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# AN EVALUATION OF ENHANCEMENT OF LIGHT INTENSITY DIFFERENCES ON COLOR AERIAL PHOTOGRAPHS AND THERMAL INFRARED IMAGERY FOR THE OZETTE ISLAND - CAPE ALAVA AREA OF THE OLYMPIC COAST OF WESTERN WASHINGTON*

by

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## INTRODUCTION

In order to test the utility of light intensity separated images in evaluating the natural resources of geologically complex coastal areas of the Pacific Northwest, the Office of Marine Geology and Hydrology of the U. S. Geological Survey asked Philco-Ford to prepare enhanced, light intensity separated images from a color aerial photograph and from a thermal infrared image of the Ozette Island - Cape Alava area of western Washington (fig. 1). A black and white print of the original color photograph is shown as figure 2, and a portion of the original infrared image is shown as figure 3. Seventeen separate intensity "splits" were obtained from the original color photograph after it had been rephotographed with a minus red filter; thirteen separate intensity splits were obtained from the original thermal infrared image. Examples of three intensity splits from the photograph are presented in figure 4, and examples of three intensity splits of the infrared image are presented in figure 5. The individual splits were printed on transparent overlays, and could be studied individually or in combinations. Low number splits represent low intensity light (i.e. dark) and high number splits represent high intensity light (i.e. light).

## APPLICATION TO COLOR AERIAL PHOTOGRAPHY

### Background

Reasonable approximations of ocean bathymetry over the Bahama Banks (Conrad and others, 1968) and along low relief coast lines (Ross, 1968) have been obtained by applying the Philco-Ford techniques of separating and enhancing small differences in light intensity on small scale photographs. The same technique also has important potential applications in medicine and astronomy (Life, 1969). The theory of the separation and enhancement process and its application to depth analysis is explained by Ross (1968).

The western Washington study area is typical of much of the rugged Pacific Coast, but drastically different from the low relief coastal areas to which the intensity separation technique has previously been applied. The present study area is characterized by a prominent seacliff and an irregular surf-cut rock platform that is only partly veneered with modern marine sediment. The rocks and surficial deposits are obscured by a dense spruce-cedar-hemlock forest.

The geologic history of the area is complex and poorly understood because of limited access and poor exposures; thus, geophysical and remote sensing techniques may prove to be valuable geologic tools. Reconnaissance study of seacliff exposures by P. D. Snavely, H. C. Wagner, and N. S. MacLeod (U. S. Geol. Survey, unpub. data, 1969) indicates that the Olympic coast is characterized by prominent north-trending shear zones, that Tskawahyah Island and the main coast near Cape Alava is underlain by complexly-deformed interbedded sandstone and siltstone with occasional conglomerate beds, and that Ozette Island is underlain by northwest-striking, massive to thickly bedded sandstone unconformably overlying highly deformed conglomerate and breccia. Rocks resembling those at Cape Alava crop out about 1.1 miles northeast of Tskawahyah Island and contain late Eocene-early Oligocene coccoliths. The massive sandstone on Ozette Island resembles late Miocene rocks in other parts of the Olympic Coast. An important nearby structure is the 2000 foot wide, N70W-trending Calawah fault zone (Gower, 1960) which if projected westward would intersect the coast at or just north of Cape Alava. The pre-Quaternary rocks are commonly covered by a thick mantle of till, outwash, and loess that was deposited during the Salmon Springs glaciation when the entire study was covered by the Cordilleran ice sheet, and during the younger Vashon stage of the Fraser glaciation when the glacial terminus was only 20 miles northeast of Cape Alava (Crandell, 1965).

Evaluation of Procedure

The usefulness of the light intensity separation techniques in the Cape Alava - Ozette Island area was evaluated by first critically studying the original 1:5,000 color aerial photographs (043 WRD 10B6, May 28, 1966) and showing on a transparent overlay the features that would interest a natural scientist working in this area. This overlay was then superimposed on each of the light intensity splits and on various combinations of splits in order to see if the light intensity separated images enhanced or hindered my perception of the features originally noted on the aerial photograph. Figure 6 is a print of the overlay which shows features clearly depicted. The same procedure was used to evaluate the utility of light intensity separation in interpreting the thermal infrared image. See figure 7.

Features that were observed on the original aerial photograph and that formed the basis for comparison include the following:

1. Wave refraction patterns for wind chop and longer period sea swell. The swell decreases in wave length and increases in amplitude as it moves shoreward and starts to "feel" bottom.

2. Five distinctive vegetation types. The species composition of each vegetation type is unknown, but the different types appear as follows on the photo:

   Type one consists of medium to dark green forest with large individual tree crowns clearly visible.

   Type two consists of an assembledge of much smaller plants with a medium green color, and occasional brownish spots.

   Type three resembles type one but has a scatter of prominent gray green crowns and the over-all color is medium green.

   Type four consists of dark to very dark green forest with individual tree crowns that are less clearly defined than those in types one and two.

   Type five is grassy meadow upon which the forest appears to be encroaching.

3. A prominent surf-cut platform. This platform northeast of Tskawahyah Island is thinly veneered with modern beach sand displaying prominent sandwaves that are nearly parallel to the shoreline (locality A, fig. 6). The sand beach at the inner edge of the platform due west of the south end of the large meadow displays prominent beach cusps (locality B, fig. 6). Protuberances on this platform south of the large meadow have obvious "sand shadows" on their shoreward side (locality C, fig. 6).

4. Contrasting shore morphology on opposite sides of Ozette Island. The southwest shore has a narrow surf-cut platform and continuous coarse bouldery beach; whereas, the northeast shore has a wide surf-cut platform and discontinuous thin beach deposits. This difference in morphology probably reflects the bedrock differences observed by Snavely and others, because the differences are opposite from what one would anticipate if it resulted from asymmetry of storm wave attack.
5. Fracture traces on the surf-cut platform. The two most pronounced and continuous traces are the north-trending trace at the southeast end of Ozette Island and the west-trending trace immediately south of Tskawahyah Island. The former may be etched out along one of the north-trending shear zones. The latter is not parallel to any structure observed in the sea-cliffs close to Cape Alava, but it is nearly parallel to the Calawah fault zone (Gower, 1960). Many of the shorter less prominent traces appear to be parallel to observed bedding altitudes.
6. Four separate sets of vegetation alignments. An indistinct north-northeast trending vegetation alignment near Tskawahyah Island is roughly parallel to the topographic slope; the other three alignments, however, are oblique to the slope and are probably true fracture traces. The physical significance of the prominent west-trending vegetation alignments between the large meadow and the shoreline, and the northwest-trending alignment in the area south of the large meadow is unknown,

although these alignments are nearly parallel to the Calawah fault zone. The prominent north-trending alignment in the large meadow, as well as the abrupt linear eastern edge of the meadow may be additional indications of north-trending shear zones. The meadows most likely represent alluviated rock basins scoured out along shear zones by the southward-flowing Cordilleran ice sheet.

7. The west-trending "channel" across the surf-cut platform may be related to cultural activities at the former Indian village near Cape Alava.

The only feature that was clearly discernible after light intensity separation, but that was obscure on the original aerial photograph, is the pronounced linearity and west-northwest trend of the seaward edge of the surf-cut platform at the north end of Ozette Island. This feature is best delineated on light intensity split two.

The light intensity separation process, however, did enhance the following features:

1. The trend of wave crests, especially in areas of sun glint.
2. The contrasting shore morphology on opposite sides of Ozette Island.
3. The seaward edge of the surf-cut platform.
4. The west-trending fracture trace south of Tskawahyah Island.
5. The north-trending fracture trace at the southeast end of Ozette Island.
6. The vegetation types.
7. The northwest-trending vegetation alignments.
8. The nearshore bathymetry.

Although these features are more clearly discernible on individual brightness splits or composites of several splits than on the original aerial photograph many of these features were still more clearly defined on color aerial photographs adjoining the photograph used in the separation process.

Features that were more obvious on the original photograph than on the enhanced, light intensity-separated splits or composites include the following:

1. The changing geometry (especially the changing amplitude) of the sea swell as it approaches the shore.
2. The sand waves, beach cusps, and sand shadows.
3. The west-trending channel across the surf-cup platform.
4. The north- and east-trending vegetation alignments.
5. Some of the short fracture traces on bedrock.

My evaluation of the utility of the various individual light intensity splits and combinations is attached as Appendix 1.

Composites of light intensity splits have previously been used to separate discrete bathymetric intervals to depths of more than 30 fathoms. However, in the western Washington area, all the bathymetric intervals were in less than 3-1/2 fathoms of water. Discrete bathymetric increments could best be observed on a composite of only every third light intensity split because of the limited light penetration.

Summary of Application to Color Photography

Application of the Philco-Ford light intensity separation technique to the Cape Alava-Ozette Island area is of only limited utility; the technique does enhance some features, but it also obscures other features of equal significance. The limited utility for interpreting geologic structure results from the fact that in areas of dense vegetation, many features of photogeologic significance are defined by contacts between light and shadow, or are comprised of elements of varying light intensity. The limited utility for determining nearshore bathymetry apparently results more from the limited light penetration in this area than from limitations of the method.

Potential Future Application

Types of study areas where the light intensity separation technique may prove to be a useful photogeologic tool include the following:

1. Areas of sparse vegetation east of the Sierra Nevada Cascades precipitation barrier; however, other remote sensing techniques, such as multiband photography, might be even more rewarding.

2. Areas of moderately dense vegetation that have first been rephotographed with a minus green filter. The area of the Tillamook burn in northwestern Oregon or some of the chaparral areas of southern California are examples.

3. Areas of shallow water sedimentation. This tool has considerable potential in the study of sedimentation in harbors and reservoirs.

Shallow bays are the most favorable type of Pacific Coast area for which the light intensity separation technique may yield useful bathymetric information. Bays with on-going projects include San Francisco Bay and Bolinas Lagoon in California, Alsea, Yaquina, and Tillamook Bays in

Oregon, and Willapa Bay, Washington. Application of this technique to time-sequential photographs of areas of shallow water sedimentation may provide useful data in evaluating the effects of catastrophic floods or storms, seasonal changes in beach morphology, delta growth, and similar phenomena.

Future attempts to define shallow water bathymetry on the basis of light intensity separation should plan to use photographs taken at a time of the day and year that would minimize sun reflection; if flight scheduling is sufficiently flexible photographs should also be taken when water surface, suspended sediment, and biological activity allow maximum light penetration. If sun glint presents a problem on the available photographs, a more useful image can probably be obtained by forming a composite of the glint-free portions of adjoining photographs.

## APPLICATION TO INFRARED IMAGERY

### Interpretation

The light intensity separated images used in this evaluation were made from a photographically enlarged portion of a thermal infrared image of a three-mile-wide area extending from six miles south of Cape Alava to 2.5 miles north of the Cape (fig. 3). Features clearly visible on the original image, in order of decreasing infrared radiation, include the following:

1. Meadows and "prairies".
2. Beach.
3. Surf-cut platform with sand waves.
4. Vegetation west and north of the large meadow.
5. Pronounced north-trending lineament, north of the large meadow.
6. "Average" offshore water.
7. Coastal vegetation belt and ocean surface over the submerged valleys on the surf-cut platform.
8. Vegetation pattern resembling an inverted fish hook around the meadows.
9. Ozette Island.
10. Ozette River (not included on the enlarged image).

The fact that at the time the imagery was obtained (Aug. 16, 1967 - 1743 to 1825 hours) the Ozette River radiated less thermal infrared energy than the Ocean is surprising because the rivers of this area are generally considered to be warmer in the summer than the ocean.

This apparent discrepancy can be explained if one realizes that the temperature difference between the ocean and river is small, that the ocean is likely to be much more thermally stratified than the river, and that the radiated infrared energy is transmitted from only a surface "skin" several microns thick.

The infrared image was generally less revealing than the color photograph of the same area. The infrared image, however, did show a prominent north-trending lineament north of the large meadows that was very obscure on the color photograph and only detected after first being observed on the infrared image. This lineament is most likely a line of springs and seeps along a north-trending shear zone. Similar trending but much fainter features also show on the infrared image south of the meadow and on the west side of Rooses Prairie.

The varying amounts of infrared radiation recorded on the land areas of the image apparently represent the pattern of different plant communities. Accurate comparison of the presumed vegetation pattern on the infrared image with the vegetation pattern recognized on the color photograph is difficult because of distortion in the infrared image. Qualitative comparison, however, reveals that the two patterns are only grossly similar. Possibly, the pattern on the infrared image results from differences in slope exposure, soil moisture, proximity to the coast, and other factors as well as vegetation differences.

The infrared image suggests the presence of several offshore springs of relatively cool water in small submerged erosional valleys between Cape Alava and Sand Point. These springs discharge sufficient water to lower the local ocean surface temperature directly over the subsea valleys. Springs may also occur in the seacliffs near these submerged valleys; such springs would be a useful source of water for overnight hikers in this part of Olympic National Park.

The presence of springs along the prominent north-trending lineament suggests that it is more likely to reflect a penetrating geologic structure than the west- or northwest-trending lineaments which are apparently not associated with springs. Moreover, the springs along the north-trending lineament, in contrast to the cool subsea springs, show as a narrow linear area that is emitting a relatively large amount of thermal infrared radiation. The large amount of radiation may result from plant activity along the spring line, or it may result from warmth from the springs themselves because warm springs with curious chemical compositions suggesting possible deep origin do occur elsewhere in the Olympic Peninsula (Ivan Barnes, oral commun., March, 1969).

As in the evaluation of the application to the color photograph, a transparent overlay was made to show all the features that were clearly discernible on the enlarged infrared image. This overlay (fig. 7) was then compared with each of the light intensity splits and various combinations of splits. The numbered areas in figure 7 represent areas of similar pattern and amount of emitted infrared radiation. Most of the boundaries are subjective because the individual areas are characterized by a mottled pattern and are distinguished from neighboring areas only by subtle differences in average amount of emitted radiation. The areas are numbered in order of decreasing average amounts of emitted radiation.

A second overlay was made some weeks after the first one; the boundaries between areas of different infrared emitting characteristics, and the relative ranking of these areas in terms of average amount of emitted radiation were slightly different on the two overlays. The differences, however, were not sufficient to result in a major change in interpretation.

The enhanced, light-intensity separated image of the enlarged thermal infrared image of the Cape Alava-Ozette Island area did not yield any new significant information. In fact, the separated image slightly obscured the prominent north-trending lineament. However, the light intensity separated images do facilitate the drawing of more objective boundaries between areas emitting different amounts of radiation, and thereby could significantly diminish operator varience. Moreover, it would be interesting to apply the separation technique to the banded thermal plumes reported by Snavely and MacLeod (1968) at the mouths of the Queets, Quinault, and Hoh Rivers.

Summary

The thermal infrared imagery shows a prominent north-trending lineament that is very obscure on the color aerial photographs, and suggests the presence of two different types of springs - cool subsea springs of "normal" ground water and slightly warmer springs along a north-trending lineament. Light intensity separation does not enhance the thermal features on this image. Objective boundaries between areas that are radiating different amounts of thermal infrared energy can be drawn more precisely on the separated image than on the original image.

## CONCLUSIONS

Enhancing light intensity differences on color photographs and thermal infrared imagery of the Ozette Island-Cape Alava area does not generate significantly more useful information than what can be obtained from the original photograph and image. Nevertheless, the technique may yield significant results if applied to photographs of areas of shallow water sedimentation and infrared images of thermal plumes. The use of infrared imagery along with color aerial photographs does generate significant new information in this area.

## APPENDIX 1 - Utility of Individual Light Intensity Splits and Combinations

The black and white renditions of the intensity splits that were used to generate the false color renditions were generally as revealing as the final product. The false color series gave a clearer rendition of the near shore bathymetry than the black and white series; whereas, the black and white series gave a much clearer rendition of the sand waves northeast of Tskawahyah Island, and the wave refraction pattern. Split two emphasizes the linearity and northwest-trend of the seaward edge of the surf-cut platform at the north end of Ozette Island. Individual splits two through six show the contrasting shore morphology of the northeast and southwest sides of Ozette Island. Split three shows the northwest-trending vegetation alignment in the southern portion of the photograph. Individual splits three through six show the north-trending fracture trace at the southeast end of Ozette Island. The combination of splits six and seven emphasizes the west-trending trace south of Tskawahyah Island and accurately portrays the seaward edge of the surf-cut platform. Splits eight and nine are the splits that best show the short bedrock lineations west of the large meadow, but these lineations are much more distinct on the original aerial photograph. Split 11 emphasizes the northwest-trending vegetation alignments and shows the trend of wave crests in less glary areas. Split 13 shows an east-west "grain" to the vegetation west of the large meadows, but does not show the distinct individual lineations that are prominent on the original photograph. The combination of splits 13 through 15 clearly defines the limits of the sand covered beach. Individual splits 15 and 16 show most clearly the trend of wave crests in areas of sun glitter.

Composites of every other split or of all the splits emphasize the near-shore bathymetry, the vegetation pattern, and the contrasting shore morphology on opposite sides of Ozette Island. The composite comprised of only alternate light intensity splits was as revealing as the false color series.

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Snavely, Parke D. Jr., and MacLeod, Norman S., 1968, Preliminary Evaluation of Infrared and Radar Imagery, Washington and Oregon Coasts: U. S. Geol. Survey Open File Report, 8 p.

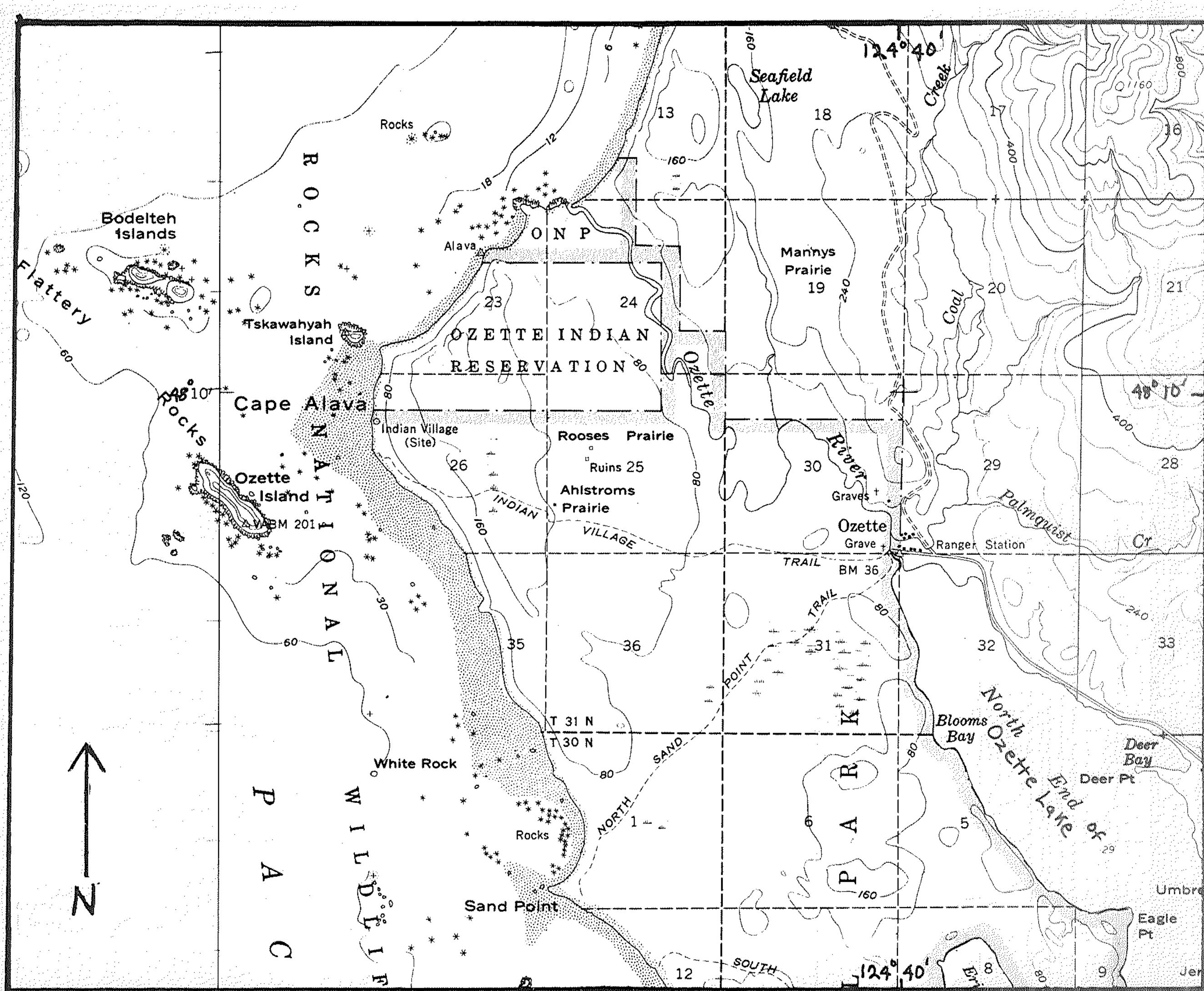


Figure 1. Location Map of the Ozette Lake - Cape Alava area from U. S. Geological Survey Ozette Lake 1:62,500 topographic quadrangle, 1956 edition.

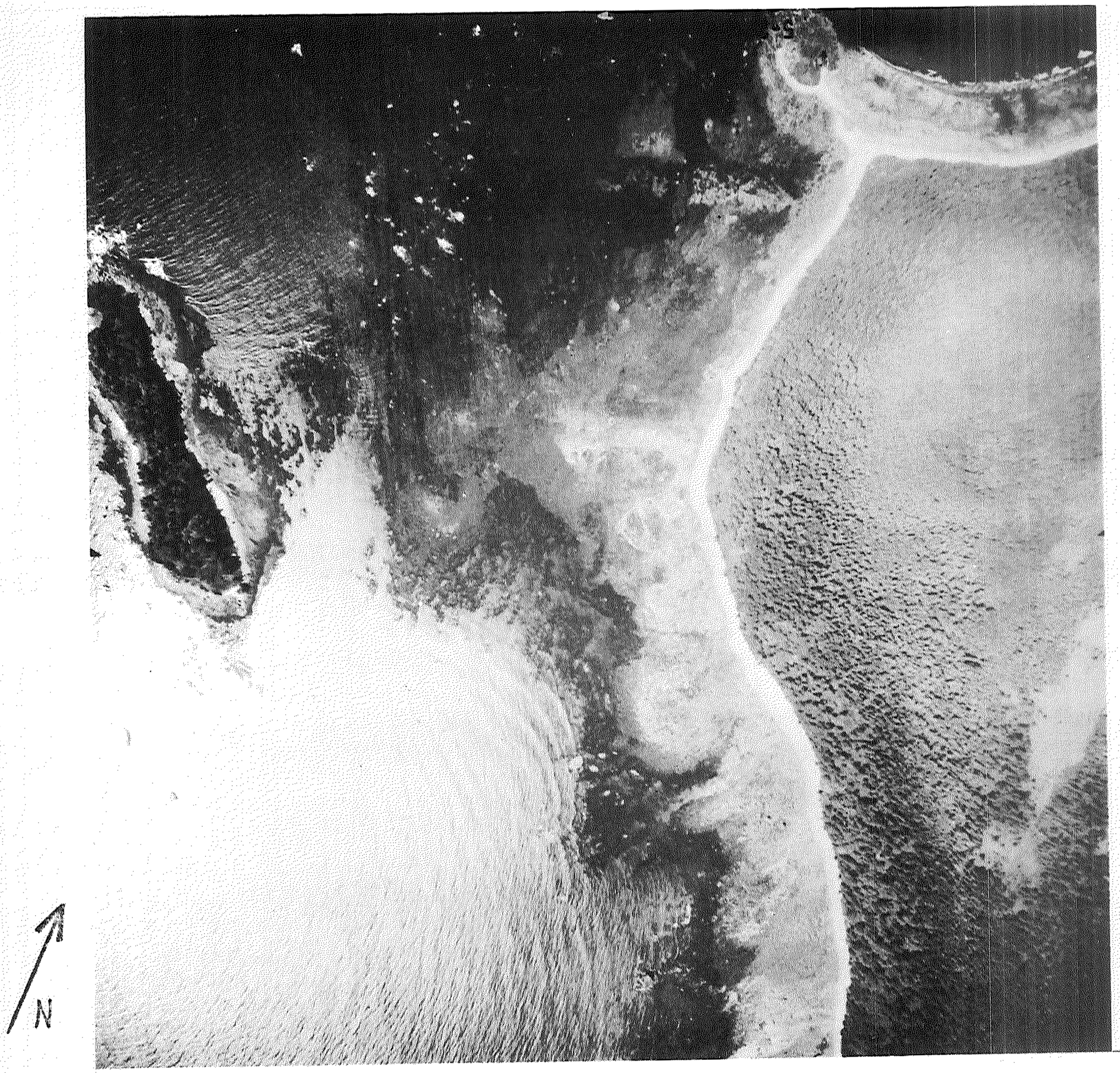


Figure 2. Black and white print of original color aerial photographs (043 WRD 10B 6), May 26, 1966, Ozette Island - Cape Alava area.

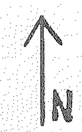


Figure 3. Thermal infrared image of the Ozette Island - Cape Alava area obtained August 16, 1967, 1743 to 1829 hours.

Figure 4. Light intensity splits 3, 11, and 19 of the color photograph of the Ozette Island - Cape Alava area taken on May 28, 1966.

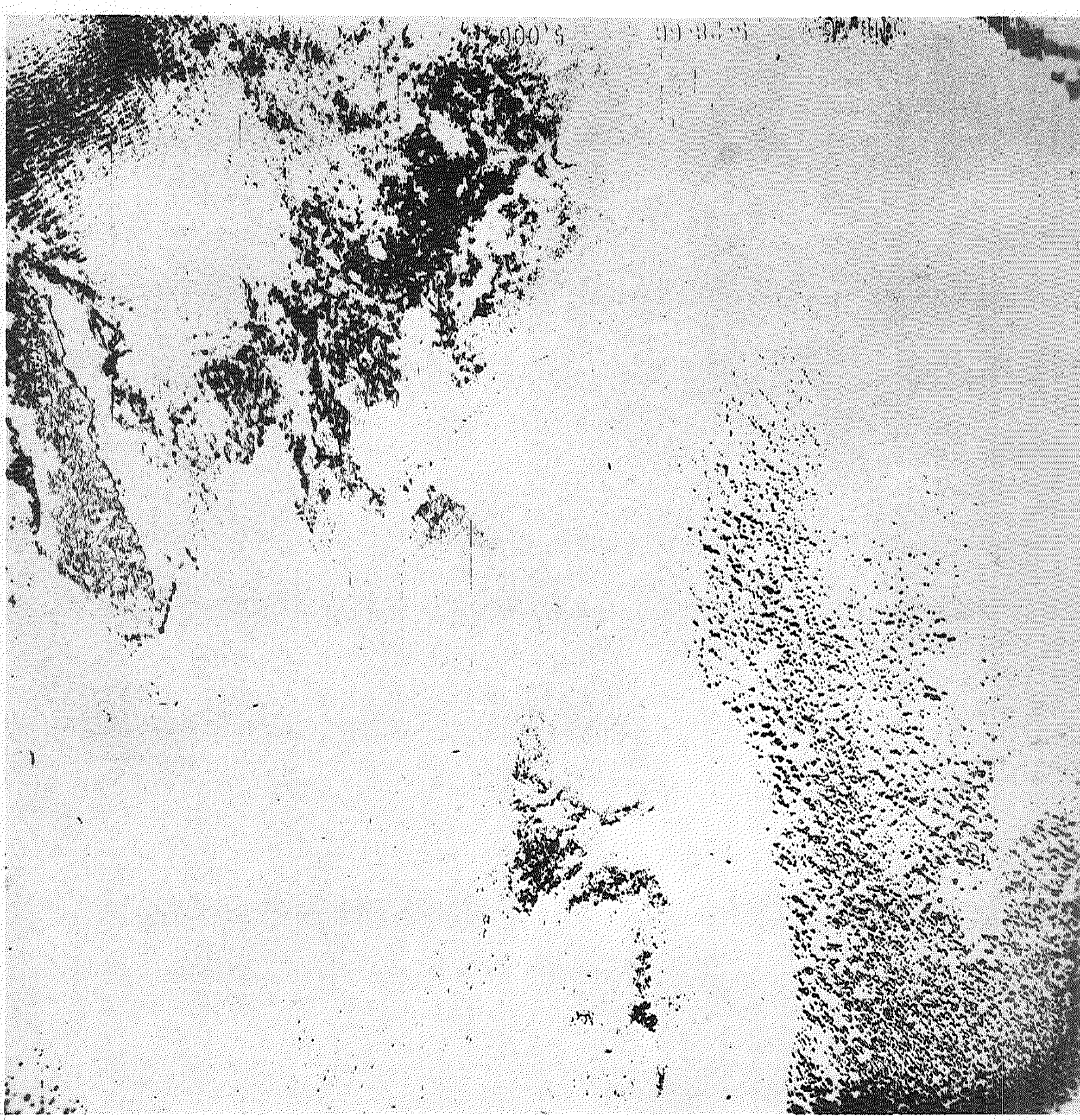

Figure 4a. Light intensity split 3 of color aerial photograph (May 26, 1966).

Figure 4b. Light intensity split 11 of color aerial photograph (May 26, 1966)

Figure 4c. Light intensity split 19 of color aerial photograph (May 26, 1966).

Figure 5. Light intensity splits 6, 12, and 17 of the infrared image of the Ozette Island - Cape Alava area.

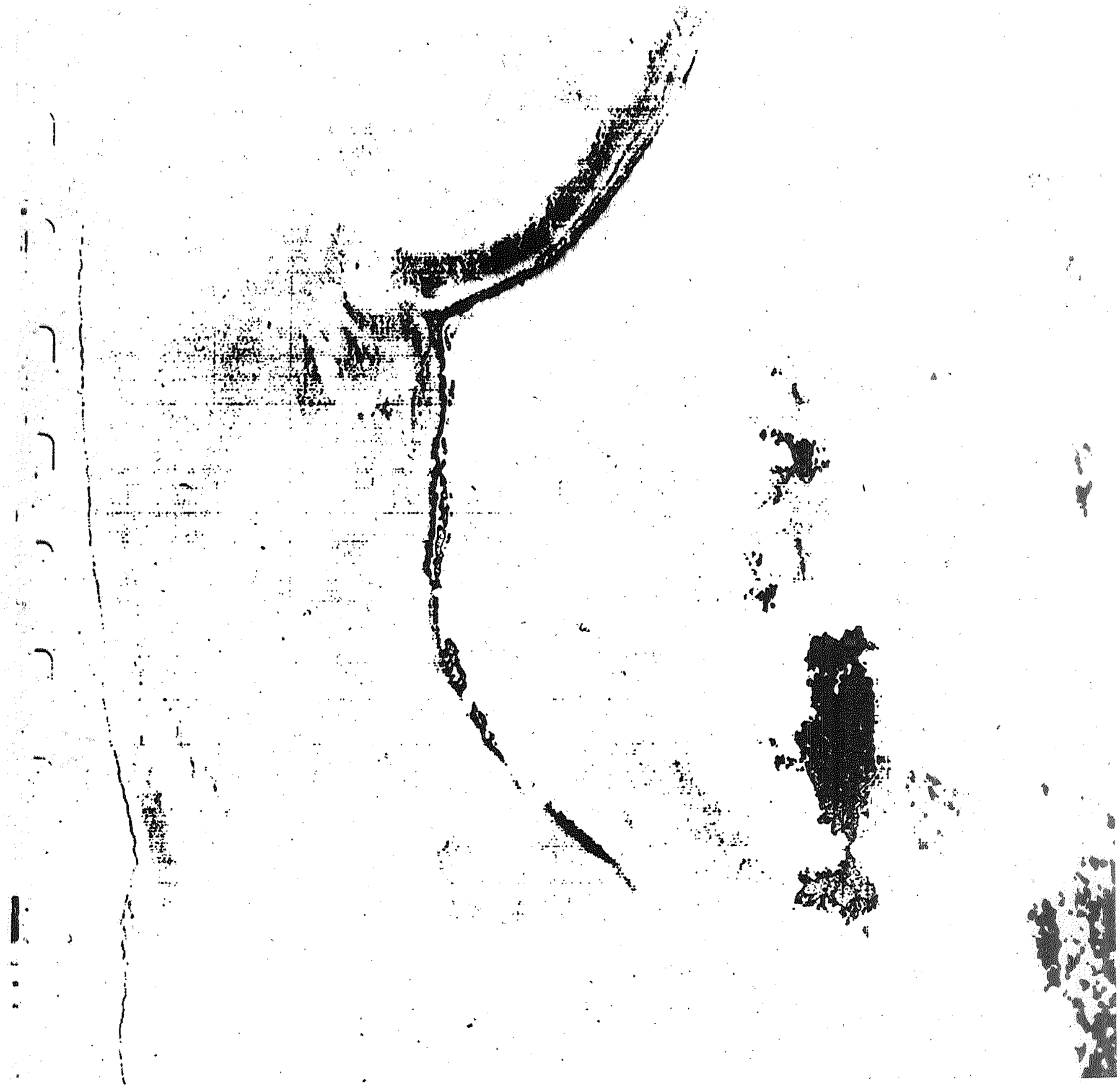

Figure 5a. Light intensity split 6 of thermal infrared image (August 16, 1967).

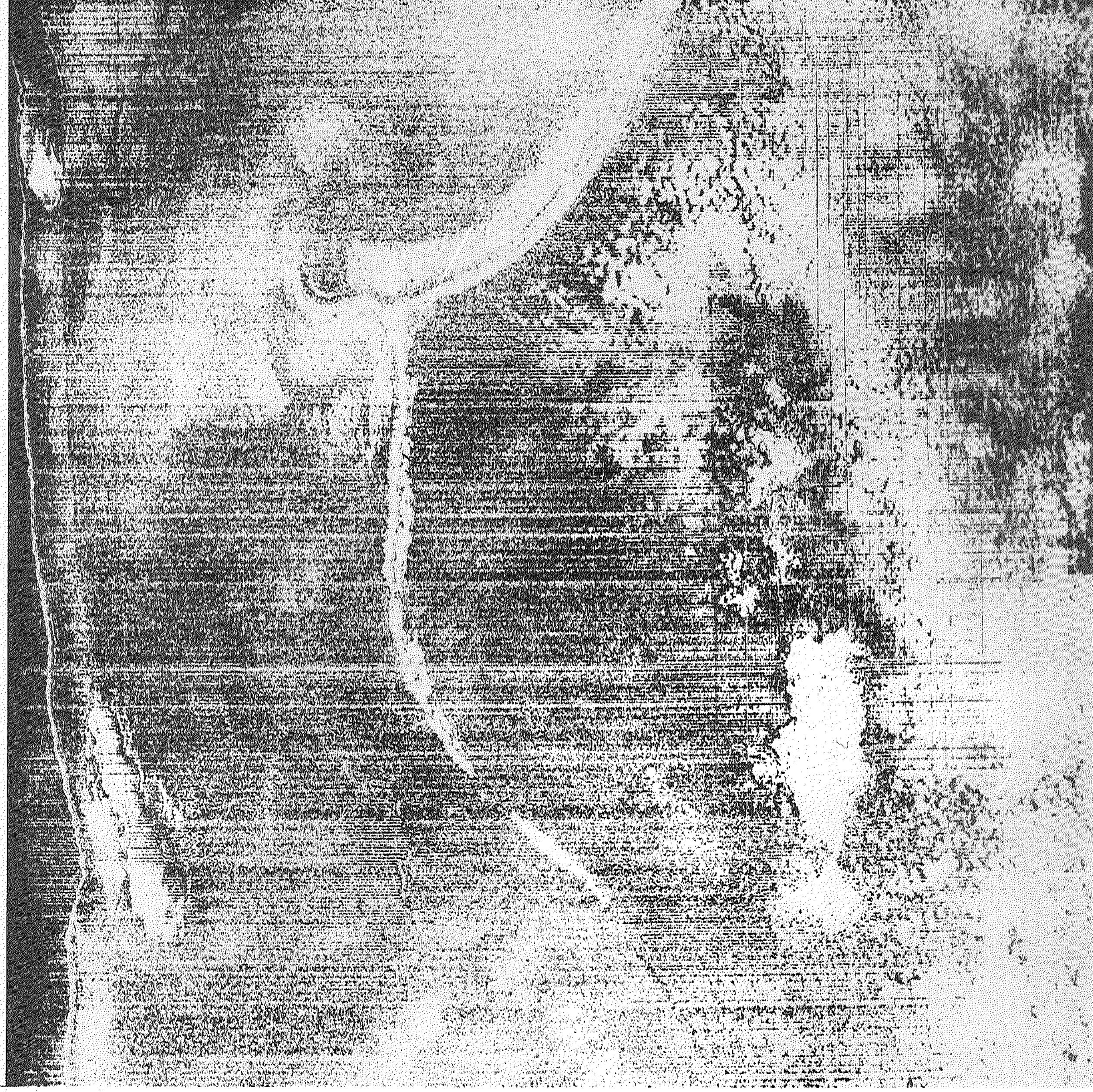

Figure 5b. Light intensity split 12 of thermal infrared image (August 16, 1967).

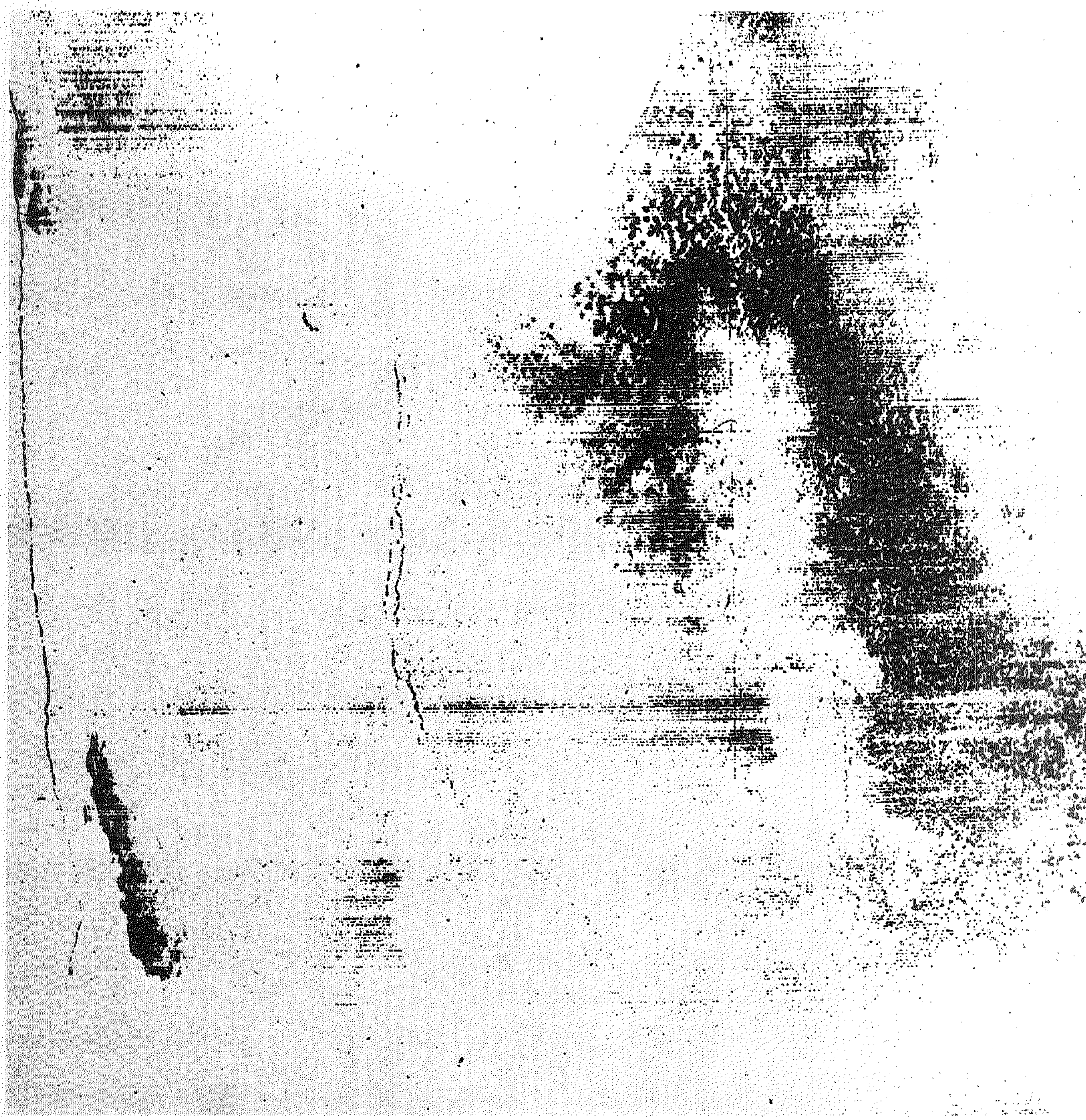

Figure 5c. Light intensity split 17 of thermal infrared image (August 16, 1967).

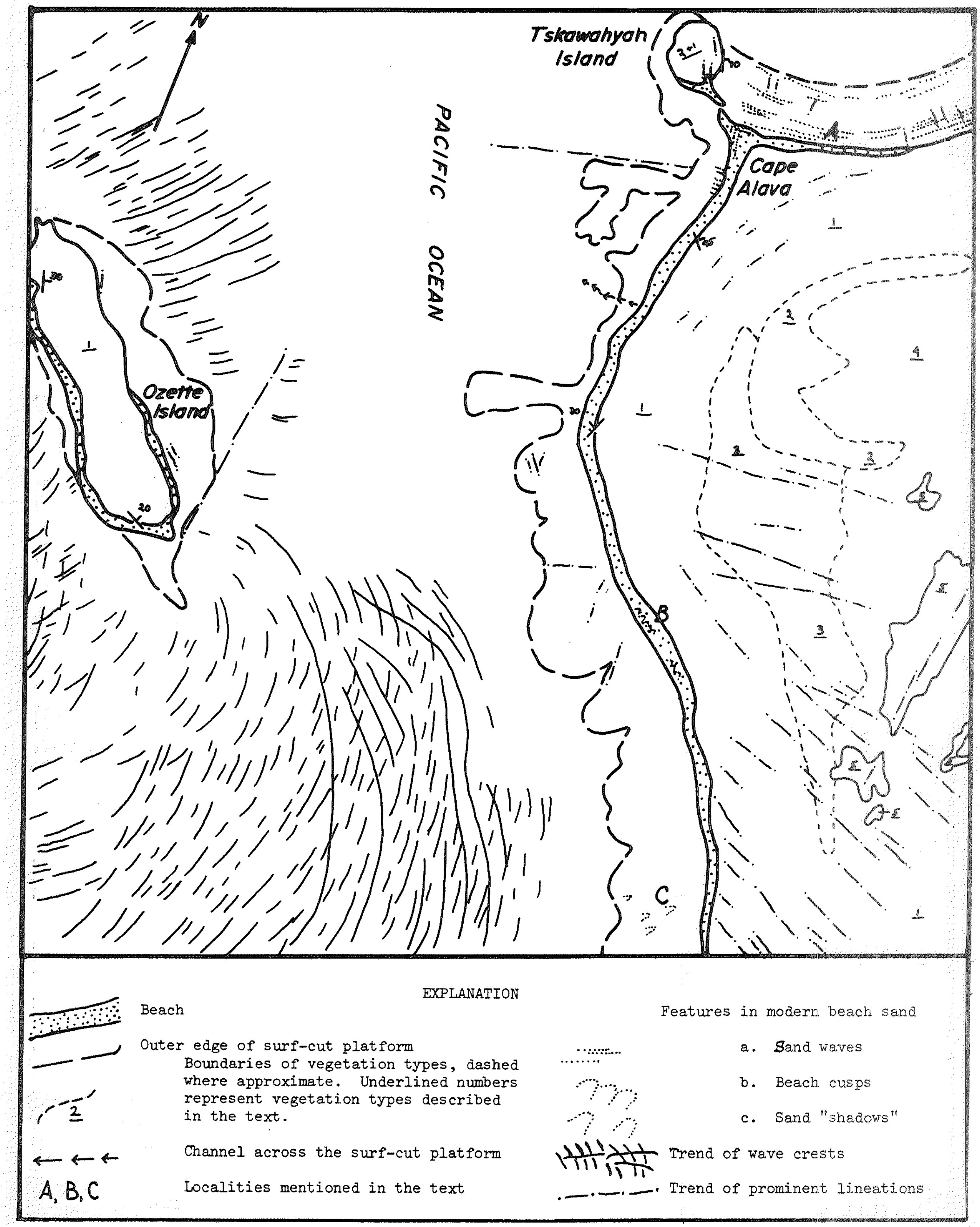


Figure 6. Features clearly depicted on color aerial photograph (043 WRD 10B 6, May 28, 1966) of the Ozette Island-Cape Alava area of western Washington.

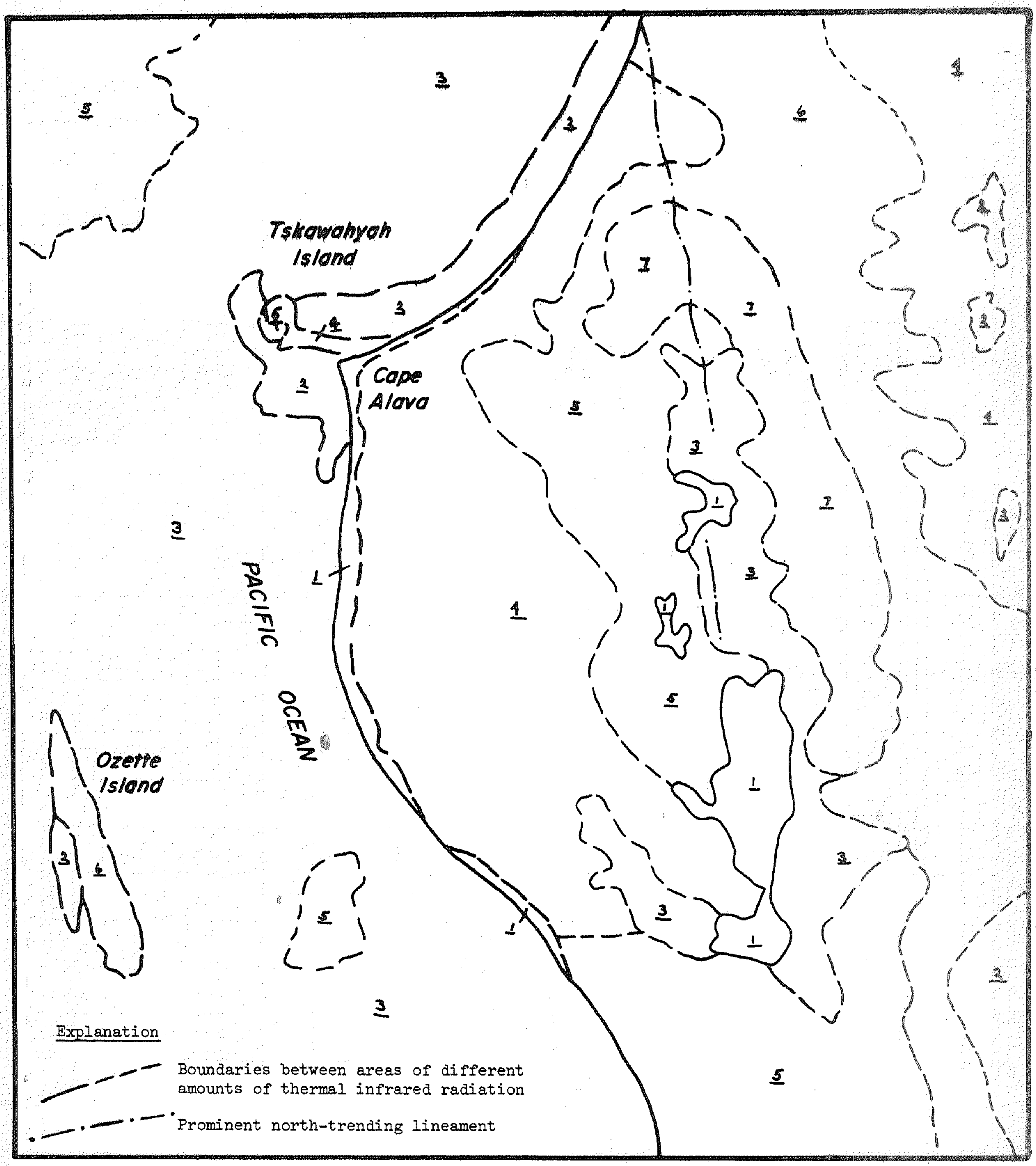


Figure 7. Features clearly depicted on thermal infrared imagery of the Ozette Island-Cape Alava area of western Washington taken on August 16, 1967 at 1743 to 1825 hours. Areas are numbered in order of decreasing amounts of emitted thermal infrared radiation; numbers do not correspond with the features listed on page 10.