle qualitative change between landscape types is rendered ambiguous on a color photograph because of complex interactions of atmospheric attenuation factors and the gradual change in the spectral reflective properties of the two entities involved. These influences combine to produce a low contrast ratio between the entities. When a separation plate is produced some ambiguity due to attenuation and to different reflectances in each layer is filtered out. More importantly, because the cutoff values for the information contained in the particular spectral region are relatively sharp, minor shifts in boundary location take place.

It is not surprising, therefore, that even experienced interpreters confronted with two presentations of fundamentally identical data arrive at different conclusions regarding the discrimination of subtle landscape changes. In part this also will arise from different ways of lumping and splitting. Some observers are born lumpers; other are born splitters; yet others are fuzzy-minded academics with no consistency at all. The same problems of lumping and splitting apply to all qualitative judgments by men. It even applies to maps such as those prepared by Perry (1961), themselves substantially based on aerial photographs, which we have used as "Ground Truth" to compare with the space photograph.

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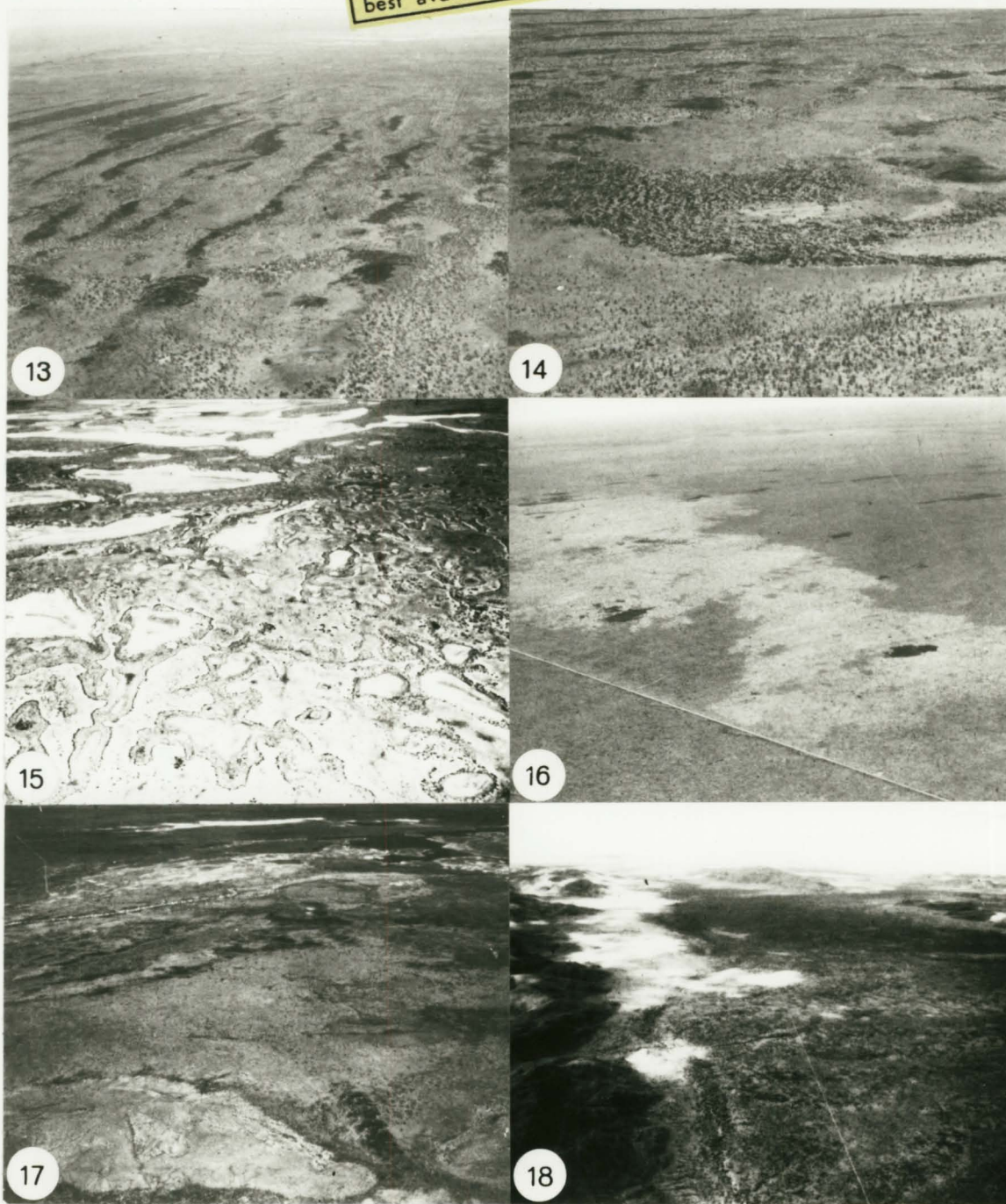


Figure 10. Aerial oblique photographs mostly near Napperby Salt Lake. The numbers are keyed for location to those given in Figure 12: 13 dunes west of Napperby Salt Lake. 14 Mulga and dunes west of Napperby Salt Lake. 15 Salt pans in troughs between irregular dunes west of Napperby Salt Lake. 16 Looking northeast from Aileron homestead. 17 Confluence of Napperby Creek and Napperby Salt Lake. 18 Looking E.S.E. from Mount Chapple to Redbank Hill.

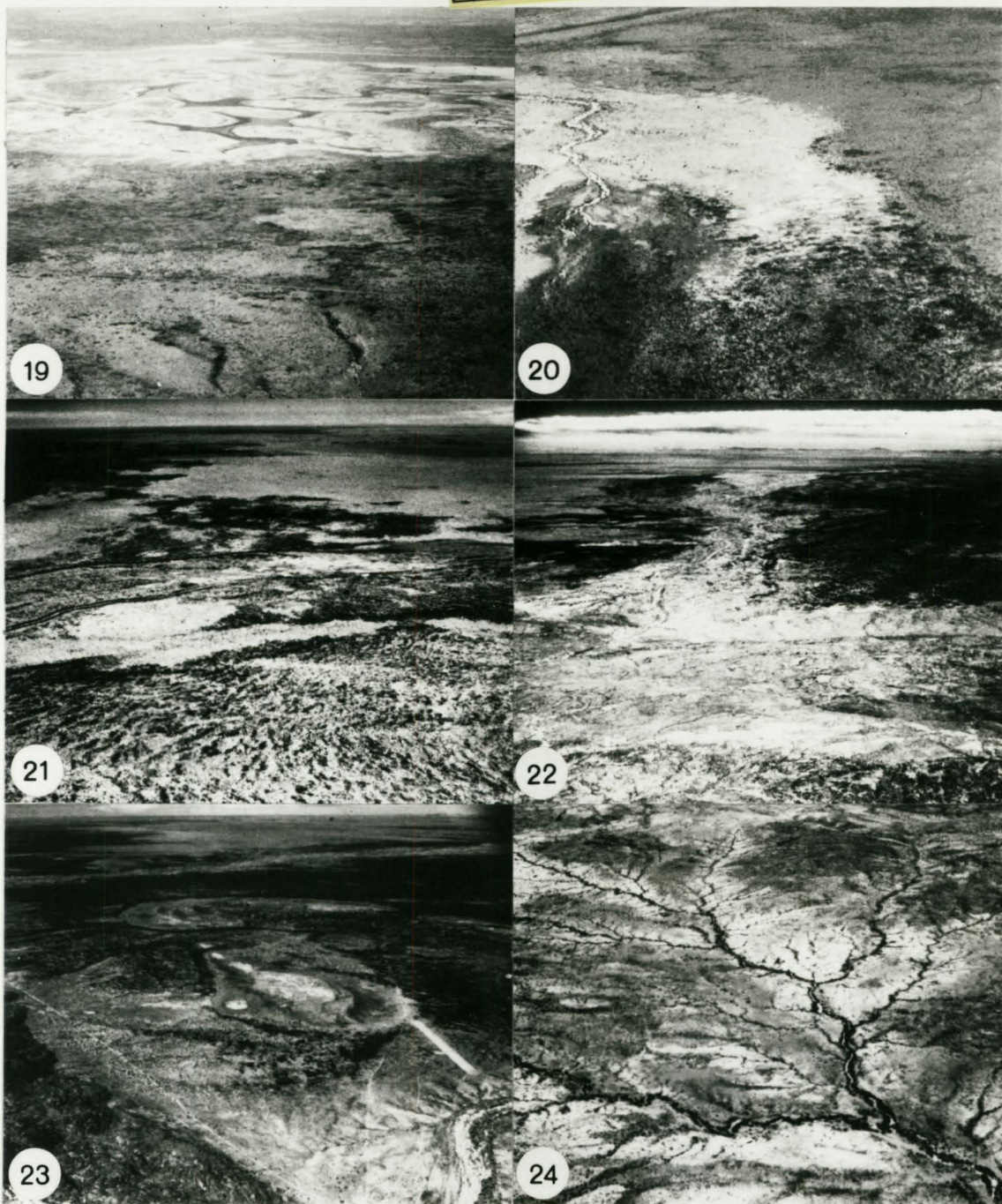


Figure 11. Aerial photographs mostly near Gidyca, Napperby and Day Creeks. The numbers are keyed for location to those given in Figure 12: 19 Looking south to Napperby Salt Lake. 20 Looking N.N.E. along Gidyca Creek. 21 Woodford River in mid distance looking east near Ti-Tree. 22 Looking south along Day Creek. 23 Napperby Station, airfield and Napperby creek in foreground, Day Creek in distance. 24 Headwaters of Day Creek in area of dissected lateritic residuals.

Boundary Verification

One of the primary aims of this report is to demonstrate relationships between boundaries discernable on space photography and terrain features, and through this to gain insight into the meaning of such boundaries. The oblique photographs in Figures 10 and 11 are black and white reproductions of color photos and illustrate a range of terrain conditions through which we can begin to appreciate the nature of entities encountered and their spatial confines.

The location of each of the obliques is plotted on the Alice Springs photograph in Figure 12. By comparing the obliques with the corresponding area on the space photo it is possible to make point-by-point comparisons of the efficiency of the space photo in aiding boundary detection and delineation of "real entities". An even more detailed comparison is feasible in Figures 13 and 14 which show for four regions - the locations of which are noted on Figure 1 - reproductions of an air photo mosaic based on pan minus blue 1:48,000 scale photos and the 1965 Gemini photo brought to a common scale of 1:500,000.

In order to make such comparisons compact we have collected them into Table 1, which should be examined carefully in conjunction with Figures 10, 11, 12, 13 and 14. In Table 1 we give in turn the location of the obliques, the terrain types portrayed, the distinctness of the boundaries as seen on the color obliques and the detectability of the boundaries on the space photo. The content of Figure 13 and 14 enable those figures to stand alone.

A full comparison of each item would be wearisome. Summarizing all these checks and comparisons we conclude that:

1. Even minor juxtaposed point to point changes in tone on the Gemini photo are meaningful. The fact that we are unable to decipher the meaning without detailed field work is at this time immaterial. It is encouraging to realize the very modest changes in plant communities which may be detected. Thus, quite subtle differences between crests and swales of dunes mantled mainly with spinifex are detected because of their linearity.

TABLE 1

DETECTABILITY OF LANDSCAPE BOUNDARIES FROM SPACE

PHOTO OBLIQUE AND AREA	TERRAIN TYPES PORTRAYED ON B & W OBLIQUE PHOTOS	DISTINCTNESS OF BOUNDARIES AS SEEN ON OBLIQUE PHOTOS	DETECTABILITY (SPACE PHOTO)
Figure 10; 13 and 14 Dunes West of Napperby Lake	a) dense mulga groves (dark grey) b) spinifex on dune flanks (med. grey) c) mulga savannah (speckled)	very distinct ill-defined moderate to ill-defined	Excellent; depends on length- width of grove Not discriminable except by deductive association Detail lost by generalization; interpreted as spinifex sand plain (Figure 11)
Figure 10; 3 Napperby Lake	a) salt pan (white) b) spinifex dunes (mottled grey- light grey) c) short tree & shrub (mulga) (dark grey)	very distinct complex but distinct pattern distinct to ill-defined belts	Excellent for large entities; ambiguous when next to spinifex Detail lost by generalization; interpreted as spinifex sand plain (Figure 11) Not detectable
Figure 10; 4 Near Alleron Station	a) spinifex sand plain (medium grey) b) short grass-forb (light grey) c) Stuart highway (white line) d) dense mulga groves (shadows) (dark grey)	distinct to gradational very distinct very distinct	Not detectable Not detectable (< system resolution) Very poor (most groves too small)
Figure 10; 5 Confluence Napperby Creek and Napperby Salt Lake	a) dense mulga (dark grey) b) salt pan (some white/some with water) c) short grass & forb w/scattered trees (light grey) d) redgum stringer e) spinifex sand plain	very distinct distinct/very distinct very distinct/ gradational very distinct very distinct/ gradational	Poor/ambiguous; entities mere specks Detectable as gross features; detail lost Good/excellent Moderate; seen as pale line Good/excellent when adjacent to short grass

(Continued on Following Page)

TABLE 1 (Cont.)
DETECTABILITY OF LANDSCAPE BOUNDARIES FROM SPACE

PHOTO OBLIQUE AND AREA	TERRAIN TYPES PORTRAYED ON B & W OBLIQUE PHOTOS	DISTINCTNESS OF BOUNDARIES AS SEEN ON OBLIQUE PHOTOS	DETECTABILITY (SPACE PHOTO)
Figure 10;6 Mt. Chapple - Red bank Hill	a) hills and mountains (dark grey- in shadow) b) mulga clumps & savannah	very distinct distinct to ill-defined	Excellent Not detectable individ- ually; interpreted as spinifex-mulga transition in Figure 17
Figure 11;7 Napperby Lake	a) spinifex islands (white/med grey) b) irregular spinifex dunes (?) (med-dark grey) c) spinifex w/scattered low tree (med. grey) d) mulga clump? redgum stringer? (dark grey) e) Yuendumu road (med. grey line)	very distinct when water present, less so when not distinct distinct/gradational distinct fairly distinct	Fair/good for largest islands; detail apparent but not coherent Boundary with lake distinct, others not detectable Not detectable except as continuation of (b) Not detectable } < system resolution Not detectable
Figure 11;8 Gidyea Creek	a) spinifex sand plain (med.-light grey) b) short grass-forb w/scattered low trees (light grey) c) mulga scrub (dark-very dark grey) d) red gum stringer	very distinct very distinct distinct/gradational very distinct	Excellent; high contrast with (b) Excellent; high contrast with (c) Good/excellent; boundary with (a) somewhat diffuse Poor/not detectable; < system resolution
Figure 11;9 Woodford River	a) mulga scrub (cont. dark grey) b) dune field (as in Figure 10, photo 12)	very distinct very distinct	Good/excellent diffuse boundaries in some locations Excellent detection of field boundary; dune detail lost; interpreted as mulga scrub in Figure 17

Continued on Following Page

TABLE 1 (Cont.)

DETECTABILITY OF LANDSCAPE BOUNDARIES FROM SPACE

PHOTO OBLIQUE AND AREA	TERRAIN TYPES PORTRAYED ON B & W OBLIQUE PHOTOS	DISTINCTNESS OF BOUNDARIES AS SEEN ON OBLIQUE PHOTOS	DETECTABILITY (SPACE PHOTO)
Figure 11;9 (cont.) Woodford River	c) spinifex sand plain (med. light grey) d) short grass/scattered tree (light grey)	very distinct very distinct	Excellent adjacent to (a); merges imperceptibly to mulga savannah Excellent; gradational to mulga savannah
Figure 11;10 Day Creek	a) mulga scrub (cont. dark grey) b) short grass w/scattered trees (med. grey) c) kerosens grass w/scattered trees (med. grey)	very distinct/distinct distinct-diffuse diffuse	Excellent; high contrast with (b) Excellent; diffuse boundary with spinifex Excellent; entity ambiguous with mulga scrub
Figure 11;11 Napperby Station	a) mulga scrub (dark grey) b) mulga savannah/short grass (speckled-med-light grey) c) red gum stringer d) hills	very distinct/distinct very distinct distinct distinct	Excellent; intricate detail Excellent Fair; ambiguous pale grey line Fair/poor; ambiguous
Figure 11;12 Headwaters Day Creek	a) low tree/shrub-spinifex (light to medium grey) b) red gum stringers (very dark grey)	gradational very distinct	Not detectable; detail lost by generalization Very poor; present but incoherent

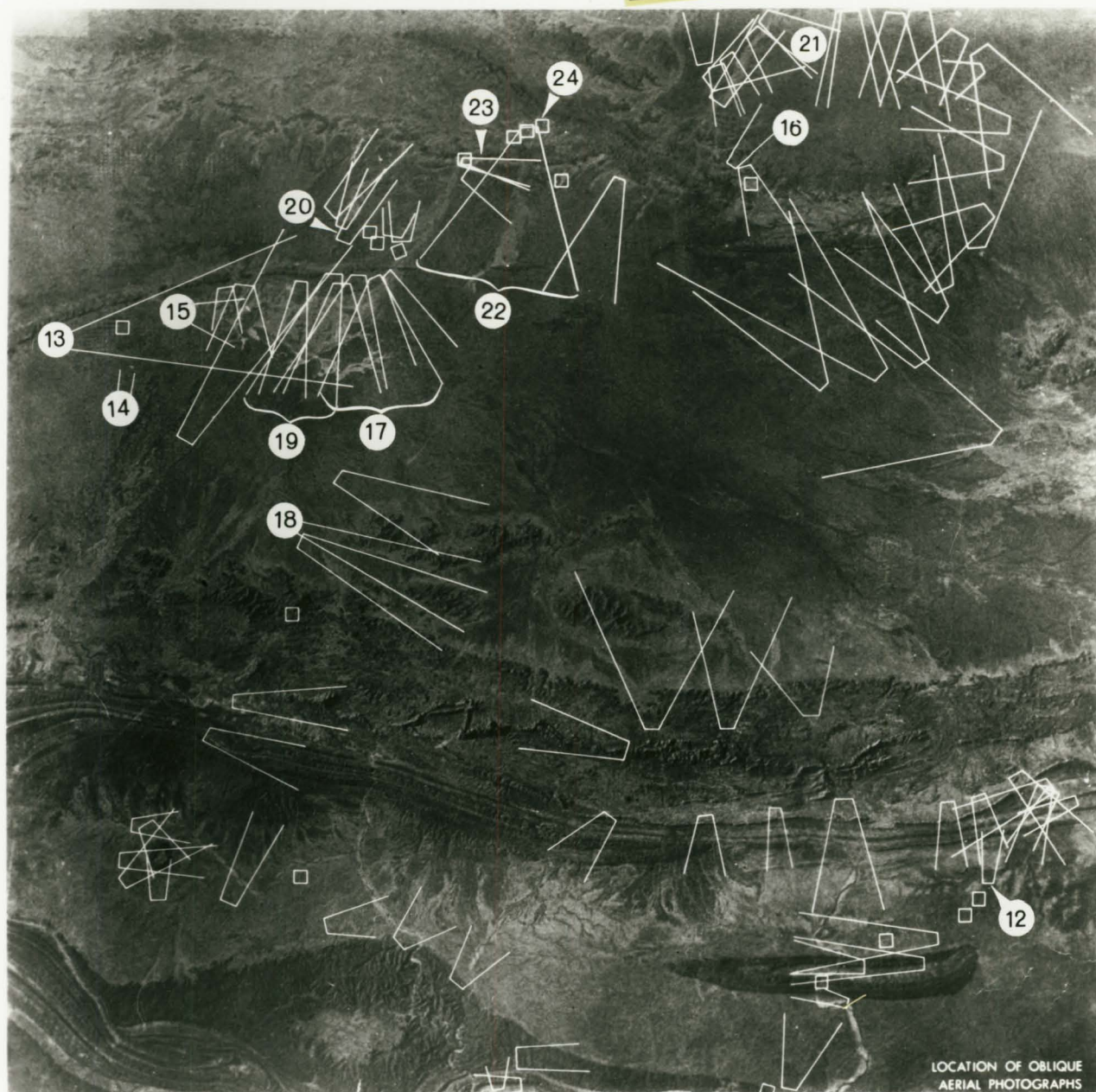
LOCATION OF OBLIQUE
AERIAL PHOTOGRAPHS

Figure 12. Locations of low altitude aerial oblique photographs. Numbers correspond to photographs illustrated in Figures 10 and 11.

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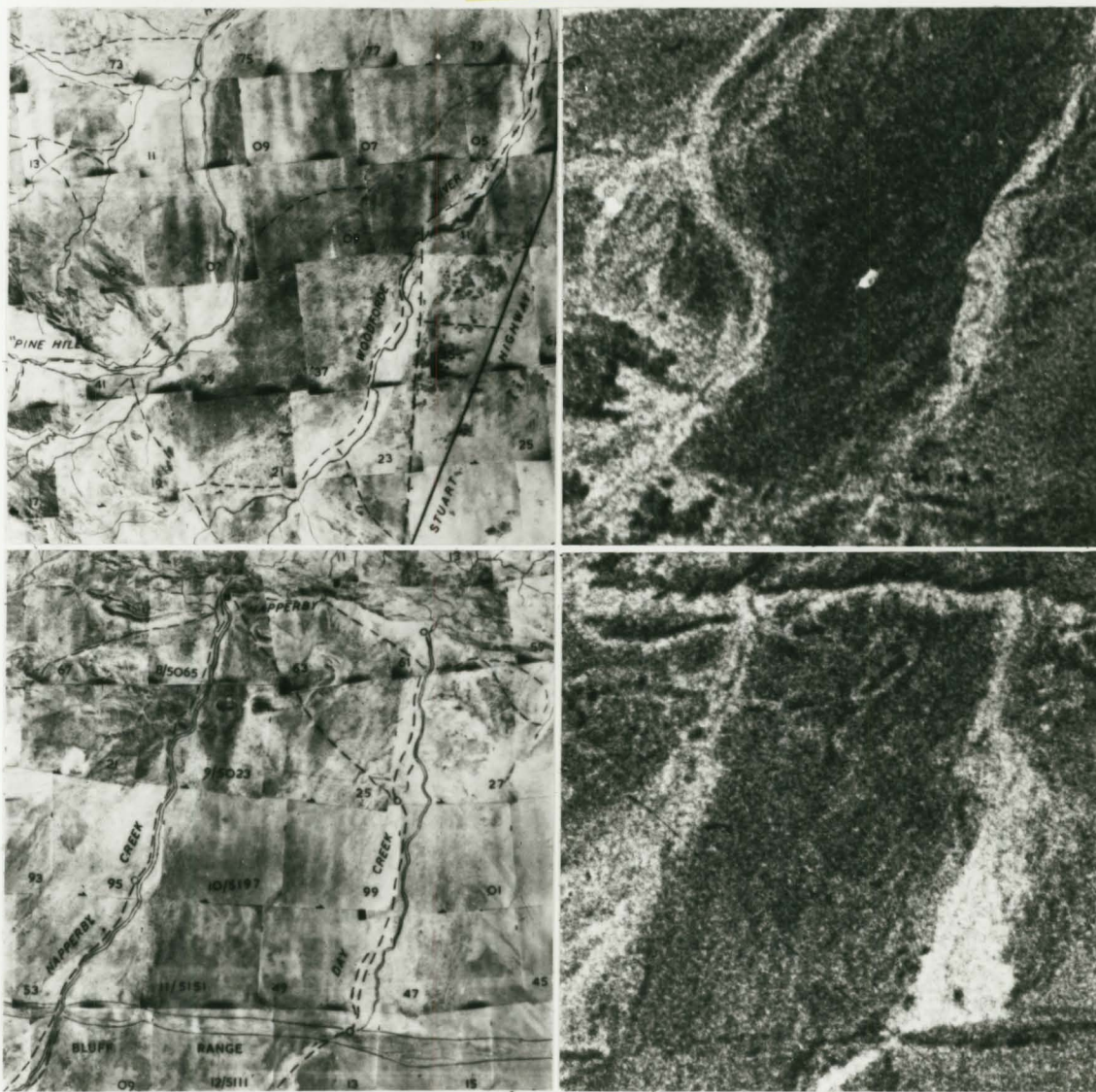
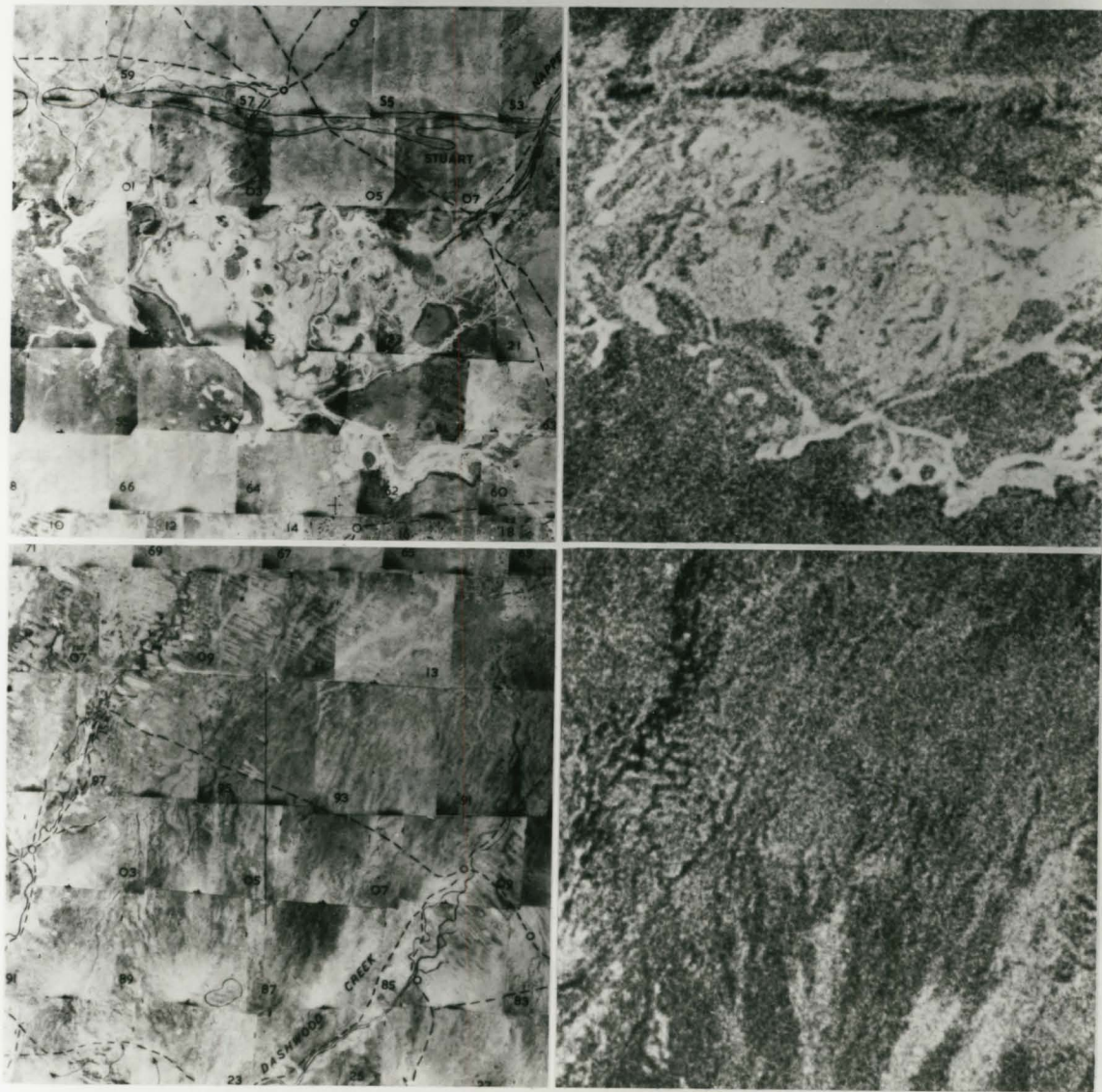


Figure 13. Comparison of air photo mosaics with red separation plate enlargements. Top, Woodford Creek area; bottom, Napperby and Day Creeks. Scale of reproduction 1:500,000. The center of each area is indicated on Figure 1 with the number 13 and the letter T or B for Top or Bottom.

2. High contrast juxtaposed point to point changes signal that different entities are being sampled. If each entity is regarded as having its own three-dimensional probability density function for each resolution cell (the three dimensions arise from the color bands in the lumped model of Figure 6) then changes above a certain degree unambiguously indicate the presence of these entities. In short, marked changes in tone are never noise even at the resolution cell level. This is very well evidenced in the comparison between dark, light and mid grey tones on the red separation plate near Napperby Salt Lake. Dark points are always mulga, light are always salt pans, and mid tones are spinifex sand plains; see for example Figure 14 where this is readily confirmed.
3. The space photo enables many quite transitional or fuzzy boundaries to be integrated and detected readily in comparison to using air photos of different acquisition dates, times and hence sun angles. Figure 13 shows this well in the Napperby and Day Creek area comparison.
4. In order reasonably to capture the environmental variability of this region a resolution with a 1.6:1 contrast ratio of 50 feet would be essential, though 100 feet would be acceptable. To obtain such resolution would require a system with an average of 30 line pair/mm resolution on a low contrast target and a focal length of no less than 12 inches and preferably 24 inches (Doyle, 1967). The scale of significant variation in this environment cannot be captured with a 400 to 500 foot resolution as in this Gemini photo (calculations confirming these estimated resolutions on the Gemini photo will be made when further data, requested from NASA/MSC is on hand).

Variations Between Photo-Interpreters

From the nature and degree of boundary differences we encountered in delineating boundaries, a number of questions arose concerning, first,



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Figure 14. Comparison of air photo mosaics with red separation plate enlargements. Top, Napperby Lake; bottom, Dashwood Creek southwest of Napperby Lake. Scale of reproduction 1:500,000. The center of each area is indicated on Figure 1 with the number 14 and the letter T or B for Top or Bottom.

the ability of experienced interpreters to accurately map unfamiliar environments and, second, the comparability of their efforts. To gain insight into this problem a test area containing many of the vegetation types and boundary conditions was selected on the red separation plate. Twelve interpreters with no first-hand knowledge of this area were asked to perform a three category boundary delineation similar to that carried out by G. R. Cochrane who prepared the master boundary delineations.³ No constraints were placed upon the interpreters as to what they should be looking for; simply that they should map as consistently as possible any boundaries they detected.

The results of these efforts clearly showed the extent of variation between interpreters and helped focus attention on the general problems of line detection. Four of the twelve interpretations, representing a fair cross section of all, were selected for comparison with the original work of Cochrane. Based on these interpretations Figures 13 through 16 illustrate the degree of variation encountered in four fundamentally different boundary situations. The name of the interpreters are keyed to the illustrations as follows: 1) G. R. Cochrane, 2) S. A. Morain, 3) W. G. Brooner, 4) F. M. Henderson, 5) D. E. Egbert.

Each of the four sets of boundary conditions contains its own problems of line detection. In Figure 15 attention is directed toward a portion of Napperby Dry Lake in which a complex pattern of salt pans, spinifex islands, and salt grass rises occurs. Comparing the five interpretations, it is clear that no two observers saw things alike, although there is fairly high congruence of boundaries in the lower portion of the area. Toward the center of the lake, however, where low contrast ratios prevail, there is virtually no comparison between interpretations. Here is a situation, according to the film density trace, in which numerous, small, moderately contrasting elements are contained in larger, area-

³ Cochrane's map was revised by Morain and checked by Simonett. We felt this procedure of serially reconciling differences was the most appropriate.

VARIOUS INTERPRETATIONS OF BOUNDARY CONDITIONS ON SPACE PHOTOGRAPHY Alice Springs, Australia

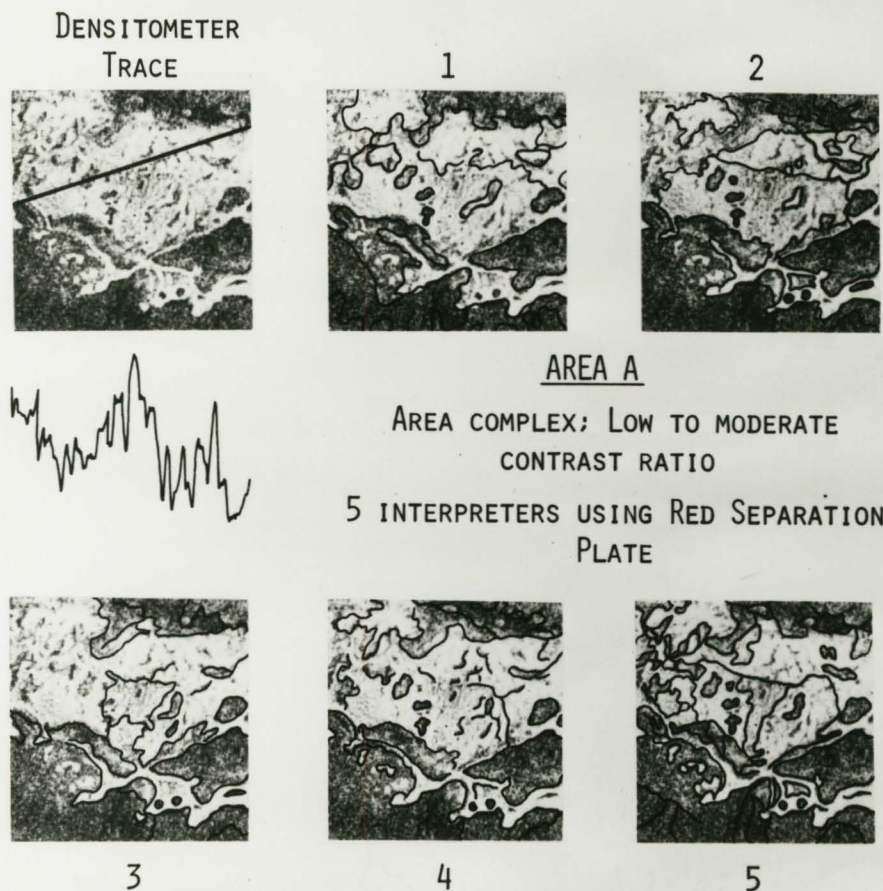


Figure 15. Interpretations of boundaries by five interpreters in an area where a complex of small entities containing low to moderate contrast ratios between entities occurs.

VARIOUS INTERPRETATIONS OF BOUNDARY CONDITIONS ON SPACE PHOTOGRAPHY Alice Springs, Australia

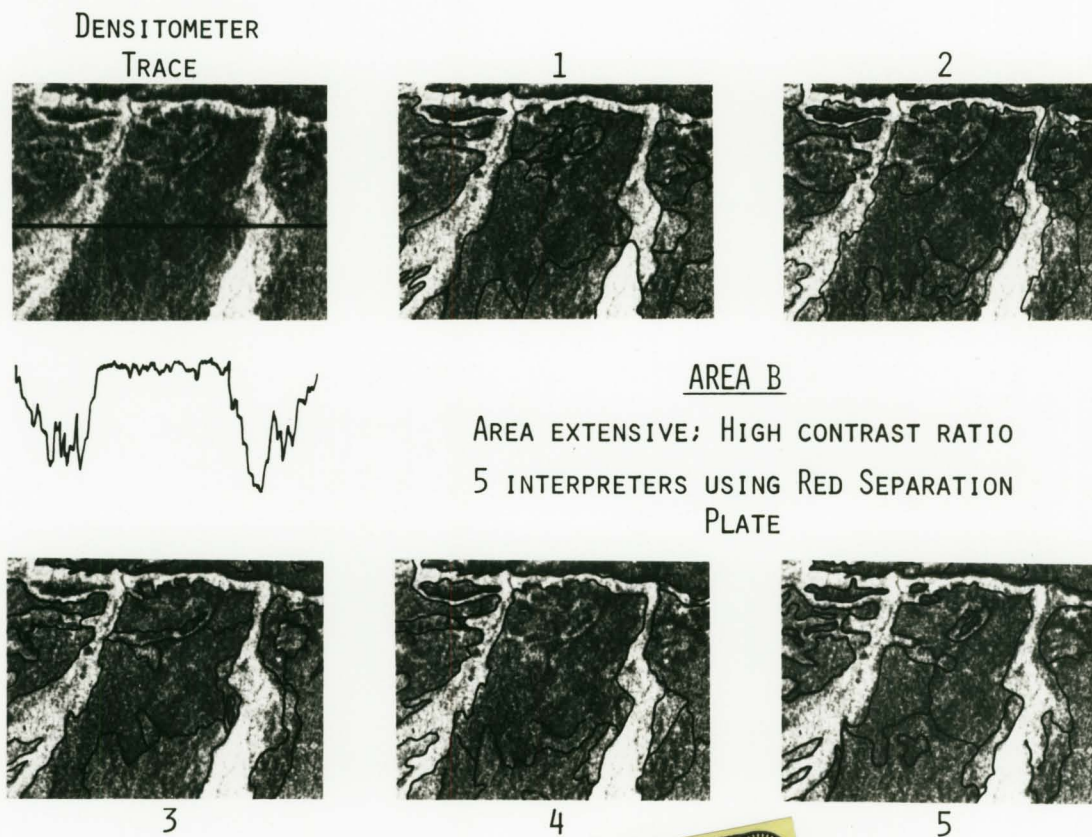


Figure 16. Interpretation of boundaries by five interpreters in an area where extensive entities are separated by high contrast boundaries.

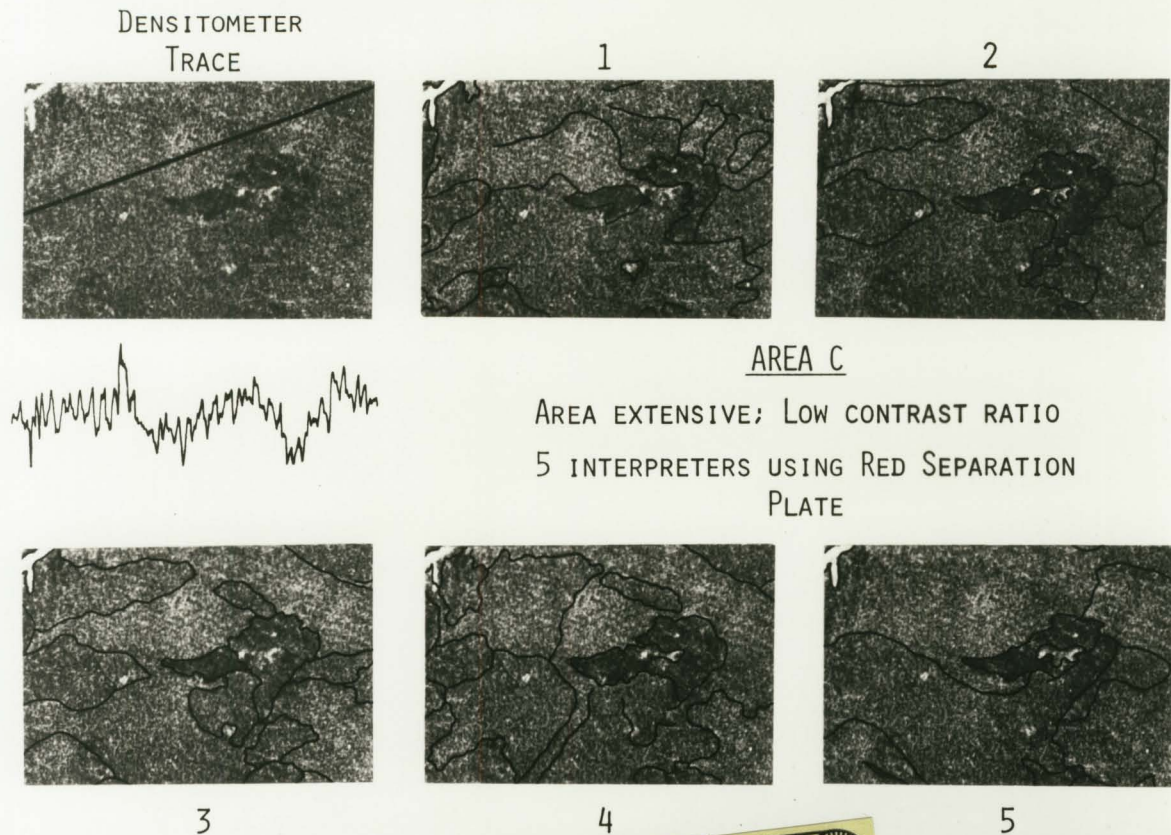
extensive elements with lower contrast ratio. Such a condition is confusing to interpreters because the boundaries most readily detected lie at a scale too small to map; whereas those that perhaps should be mapped at a reconnaissance scale are difficult to discriminate.

The greatest comparability between interpreters is found wherever the phenomena being separated are extensive and contrast sharply with neighboring types. Figure 16 depicts this set of conditions in the area from Napperby to Day Creek and except for unavoidable differences in detail, all interpreters saw essentially the same pattern of boundaries; at least they all distinguished the creeks. In the areas between the creeks, however, everyone had a different view, and if each interpretation is considered by itself, the basis for each man's decisions can be appreciated. In fact, if judged solely by individual merits all of them are "believable" interpretations.

At the opposite extreme the least comparable results were obtained in situations characterized by extensive, low contrast areas. The region illustrated in Figure 17 is predominantly a mulga scrub and spinifex landscape with linear sand dune country in the upper half of the area. The film density trace shows clearly that almost no discrimination capability exists in this type of environment. About the only point of similarity between the interpretations is that all recognize the presence of Mt. Harris, the dark anvil-shaped area in the center of the frame. In terms of mapping, the area-extensive, low-contrast situations present essentially the same problem as do area-complex, moderate-contrast types. They all resolve to a question of how much detail is required to complete a given task.

The last example of boundary conditions, Figure 18 depicts a complex pattern of highly contrasting types. The topography in this locality is hilly to mountainous which means the interpreter may inadvertently delineate shadows with other dark toned entities, and sunlit spots with light toned types. This problem has been magnified in this example because a black and white separation plate was used for analysis. The original color photo would give a more accurate view of variable illumination.

VARIOUS INTERPRETATIONS OF BOUNDARY CONDITIONS ON SPACE PHOTOGRAPHY Alice Springs, Australia



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Figure 17. Interpretation of boundaries by five interpreters in an area where extensive entities are separated by low contrast ratios.

VARIOUS INTERPRETATIONS OF BOUNDARY CONDITIONS ON SPACE PHOTOGRAPHY Alice Springs, Australia

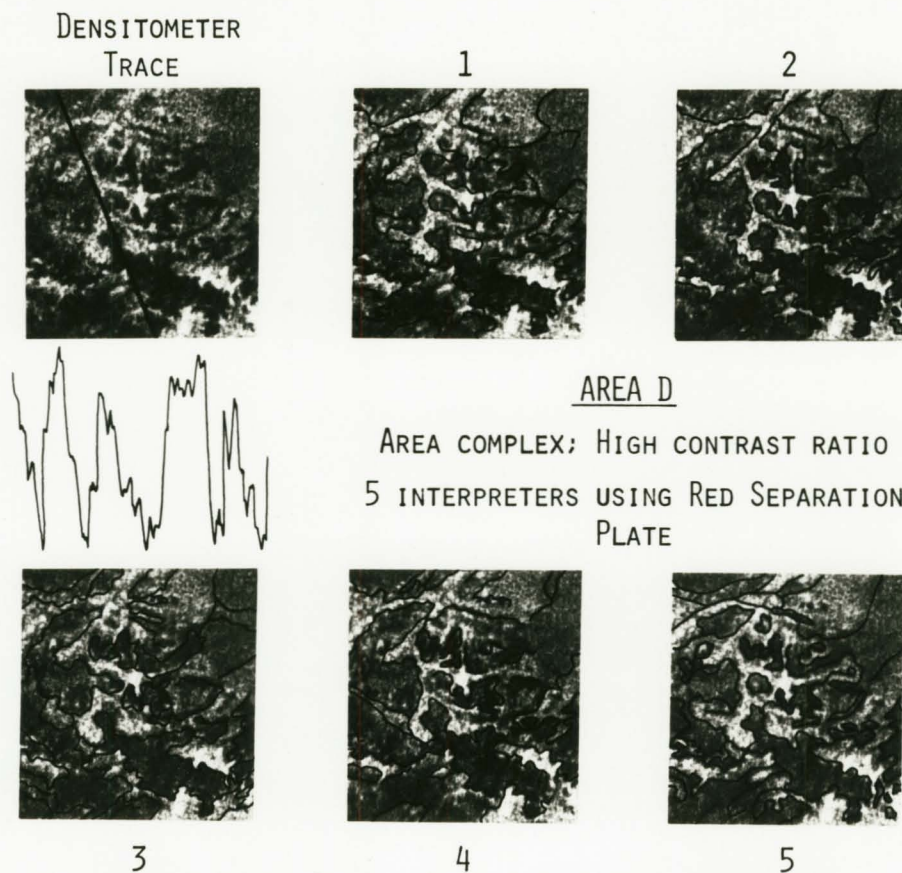


Figure 18. Interpretation of boundaries by five interpreters in an area where a complex of small sharply contrasting entities may be found.

Classifying Entities

Our ultimate design in resource mapping from space is to interpret the meaning of those areas delineated. From the discussion of boundary detection, however, it is clear that at least in desert and semi-desert environments, good quality but modest resolution space photography contains many more meaningful boundaries than can possibly be mapped and categorized at survey scales. There is a two fold problem here; that of generalizing the boundary interpretation so that a map can be produced, and that of classifying the areas delineated. The first of these problems has not been studied and will not be considered further in this report. Except for a few loose rules regarding the minimal area that can be mapped at a given scale, generalizing by human interpretation is entirely subjective, whether done on air photos or on space photos.

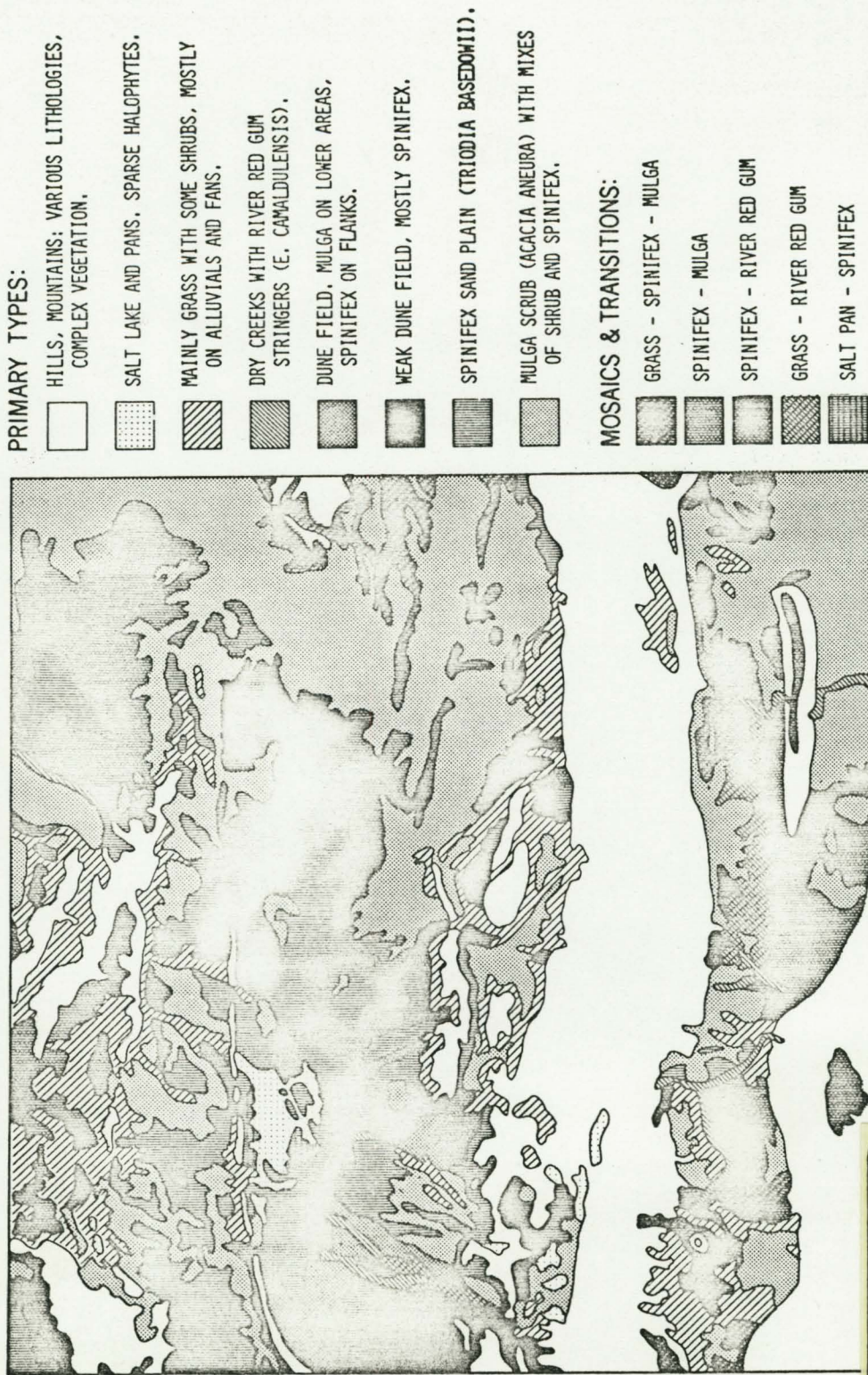
In the final analysis categorization of areas must be qualitative because dissimilar entities are grouped together during the process of generalizing. In a sense this is precisely what we require in resource surveys - elimination of the "noise" contributed by detail. As long as we interpret space photographs with these considerations in mind we will not abuse the data.

Despite constant reference to data reduction, the Alice Springs photograph contains a vast amount of information from which a rather detailed (thirteen category) map of landscape types has been produced (Figure 19). Eight of the categories mapped are referred to as "primary types" and are considered by us to be acceptable groupings. An additional five categories constituting mosaics and transitions of these are based primarily on deductive and presumptive evidence.

Identification and distribution of the various categories was arrived at by combining the data from photo interpretation, field observation, and reference to the previous work of Perry (1961, 1962). All decisions for classifying areas were based on image qualities together with our field knowledge of the range of types present. After establishing the distribution of types, verbal descriptions of each (the legend items)

LANDSCAPES NORTHWEST OF ALICE SPRINGS, CENTRAL AUSTRALIA

Base: Space Photography



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Figure 19. Landscapes northwest of Alice Springs, Central Australia. Boundaries and categories based upon space photography.

devised in accordance with field observations and the terminology already available from Perry.

Figure 19 is an unedited attempt by a single interpreter (Morain) to categorize areas on the basis of the above information. A number of inaccuracies (or at least questionable generalizations) are already known to exist, many of which could be improved by contributions from other interpreters familiar with the area. Two classification errors from the mosaic and transition categories will serve as examples of the sort of problems encountered.

The first of these is drawn from the grass-river red gum type. According to Perry, spinifex (T. clelandii) is the dominant grass with river red gum occurring along creeks. As used in this report the word "grass" refers to any genus of grass other than spinifex, even though the latter is in fact a grass genus. The interpreter failed to recognize the spinifex as such but was successful in distinguishing the larger entity, "grass". Inspection of the photograph reveals that grass was believed present because of the light tones present in the area. Spinifex was not suspected in this case because that entity normally has a darker tone than other grasses. Clearly we cannot map reliably at the generic level.

The second example concerns the Grass-Spinifex-Mulga mosaic. Here again Perry describes the identical map areas as combinations of either Mitchell or kerosene grass, mulga and river red gum. This time spinifex was suspected but failed to be present in reality. Inability to recognize river red gum is probably less serious a problem, since it characteristically occurred only along creeks and along some only sporadically.

Certain of the categories are intuitively obvious from their photo appearance, assuming the interpreter has a basic knowledge of the region. For example, hills and mountains, major drainage ways, and to lesser extent dune fields and foot slope alluvial areas, are easily identified.

Some drainage ways are particularly easy to discriminate if red-gum stringers line their courses. Whether this is due solely to very sharp

COMPARISON OF BOUNDARIES: SPACE PHOTOGRAPHY vs. PASTURE MAP

(Base: Map from Space Photo)

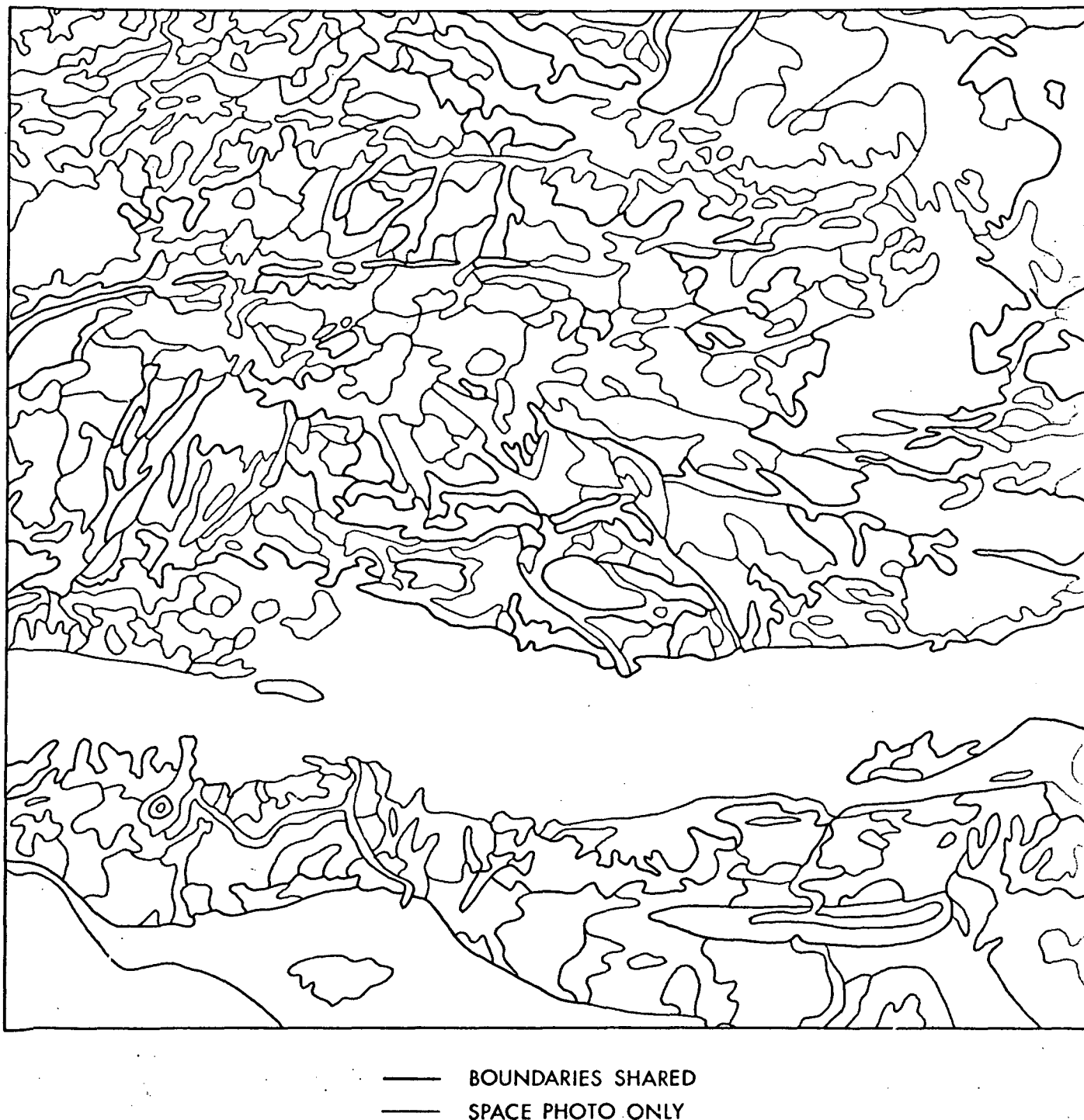
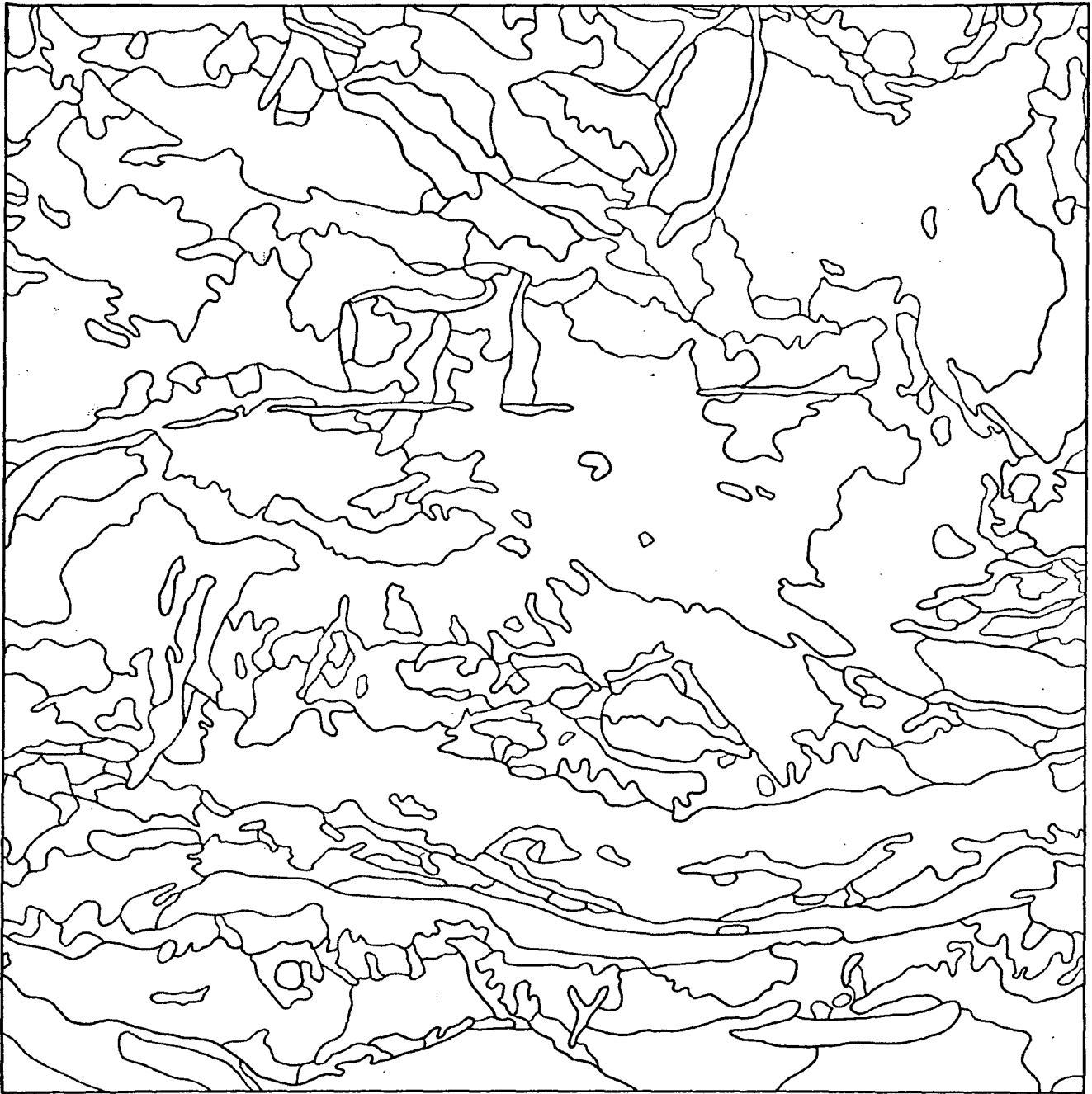


Figure 20. Comparison of boundaries delineated on space photograph and Perry's (1961) map of the Pasture Lands of the Alice Springs Region. The boundaries shared and those noted only on the space photo are given.

COMPARISON OF BOUNDARIES: SPACE PHOTOGRAPHY vs. PASTURE MAP*

(Base: Pasture Map)



— BOUNDARIES SHARED
— PASTURE MAP ONLY

*AFTER R.A. PERRY, (1961), C.S.I.R.O. DIVISION
OF LAND RESEARCH, CANBERRA, AUSTRALIA

Figure 21. Comparison of boundaries delineated on space photograph and Perry's (1961) map of the Pasture Lands of the Alice Springs Region. The boundaries shared and those noted only on Perry's map are given.

contrasts in spectral reflectance properties of the soil-vegetation interface or results from a combination of spectral reflectance and shadowing caused by tree height is not known. Many others with red gum are barely detectable after the fact but are otherwise ambiguous. The waterways themselves are reported to be only 150 feet wide, less than system resolution. The space photo was taken in late afternoon so shadows were present as may be seen in the mountains.

Some dune fields are equally easy to detect, but in this case the reason is likely attributable to vegetation contrast rather than shadowing. Wherever dunes are spaced more than about 120 yards apart (the approximate resolution of the camera system) with mulga developed in the swales, the field takes on a characteristic linear or "combed" appearance. Other dune fields are not easy to detect either because the dunes are too near each other to be resolved or because the spinifex-mulga relationship is nonexistent, or too fine to resolve, or has been weakened by drought. Due to their obscurity on the photograph (just a vague hint of the combed appearance) such dune fields are classified as "weakly developed". They are probably more wide spread than Figure 19 indicates.

The Mulga Scrub, Spinifex, and Scrub-Spinifex categories correspond fairly well spatially to the Low Tree and Shrub and Spinifex Sand Plain types mapped by Perry (Figure 2). Mulga scrub appears on the space photo in medium to medium dark tones and wherever it comes in contact with the lighter tones of alluvial grasslands, boundaries are distinct. Discrimination between Mulga Scrub and Spinifex Sand Plain is exceedingly difficult since the contact between these two is characterized by gradual shifts in their relative proportions in the landscape. Figure 19 recognizes a transitional type, Spinifex-Mulga, to draw attention to this ill-defined contact.

The final two figures (Figures 20 and 21) in this draft paper represent compilations, generalizations, and comparisons of all boundaries delineated on Perry's map and on the Gemini photo. These two illustrations were compared in the field during May and June 1969 by

Professor G. R. Cochrane. It is too early to report on these comparisons here, but he in effect has verified the basis on which each boundary appears to be erected such as differences in vegetation density, type, structure, and species; soil color, dissection, and exposure; lithology and other items. A detailed site-by-site comparison on the ground between Perry's map and the boundaries derived from the space photograph is essential to prove the meaningfulness of the boundaries in both cases.

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