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Multiband Photos for a Tidal Marsh

Ektachrome IR was superior for the differentiation of vegetative types and was most useful for delineations within marshlands whereas Ektachrome color transparencies were most useful for general interpretation.

ABSTRACT: *A variety of multiband imagery, including nine-lens multiband imagery in the 400–900 millimicron range, panchromatic, Ektachrome, and Ektachrome-Infrared photography, has been obtained for a tidelands area in San Francisco Bay. A technique for comparing their relative utility for specific geomorphic interpretations has been developed, whereby a subjective form of tracing analysis may be correlated with a more objective (and quantitative) scheme of selected microdensitometer traverses across the various negatives and positive transparencies. The results suggest that the nine-lens multiband imagery is excessive, and, that for a similar use as that of the photos studied, could be reduced to four-lens imagery. The most useful frames are the 550–630 millimicron bandwidth, the near-infrared, the Ektachrome color transparency, and the Ektachrome-Infrared transparency. Various utilities are suggested for each type of imagery, and increased experimentation by geologists with the microdensitometer is urged.*

MULTIBAND PHOTOGRAPHY

ONE OF THE NEW sensors used in remote sensing studies is a *multiband* nine-lens aerial camera which uses various narrow band filter combinations for taking simultaneous photographs in selected regions of the visible and near-infrared spectrum. The operating principle is that different types or conditions of terrain reflect solar radiation in a manner characteristic of the terrain. Changes in vegetation, soil properties, or seasonal effects on the terrain can be detected by interpretation of the relative brightness appearing on the resulting photographic imagery. Such information can be obtained in a more quantitative manner from this type of imagery than from conventional black-and-white or color aerial photography.

The Itek Corporation of Lexington, Massachusetts, has developed such an airborne spectral reconnaissance system (Molineux, 1965). Multiband imagery from this system was flown for the writer in conjunction with a study for the Geography Branch of the Office of Naval Research on tidal marsh morphology in the vicinity of San Francisco Bay, California (Pestrong 1965).

The multiband camera utilized employs three rolls of aerial film, each traversing three matched lenses equipped with appropriate filters to provide nine narrow-band inputs to the film. The system operates in the 400–900 millimicron region of the visible and near-infrared region. Six of the images are on two rolls of 70-mm aerial panchromatic film and the other three are on one roll of 70-mm aerial infrared film. Each of the nine photographs taken during one exposure is of matched image size uniform within 0.001 inch. Resolution is from 20 to 30 lines per millimeter. Camera and bandwidth data are given in Tables 1 and 2.

To supplement the multispectral photographic imagery, other cameras using the following films were utilized along with the nine-lens Multiband Camera: Kodak Plus-X Aerocon; Kodak Ektachrome Aero, High Contrast; Kodak Ektachrome Infrared Aero

TABLE 1. MULTIBAND CAMERA DATA

Lens	Nine 6-inch f/2.8 Schneider Xenotar matched lenses
Film Type	Two rolls of 70 mm. Plus X Aerographic, one roll 70 mm. Infrared Aerographic
Frame Format	Nine frames each 2¼ by 2¼ inches
Exposure Technique	Three exposures on each roll of film
Shutter System	Three parallel focal plane shutters of three slits each so as to expose all nine frames simultaneously
IMC	Modified A-9-B magazine with film drive image motion compensation

Film, Type 8443. In addition to the haze filters normally utilized in aerial photography (Kodak Wratten Filter No. 2B or HF-3), the Infrared Ektachrome film requires a Kodak Wratten Filter No. 12 or 15, in order to exclude blue light to which all layers of the film are sensitive. Additional ground photography was also obtained, utilizing Kodak Plus-X Pan film, Kodak Infrared film (with a deep red filter), Kodak Ektachrome Aero Film, Type 8443, and Kodachrome II color film. Comparison of all such photography increases the probability of more accurately describing and identifying terrestrial features and surficial differences.

Four separate flights were flown over the tidal marsh areas (Figure 1) during August and October of 1965. Photography was thus obtained from high and low altitudes (15,000 feet and 1,500 feet) and during periods of high and low tide.

MICRODENSITOMETRY

Microdensitometry is the technique of measuring either the reflection or transmission density of microscopically small image areas. The microdensitometer:

- Looks at a very small portion—as little as 1 micron diameter—of a photographic image at spectral levels selected to be compatible with the sensitivity levels and dye component spectral characteristics of the photographic materials.
- Reads the optical density of the image by means of a scanning optical system and photo multiplier—log amplifier measuring system.
- Scans the negative at a uniform rate, as slowly as 10 microns per minute.
- Presents the data graphically on a strip chart or, if used with a converter, presents data digitally to a computer for reduction and analysis (Doverspike, *et al.*, 1965).

Film density for the various bands of the imagery studied was measured with a Model 650 GAF-Ansco automatic recording microdensitometer, utilizing a circular aperture of 1.62 mm. diameter. Traverses were run across the negatives and positive transparencies studied at speeds varying from 5 to 50 mm. per minute and at image magnifications varying from 25× to 100×. Neutral optical settings were employed, in that no filters were placed in the path of the light beam. Relative density differences (on a scale of 0–4) were automatically recorded on a chart moving at a rate of four inches per minute past the recording pen.

Traverse speeds and image magnifications varied with the three specific utilities required. These were:

- ★ Density comparisons of the same traverse across the different imagery bands (at 50 mm./minute and 100× magnification).
- ★ Closely spaced traverses across a single photographic image for exploring contouring potential (at 50 mm./minute and 25× magnification), and
- ★ Traverses across tidal channels for exploring profiling possibilities (at 5 mm./minute and 100× magnification).

These rates and magnifications were selected after many trial runs and considerable experimentation with the available photography, so as to provide readout data most consistently in a manner commensurate with the desired need.

FIELD LOCATION

The area of study included the marshes and tidal flats adjacent to San Francisco Bay, in the vicinity of Palo Alto and Menlo Park, California (Figure 1). Previous investigations by the writer in this area (Pestrong, 1965) have been limited because of problems of access imposed by the environment. Morphological descriptions and measurements, and detailed mapping programs suffered accordingly. Significant amounts of information relating to the physical properties of the

TABLE 2. MULTIBAND CAMERA SPECTRAL BANDS

Lens No.	*Bandwidth (m.)*	*Filters Used*
1	400–440	Wratten 36+38A
2	460–500	Wratten 3+47
3	525–550	Wratten 65A+58
4	550–590	Wratten 21+57
5	600–630	Wratten 72B
6	650–710	Wratten 34+21
7	700–	Wratten 89B
8	775–	Wratten 87 Full Sensitivity Range of IR Film
9	825–	Wratten 87C

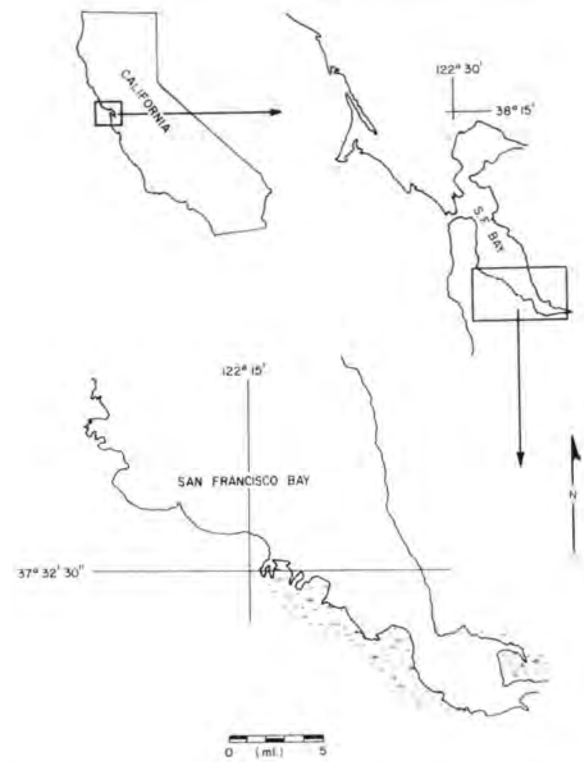

FIG. 1. Location Map, showing tidelands studied within San Francisco Bay.

materials have been obtained, however, thereby providing a useful store of available data to be utilized by other studies.

The availability of the Itek Multiband Camera, and the resultant detailed photography, provided an excellent opportunity to increase our knowledge of this important geological environment while developing a means of evaluating the utility of multispectral imagery as a geological tool.

LABORATORY PROCEDURE

In order to facilitate direct comparisons, and thereby aid determination of the relative utility of the many bands and film types, the following technique has been applied and found to be most useful. All individual transparencies of the same ground coverage, but of different spectral characteristics, are cut from their respective rolls, and mounted alongside one another in the manner shown in Figure 2.

Because of the $2\frac{1}{4}\times2\frac{1}{4}$ inch size of the 70-mm. photography, 12 different transparencies can readily be mounted within a single $8\frac{1}{2}\times11$-inch clear plastic page protector, and easily stored in standard looseleaf binders for ready use. The 12 transparencies include the 9 multiband negatives, the Ektachrome and Infrared-Ektachrome positive transparencies (all 70-mm. imagery) and a $2\frac{1}{4}\times2\frac{1}{4}$-inch portion of the 9×9-inch panchromatic negative. The entire sheet may then be studied easily on any light table.

For each location selected, tracings have been prepared for each of the 12 frames studied of drainage networks, water penetrability, vegetation differences, and environmental variation. Examples of these are presented in Figures 3 and 4. The degree of transparency of most of the common tracing papers is such that the outlines of features that are just barely recognizable on the naked negative become obscured when viewed beneath these papers on a light table. This then provides a means of rating the various frames by eliminating the vaguest images, and thereby narrowing the range of certainty of image identification. In Figures 3 and 4, the solid lines indicate certainty and the dotted lines uncertainty as to the delineation of the underlying image; the greater the separation between the dots, the greater the degree of uncertainty that exists.

This method of analysis is based on a qualitative and, therefore, subjective evalua-

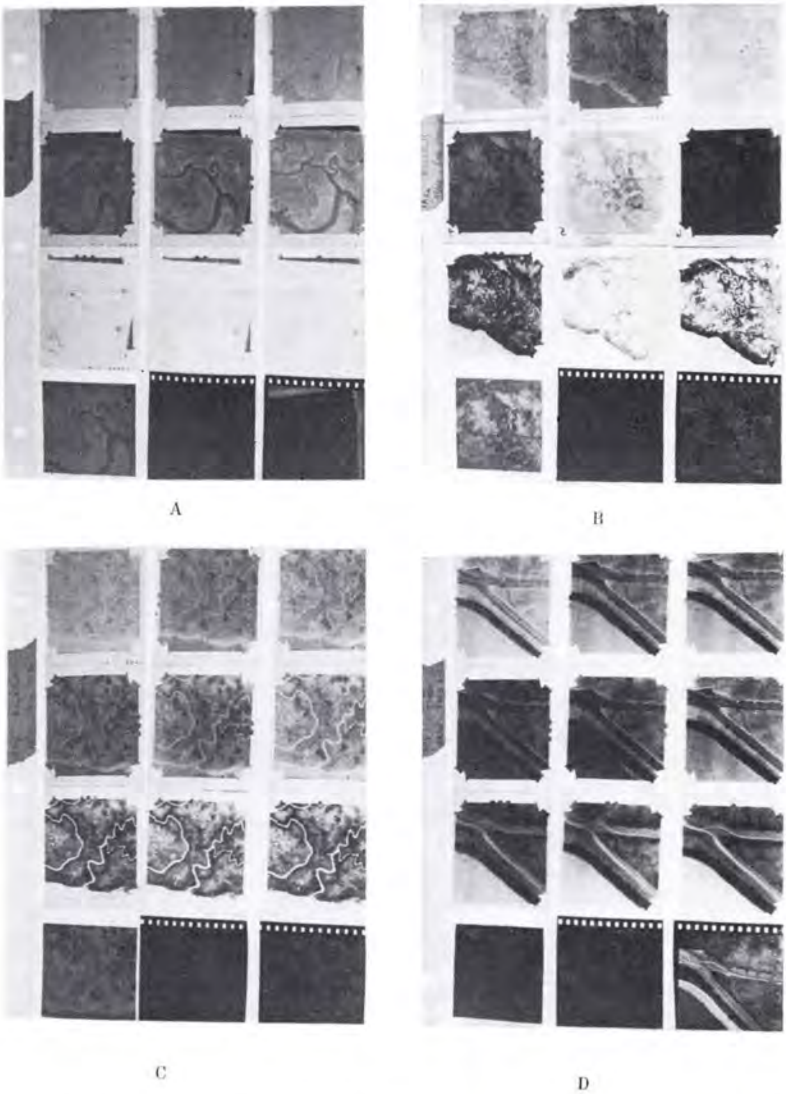

FIG. 2. Orientation of Multispectral Imagery. Four separate sets of negatives and positive transparencies are shown. *A*, Drainage patterns visible through saline waters of salt evaporation pan; *B*, Drainage channels on tidal marsh; *C*, Drainage channels on tidal marsh; *D*, Tideland environment, including marsh, channels, dike, and evaporation pan.

tion of the imagery. Conclusions based on studies of this type will vary with the skill of the investigator and the conditions at the time of the analysis. An objective, quantitative, technique, the results of which could be compared with the tracings just described, was developed utilizing the GAF-Ansco Model 650 Microdensitometer. With this method, operator skill and physical conditions such as lighting or tracing surface are ruled out as significant factors in the evaluation of the imagery. The results of density traverses across the transparencies are recorded on a strip of chart, on which numerical values are assigned to density differences between objects and the image (Figures 5 and 6).

It is now the task of the interpreter to assign the appropriate density value to its corresponding feature on the image. From these determinations, a bar graph may be prepared showing density differences between specific features on a transparency. The density difference is a direct indication of the ease of distinguishing between the features studied, and therefore a means of evaluating their clarity and the relative utility of that

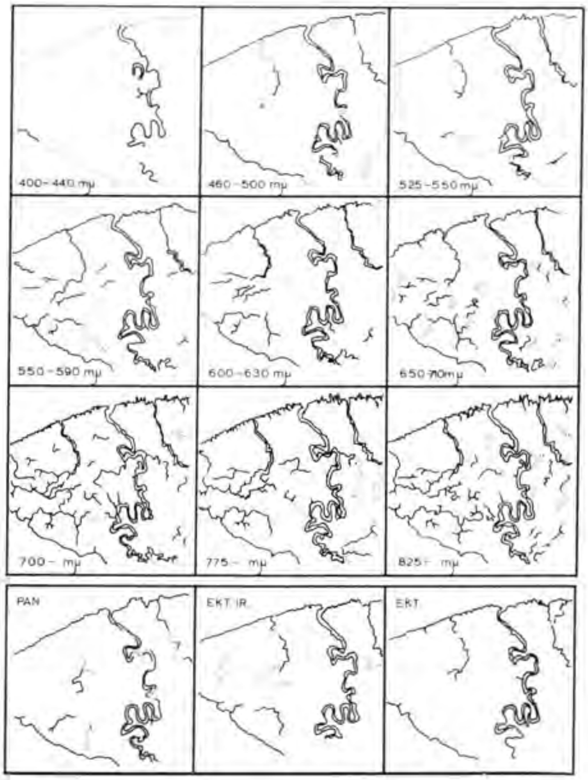

FIG. 3. Tracing analysis of tidal marsh drainage channels.

transparency for that specific purpose. Figures 7 and 8 show the results of such density graphs, each of which relates to the same features shown on the tracings of Figures 3 and 4.

This method of comparison is only strictly valid for either the black-and-white multiband photography or for the color images. Very different hues on the color photography may have more similar densities than equally discernible features on the black-and-white photographs. They are all listed together, however, for a qualitative appraisal when evaluated in conjunction with the tracings.

EVALUATION OF RESULTS

MULTIBAND PHOTOGRAPHY

RELATIVE GEOMORPHIC UTILITY

Comparisons of the data from both the tracing analyses and the microdensitometer traverses have led to the following conclusions with respect to their applicability to geomorphic studies in a tidal marsh environment.

(1) The greatest degree of precision in the differentiation of land and water boundaries may be obtained with the near-infrared photography (Bands 7, 8, and 9). The clearest delineation of drainage patterns, therefore, may be obtained with these spectral bands (Figures 3, 5, and 7).

Inasmuch as infrared radiation is absorbed by moisture, water bodies appear dark in tone on photographs recorded in the near-infrared region of the electromagnetic spectrum. The tidal flats and marshes, which are inundated daily, are composed largely of very fine clays of between 2 to 4 microns in diameter. These sediments retain most of their moisture during the time intervals between tidal floodings, and so appear dark on infrared photographs. Where some drainage has occurred from the higher, more permeable areas composed of coarser silts, the resultant imagery appears lighter gray in tone. Where natural levees are present alongside the tidal channels, they may be distinguished this way, although only a few inches of differential relief exists between the marsh and levee surface (Figure 2, B and C).

As the moisture content affects vegetative growth, various zones of marsh grass, as described in greater detail in a later section, may be delineated. Microrelief features on the

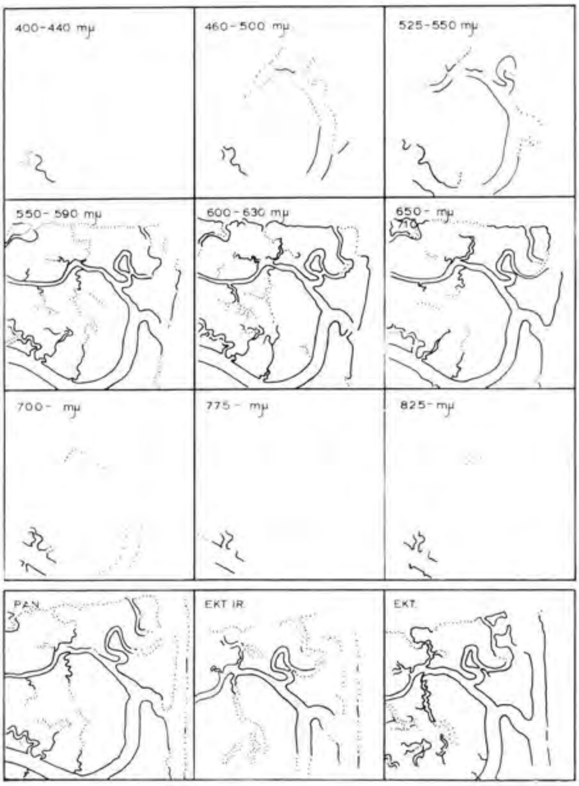

FIG. 4. Tracing analysis of water-bottom drainage configurations.

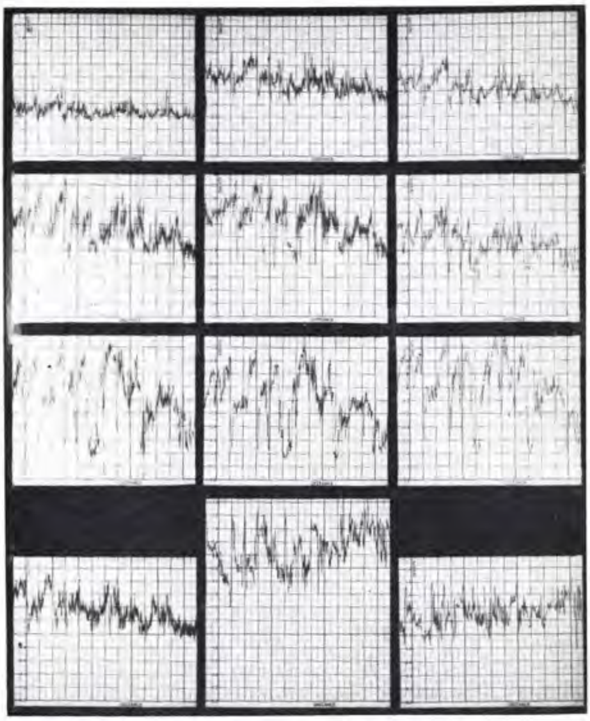

FIG. 5. Strip-chart recordings of microdensitometer readings for the same traverse across each of the 12 different multiband images. The density differences reflect varying drainage pattern delineation capacities. The traces were made across several channels draining a tidal marsh.

marsh surface, that are not apparent even when viewed stereoscopically, may readily be interpreted from infrared photography. Minor depressions impound water because of the impermeability of the marsh sediments, and appear darker in tone. Marsh pans may thus be easily identified.

(2) The greatest degree of water penetration, and therefore the greatest clarity of water bottom phenomena within the marine environment studied (35 parts per thousand salinity), occurs within the 550–630 millimicron (orange and red; Bands 4 and 5) region of the visible spectrum (Figures 4 and 8).

Colwell (1961) concludes that, in attempting to record underwater details to maximum depth on aerial photography:

- For *clear sea water*, an orthochromatic film (with supplementary sensitization in the green part of the spectrum) should be used in conjunction with a yellow filter that transmit wave lengths greater than 520 millimicrons;
- For *transparent river water*, panchromatic film should be used in conjunction with a light orange filter; and
- For *very turbid river water*, panchromatic film in conjunction with a dark orange or red filter should be used.

The writer's studies, based on an evaluation of the relative clarity of old drainage patterns covered by approximately three feet of very saline water in a diked-off salt evaporation basin, suggest that there exists within these basins a very high suspended sediment content, causing considerable scattering of light. This conclusion is based on the fact that the absorption minimum has shifted to the yellow-orange range of the spectrum (550–630 millimicrons), reflecting a high degree of scattering within the water. This appears anomalous as there are no sediment concen-

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FIG. 6. Strip-chart recordings of microdensitometer readings for the same traverse across each of the 12 different multiband images. The density differences reflect varying water penetration capacities. The traces were made across old drainage patterns presently inundated by 3 to 4 feet of water within salt evaporator basins.

trations presently being introduced into the basins. According to Mr. Robert Focht, the Chief Chemist for the Leslie Salt Company (personal communication), however, at the time of the year during which the photographs were obtained, a high algal and bacterial content is present within the saline waters accounting, therefore, for the scattering due to the high suspended content of fine biotic material.

(3) Two seed plant vegetational zones dominated in the marsh area studied. These are the *Spartinetum* (California Cord Grass), a tall, firm plant with long, narrow leaves, that may reach heights in excess of four feet, and the *Salicornietum* (Pickle-weed), a plant whose stems appear to be a series of long, narrow pickles attached end-to-end. This succulent plant may reach heights of 12 inches and, like the Cord Grass, is restricted to salt marshes because of its high tolerance to salty and alkaline soils.

Tidal submergence and emergence exert an effective control over the limits of vertical distribution of these seed plants of which the salt marsh associations are composed. The Cord Grass, because of its ability to endure up to 21 hours of continual submergence, occupies the lowest levels of the marsh. The Pickle-weed, lacking the air-storage tissue present in the Cord Grass, cannot withstand the longer periods of inundation and so occupies the higher levels of the marsh (Pestrong, 1965).

As the vegetation is so closely controlled by marsh height and, therefore, soil moisture, broad patterns of plant distribution may be delineated on the near-infrared photographs, which most clearly depict zones of moisture content variation. Bands 4, 5, and 6 (green-yellow, orange, and red), however, also are very useful for distinguishing among zones of plant varieties.

The Cord Grass plants are generally found at the water edges of the marsh and alongside the channels draining the marsh surface, whereas the Pickle-weed plants normally colonize the interior, and higher, marsh areas

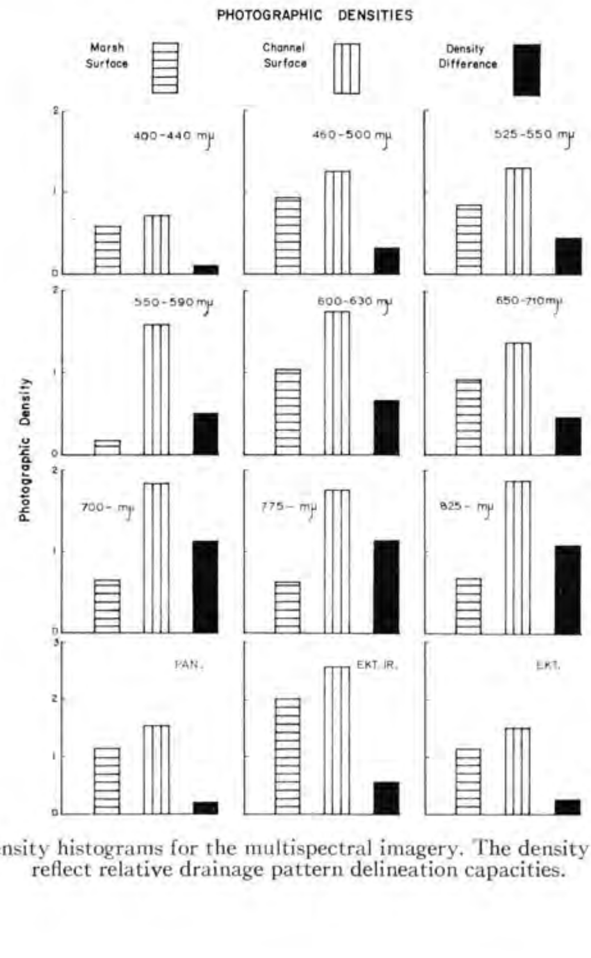

FIG. 7. Density histograms for the multispectral imagery. The density differences reflect relative drainage pattern delineation capacities.

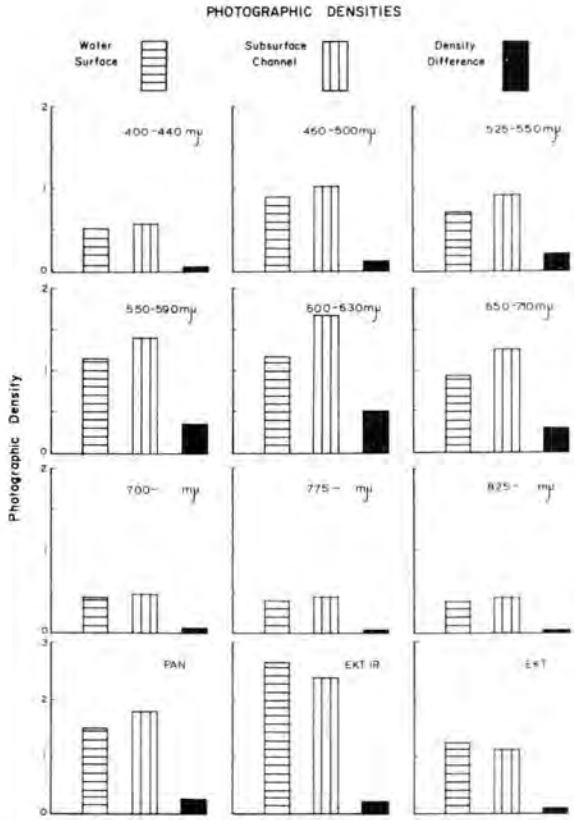

FIG. 8. Density histograms for the multispectral imagery. The density differences reflect relative water penetration capacities.

The darker areas of the photographs, therefore, generally indicate the presence of Cord Grass, and the light, Pickle-weed.

The lighter gray tones on infrared film result from the degree of infrared reflectiveness of an object rather than from its true color in the visible range. Broad-leaved vegetation, for example, is highly reflective and therefore photographs in light tones; coniferous or needle-leaf vegetation tends to absorb infrared radiation and so registers, in much darker tones. The same situation exists within the tidal marshes, where the broad-leaved Cord Grass is also highly reflective of infrared radiation, and therefore, appears much lighter in contrast to the surrounding succulent Pickle-weed.

The degree of infrared reflectance from a leaf is a function primarily of the structure of the parenchyma cells within the mesophyll layer (middle portion of the leaf) (Colwell, 1956). In angiosperms (flowering seed plants, generally broad-leaved), these cells are often widely spaced with numerous voids in between. Infrared light is bounced back and forth from these many spaces and voids, and reflected to the atmosphere. Within gymnosperms (coniferous seed plants), however, these cells are generally more tightly compacted, with a resulting decrease in void spaces and therefore less infrared reflectance. The Cord Grass and Pickle-weed, although both angiosperms, show these same relationships. The Cord Grass, with its characteristic broad leaves, has a much looser parenchyma layer, with more air spaces, then the Pickle-weed, which has a very dense mesophyll. The Pickle-weed, therefore, does not reflect in the infrared as effectively at the Cord Grass.

(4) The major tideland environments include: (a) the lower tidal flat, always submerged; (b) the upper tidal flat, periodically submerged and re-exposed; (c) the lower tidal marsh, periodically submerged and re-exposed; (d) the upper tidal marsh, always exposed; and (e) the tidal channels draining

the marsh onto the tidal flat, periodically submerged and re-exposed, depending on depth of incision beneath the marsh surface.

The greatest clarity of these individual features may be obtained from Bands 4, 5, and 6. Nearshore water bottom features are best seen within these bandwidths, and the absence of the extreme contrast present in the infrared imagery makes these frames more generally useful for overall environmental identification.

PROFILING TECHNIQUES

It was discovered that, if a microdensitometer traverse was run at a very slow speed (5 mm/minute) across a negative of a drainage channel filled with water (at bankfull stage of high tide), the resultant trace approximated the actual channel profile as obtained in the field surveys. Figure 9 demonstrates the correlation between field measurements and microdensitometer traverses, for five small tidal marsh channels near Palo Alto. All the traverses were made on Band 5 negatives, which demonstrate the greatest water bottom clarity.

As the traverses reflect the negative density which, in turn is a function of water turbidity, major discrepancies in channel shape may be attributed to variations in suspended sediment content of the waters. In addition, vegetation overhanging the channel banks tends to produce erroneous results. Despite these factors, however, the microdensitometer traverses are remarkably similar to the field traverses, and suggest a potentially valuable tool for channel profiling when field access is not possible.

CONTOURING POTENTIAL

If a number of closely spaced, parallel traverses were run across a negative with the microdensitometer, the resultant readings, if contoured, or somehow differentiated into distinct groups of equal densities, should reflect the tonal pattern of the negative. This, in turn, is a function of the terrain, and, therefore, should indicate the ground pattern.

The above technique was attempted with a negative showing drainage patterns present beneath three feet of water within a salt evaporator basin (Figure 10). Fifteen equally spaced traverses were run across the negative, and the resultant density patterns plotted in Figure 11. Except for the large, well defined

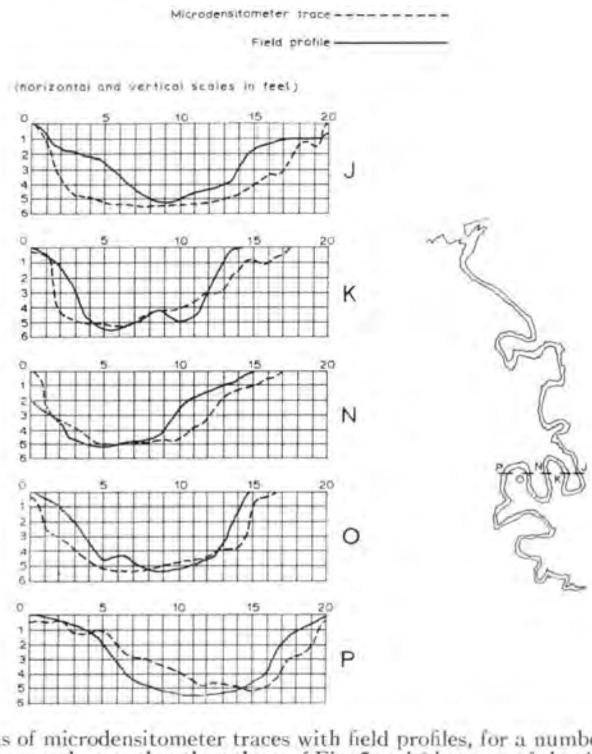

FIG. 9. Comparisons of microdensitometer traces with field profiles, for a number of small tidal marsh channels. The traces are much smoother than those of Fig. 5 and 6 because of the slow speed (5 min/min.) at which they were run.

FIG. 10. Tracing of submerged drainage patterns used in microdensitometer contouring attempt.

drainage channel in the south eastern portion of the tracing, no other drainage networks or patterns are clearly portrayed. Many possibilities for inferring channels exist, but none with any high degree of certainty.

It is apparent that the 15 traverses provided insufficient data for defining the terrain patterns. As the number of traverses is increased, the ground terrain becomes more clearly defined with greater degrees of certainty. This method, however, involves a great deal of tedious work in extrapolating density readings from the readout chart and recording them on a map in their appropriate locations.

Colwell (1968) describes a technique whereby photoelectric sensors can be used to scan all the multiband images directly. For each spot scanned, the sensors automatically determine a tone signature, which should be identifiable with some signature established from the test site. This technique, though prohibitive in cost, may be extended, utilizing magnetic tape printouts of the tonal variations, so that a complete inventory of ground signatures is available shortly after the imagery is recorded.

PANCHROMATIC PHOTOGRAPHY

The principal film used for aerial mapping and interpretation in the United States is panchromatic, a black-and-white negative material having approximately the same range of sensitivity as that of the human eye. Images on panchromatic photographs are rendered in varying shades of gray, with each tone comparable to the density of an object's color as seen by the human eye.

As shown in Figures 3 and 4, panchromatic film is moderately useful for drainage pattern differentiation and sub-water penetration. The broad range of sensitivity also makes this photography valuable for general environmental evaluation. It is the single most useful

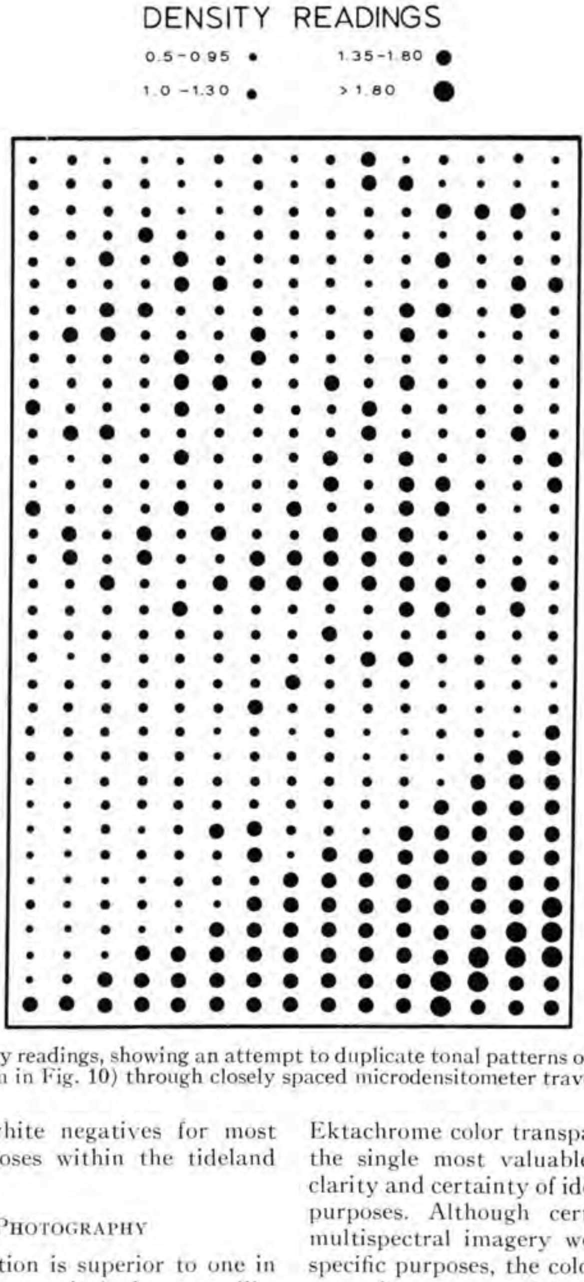

FIG. 11. Map of density readings, showing an attempt to duplicate tonal patterns of the negative (tracing shown in Fig. 10) through closely spaced microdensitometer traverses.

of the black-and-white negatives for most interpretative purposes within the tideland environment.

COLOR PHOTOGRAPHY

A color reproduction is superior to one in black-and-white because it looks more like the original scene with many of the subtle shadings of hues and saturations represented. Color photographs, therefore, provide the interpreter with an extra, important factor, in addition to the form and shape parameters normally used in image identification.

EKTACHROME FILM

Aerial Ektachrome emulsions are reversal color films of the subtractive type. The Ektachrome color transparency proved to be the single most valuable frame for overall clarity and certainty of identification for most purposes. Although certain bands of the multispectral imagery were more useful for specific purposes, the color transparency was generally most useful. It was clearly the best frame for environmental differentiation within the tidelands, as well as for certainty of identification of man-made features such as roads, dikes, and power lines.

If economic considerations dictate the utility of only a single type of photographic imagery for general field interpretation, the imagery most useful would be color positive transparencies. Anson (1966), in contrasting the relative utility of Ektachrome, Ektachrome IR, and panchromatic photography for various field uses, also found normal color photography to be superior to panchromatic and Ektachrome IR for mapping soils and culture; Ektachrome IR photography proved to be superior to color and panchromatic photography for mapping vegetation and drainage.

In the present area of study, the high suspended clay and fine silt concentrations, which were characteristic within the channels draining the marshes and the shallow bay waters bordering them, effectively colors the waters so that they appear gray-green on the photos. The shallow depths of the evaporator pans allow the color of the yellow-brown sediment-salt concentrations beneath and within the water to show through, so that the color photos reflect these hues.

EKTACHROME-INFRARED FILM

Ektachrome-Infrared Aero Film is a three-color sensitized film consisting of one layer sensitive to infrared reflections (to 900 millimicrons) and the two additional layers sensitive to green and red wavelenths. The film is always exposed through a yellow or orange filter (Wratten Nos. 12 or 15) which prevent blue light from exposing the film; thus, only reflected green, red, and infrared wavelengths reach the emulsion. The resulting colors on the photography are blue for the green spectral regions, green for the red spectral regions, and red for the infrared spectral region. Blue objects all photograph black.

The predecessor to this film was known as Camouflage Detection film. Developed during World War II, it was produced to detect painted targets which were camouflaged to look like vegetation. Because healthy vegetation is a much stronger reflector in the near infrared than in the green portion of the spectrum, vegetation appears in various hues of red on the film; objects painted green appear blue and can be distinguished immediately. As with black-and-white infrared film, if seed plants lose vigor through disease, insect attack, or soil salinity, their mesophyll layer becomes plugged, and they reflect less infrared light, therefore showing up as a darker red or blue-green. In some cases, plants under stress show up on this film before symptoms of decadence or death are visible on the ground.

As reported by Colwell (1961), a camera lens receives infrared and green light reflected from the spongy mesophyll and chloroplasts, respectively, within the plante leaves. Loss in infrared reflectance, due either to a collapse of the leaf's spongy mesophyll or to a plugging of this tissue by a fungus, would occur long before the leaf's green color started to fade. The disease would therefore be detectable much sooner on infrared-sensitive film than on color or panchromatic photography.

Foresters and agriculturalists have extensively utilized this film in timber and crop surveys; it remains for other disciplines to discover potential uses. Geologists, in particular, ought to be able to utilize its special properties. As the film is able to detect differences in vegetative activity which may be a function of underlying geological controls, Ektachrome IR may provide a valuable tool in detecting clues to a variety of geological phenomena. It is also valuable in aerial photography because of its haze-penetrating ability.

Ektachrome IR can be utilized to differentiate on the tidal marshes between the luxuriant growths of Cord Grass (with a

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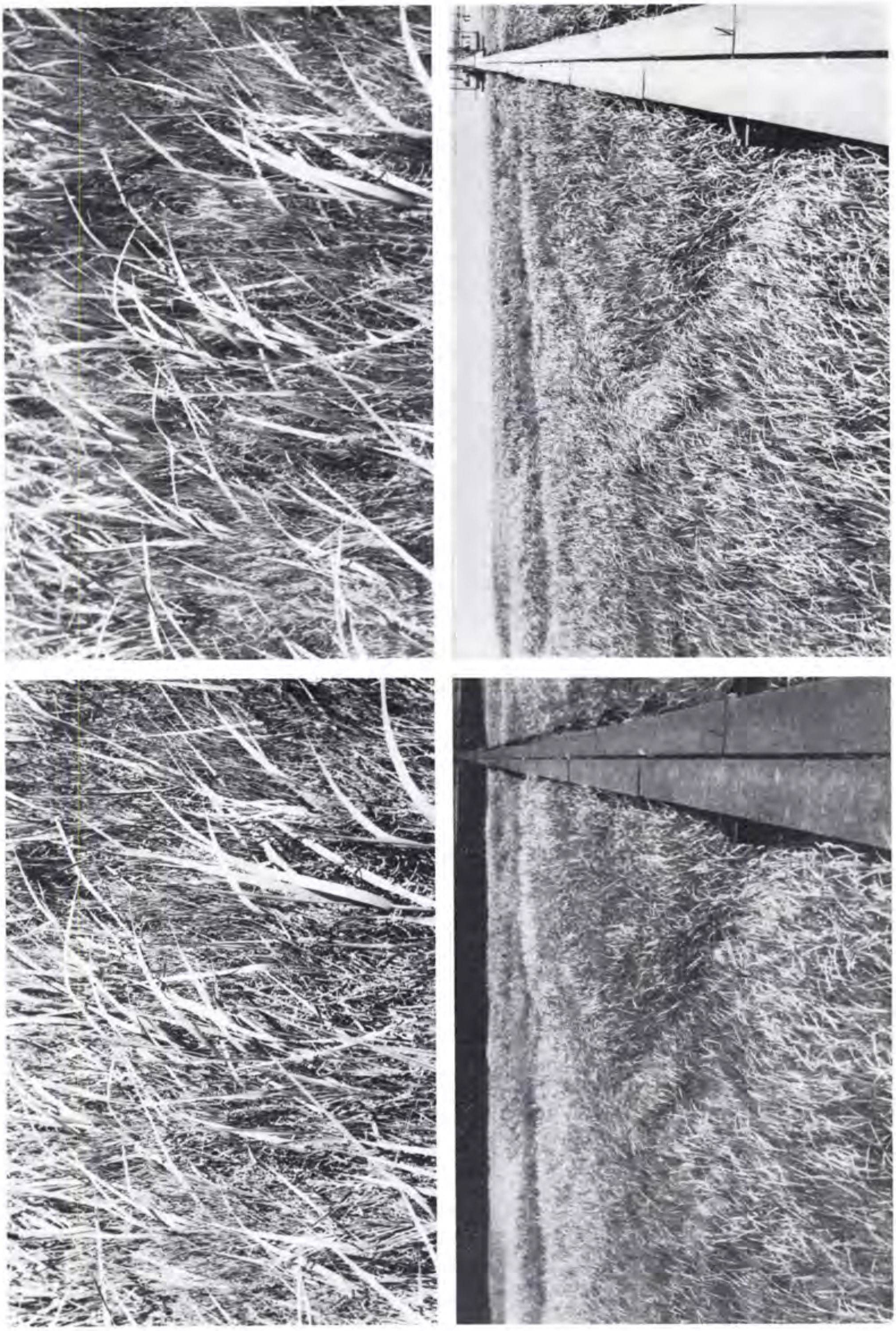
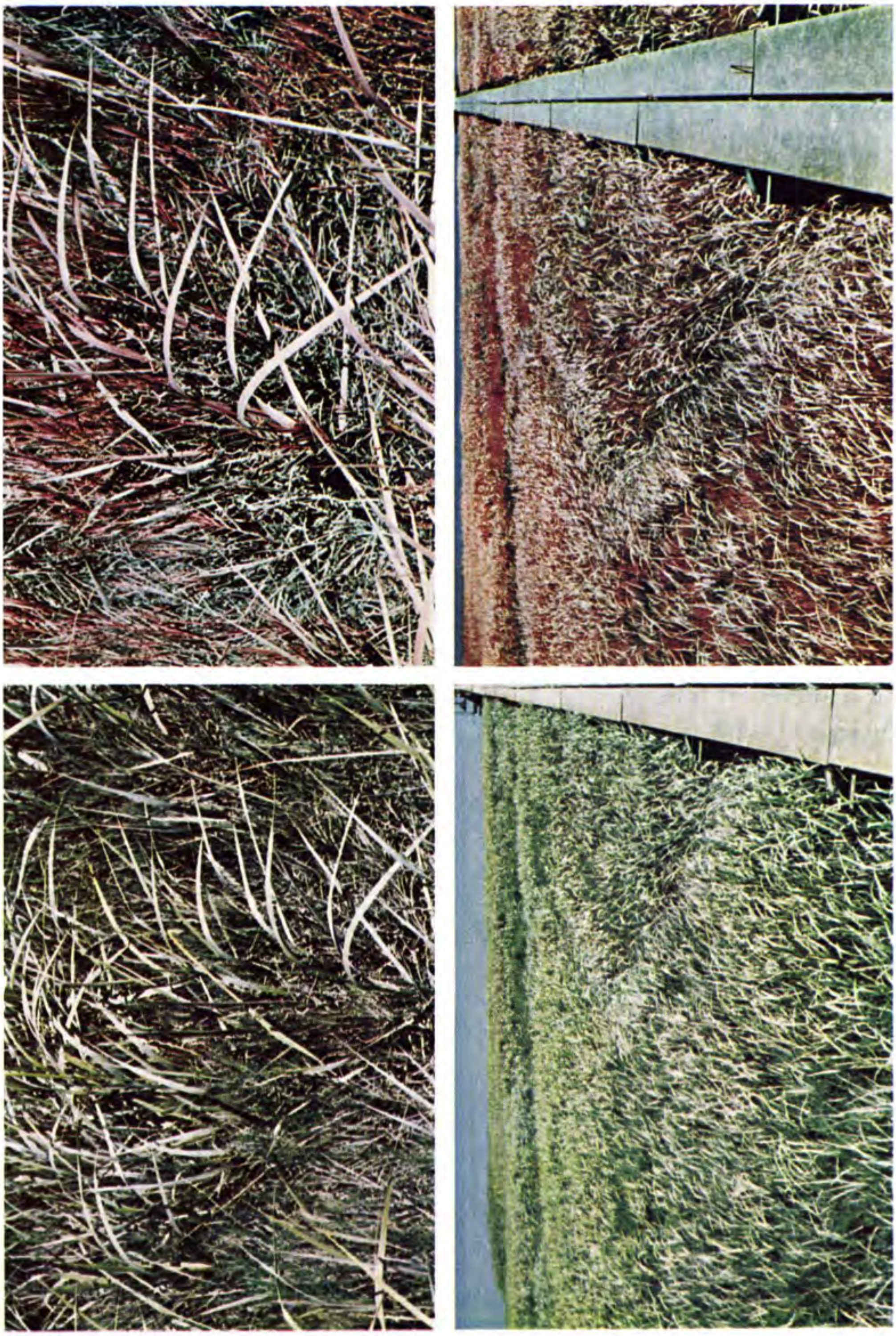
PLATE 1 (page 466) and PLATE 2 (page 467). Two views are shown of Tidal Marsh Vegetation taken on four different types of film. The two upper views of both Plates were taken simultaneously with a simplified four-frame multiband arrangement; similarly for the two lower views of both Plates. On Plate 1, Panchromatic film was used for the views on the left, and Infrared film for the views on the right. On Plate 2, Ektachrome film was used for the views on the left, and Ektachrome IR film for the views on the right.

In the upper views, note how two distinct vegetative types may be differentiated easily on the Ektachrome IR view, whereas these same plants can only be separated with considerable difficulty (and some uncertainty) on the other film types. The distinctively different colors registered by the Ektachrome IR film represent the variable infrared reflectance of the two plant types, whereas these differences are only evident as shades of gray on the Infrared film and the Panchromatic film, and shades of green on the ektachrome film.

In the lower views, note how abandoned drainage patterns stand out most clearly on the Ektachrome IR film. This is due to the fact that vegetation presently growing in these channels is at a lower level on the marsh and is therefore exposed to longer periods of inundation by sea water. This reduces the plant's vigor and decreases its infrared reflectance.





higher salt tolerance) and the less infrared-reflective Pickle-weed. As the Cord Grass is best developed alongside marsh channels, its presence can be utilized as a clue to the presence of these channels, which may otherwise be obscured because of the dense vegetation. Therefore, this film is primarily useful as the vegetative patterns it so clearly displays can be interpreted.

Although, as Fritz (1967) indicates, this film is not useful in detecting underwater objects because of the high absorption of infrared radiation by water, the presence of vigorously growing organic matter such as algae, should image red if present in sufficient quantity at or just below the surface. This is the case within the salt evaporator ponds photographed, and explains the patterns detectable. Fritz (*Ibid.*) also suggests the following optimum exposure, assuming the use of a Wratten 12 (yellow) filter: $f/5.6$ at 1/500 sec. A typical exposure series would include this value and a half-stop on either side.

The advantages of Ektachrome IR film can best be demonstrated by studying the photos shown in Plates 1 and 2. These figures show four images of the same scene taken with Ektachrome, Ektachrome-Infrared, panchromatic, and infrared film. The setting is within a tidal marsh near Palo Alto. In the upper views of Plates 1 and 2 the different marsh grasses can easily be distinguished on the Ektachrome-Infrared photo because of the greater infrared reflectance of the Cord Grass and Salt Grass (*Distichlis*, not previously mentioned) than the Pickle-weed. As these grasses are able to flourish more effectively in the proximity of the channels than the Pickle-weed, the distinctive color differences due to the varying degree of infrared reflectance point up the presence of the channels more effectively on the Ektachrome-Infrared film than on any of the others (lower views on Plates 1 and 2).

Plates 1 and 2 demonstrate applications of a simplified four-frame multispectral arrangement that has proven extremely valuable as a geomorphic tool. Considerable redundancy occurs in the 12-frame analysis technique described earlier (9-lens multiband plus Ektachrome, Ektachrome-Infrared, and panchromatic), whereas this modified arrangement is well within the economic capabilities of most geologists. The equipment can be set up with four different cameras mounted on a single frame, all triggered by a single cable release.

CONCLUSIONS

A minimum amount of equipment is required for a tracing analysis method of evaluating the relative value of different types of photography for various specific needs. A small light table was all that was necessary for such an analysis of multiband nine-lens photography (in the 400–900 millimicron range), panchromatic, Ektachrome, and Ektachrome-Infrared photography of tideland areas within San Francisco Bay, California. This method is necessarily subjective, however, and may be supplemented by, and correlated with, a negative density analysis system utilizing a microdensitometer.

The results of such comparisons clearly show the superiority of the near-infrared photography for the detection of drainage channels and for the determination of land-water boundaries. In a like manner the 550–630 millimicron region of the visible spectrum is most effective for penetrating a body of shallow, turbid, saline water within a salt evaporator pan, thereby disclosing the presence of inundated drainage patterns beneath.

The Ektachrome-Infrared photography is superior for the differentiation of various types of vegetation. As these can readily be correlated with topography on the marsh surface, this imagery is most useful for a very precise delineation of minor environmental differences within the marshlands. The most useful photos for general interpretive purposes, however, are the Ektachrome color transparencies. These most closely approximate the natural appearance of the terrain, and are at least partially useful for virtually every interpretive need.

The nine-lens multiband imagery is excessive, with a great deal of duplication. A more efficient (and much simpler) system could be constructed of four synchronized cameras utilizing Ektachrome, Ektachrome-Infrared, near-infrared, and the 550–630 millimicron bandwidth of the visible spectrum. Panchromatic film could readily be substituted for the 550–630 millimicron bandwidth with virtually similar results, so that all of the film types could be easily obtained.

The microdensitometer is a tool with much interpretative potential. Its value in defining transverse channel profiles has been demonstrated, and its possible use in conjunction with a computerized readout system for general terrain analysis explored.

Ektachrome-Infrared film, because of its unique qualities of infrared sensitivity coupled with distinctive colors, could have considerable potential as an important aid in geological investigations, and its increased use by geologists is encouraged.

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