INFRARED IMAGES
OF THE KAU AND PUNA COASTLINES ON HAWAII

by

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GEOPHYSICAL EXPLORATION FOR HAWAIIAN GROUNDWATER, PHASE II

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And there are many souls embodied in water. Truly water...is alive.... He who injures the lives in water does not understand the nature of sin or renounce it.... Knowing this, a man should not sin against water, or cause or permit others to do so. He who understands the nature of sin against water is called a true sage who understands karma....

Ācārāṅga Sūtra, 1.1
About 250 B.C.

ABSTRACT

An infrared scanner covering the 200 to 540-nanometer wavelength region has been flown over the coastline of the Puna and Kau Districts on the island of Hawaii. The images were monitored in real-time and recorded on film. Only a $5^{\circ} \times 5^{\circ}$ lens (narrow-angle) was available, hence the flight line had to be at an altitude of 11,000 feet in order to make each image about 1000 feet on a side. The films of the images have been processed and catalogued. A few areas have been mosaicked to facilitate interpretation.

This report briefly describes the equipment used, the field procedures followed, and presents an index to the catalogued films. A few frames and mosaics are presented to illustrate the image quality.

The procedure in its entirety is rather complex and much practice is necessary to obtain high quality images. The greatest difficulty seems to be due to the high-level flight line demanded by the narrow-angle lens. Future surveys will use wide angle lens, such as has just become available.

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INTRODUCTION

Previous work by Lepley and Palmer (1967), sponsored by the Office of Water Resources Research, has indicated the value of aerial monitoring of surface temperatures, using an infrared thermometer. They concluded that spot temperatures or line temperatures were difficult to analyze and that a scanning infrared system was desirable. However, the higher cost could not permit the use of an infrared scanner at that time. Since then, the technology of infrared scanners has been extended. Currently, scanners cost only about ten times as much as infrared thermometers.

A number of field studies conducted to evaluate the water-development potential of many miles of remote coastline provided additional reasons for developing an improved reconnaissance technique. Attempts to obtain information by hiking along the coastline on the shoreside or by approaching the shoreline from a boat require much time, many persons, extensive support equipment, and the risks of work in remote areas. A need for a reconnaissance procedure to indicate where the physical access should be concentrated became obvious.

Previous applications of infrared imagery have been directed to the ocean (Stommel, 1963) or land (Proceedings of the 4th Symposium on Remote Sensing of Environment, 12-14 April 1966, University of Michigan). A USGS study has been directed to coastlines of the island of Hawaii (Fischer, *et al.*, 1966), but it was conducted in conjunction with a study of infrared radiation from volcanic terrain. In 1967, efforts to verify the existence of all the thermal anomolies reported in the 1963 field work were only partially successful. In part this may be due to the difference in season between the USGS and the Water Resources Research Center efforts. The Geological Survey records were taken in January and February while the University of Hawaii field work was conducted in June of a different year.

For the foregoing reasons, a lease arrangement was made for an AGA Thermovision infrared scanner, of Swedish manufacturing, which was displayed at the symposium on "Water Resources of the Inner Planets" held by the American Astronomical Society in April 1968.

The objective of this project was to develop the capability of taking infrared imagery from an aircraft and to compile a catalogue of images of the Southeast coast of the island of Hawaii.

INSTRUMENTATION

Lessor Laision

A time-limited field effort under a leasing arrangement necessitates a thoroughly pre-planned field effort to obtain maximum use of the instrument while available. All the persons involved were thoroughly instructed in the instrumentation and the operations required. Because of the need to fly at 11,000 feet, where efficiency of physical performance is somewhat reduced, safety was a prime factor in the planning.

The field chief was sent to the Oakland office of the AGA representative to learn the details of the instrument. Flights were made with the equipment in operation until the capability, flexibility, and limitations of the system were understood. The equipment was then brought to Hawaii.

Training Sessions

In Hawaii, sessions were scheduled to teach operators what had been learned about the safest methods for optimum exploitation of the scanning equipment. Some sessions were held with the equipment mounted on the fifth floor of a building, looking at small objects at ground level. A glass of water, an ice cube in a glass, and a lighted cigar were some of the objects used. A front-surfaced mirror was used to obtain a downward view. This mirror, however, caused image reversal. The reversed image required a considerable amount of time for the operator to learn the tracking with the manual controls on the tripod. Because of the difficulty of manually tracking, the unit was installed in an airplane with only one possible axis of rotation (parallel to the axis of the plane).

The Scanning Camera

A diagram of the scanning camera is given in Figure 1. The radiation entering from the left is reflected by the spherical mirror onto a flat, front-surface mirror and through an octagonal prism onto an image surface. The image moves up-and-down in this plane as the flat mirror is vertically oscillated and laterally as the octagon prism is rotated.

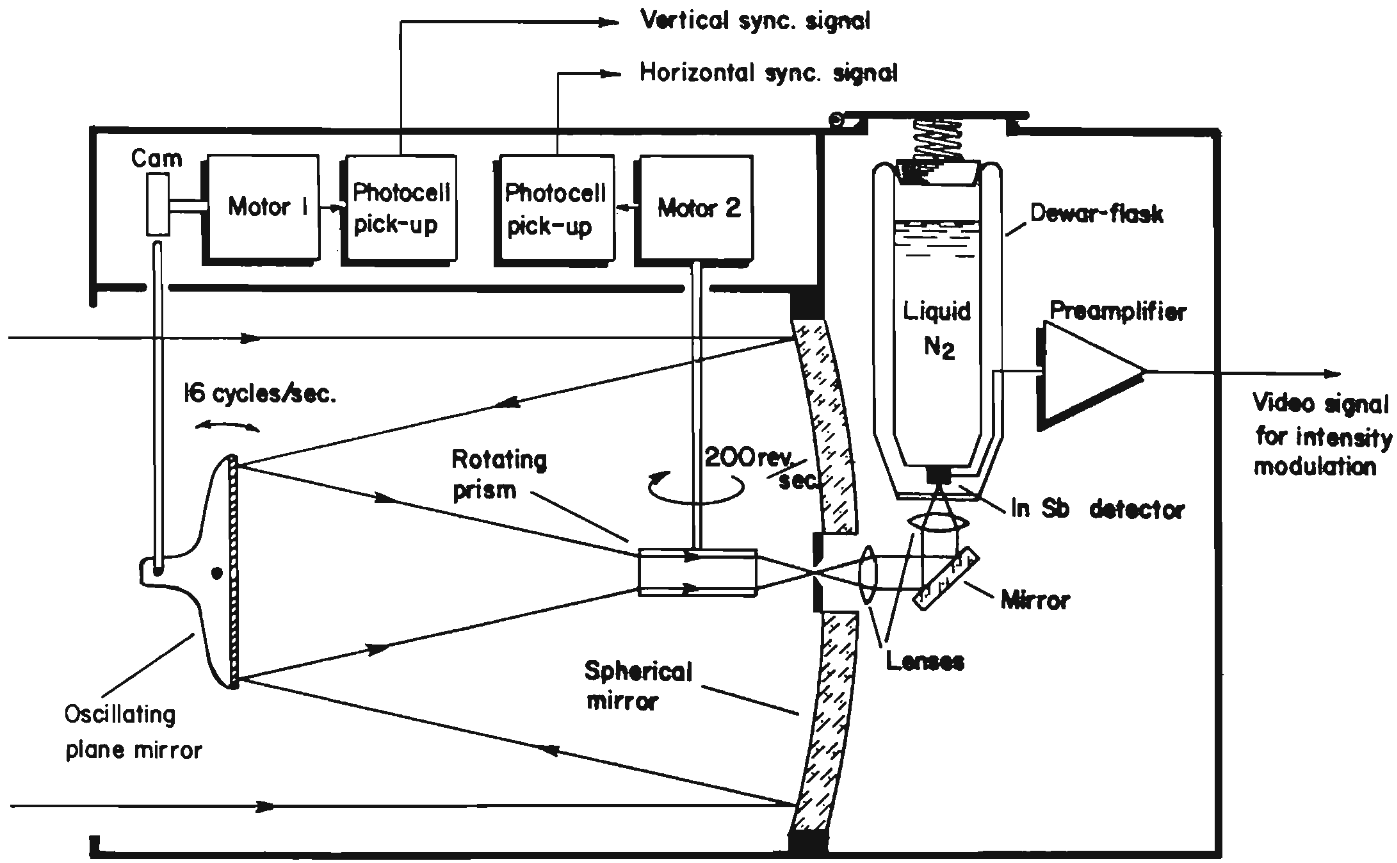


FIGURE 1: DIAGRAMMATIC CROSS-SECTION OF THE AGA THERMOVISION CAMERA

These motions occur simultaneously to give a raster scan. The portion of the image falling on the pinhole is focused onto the indium antimonide (InSb) detector, which is cooled by liquid nitrogen. This detector is dominantly sensitive to 200 to 540 nanometer wavelengths. The electrical signals from the photocell pickups on the two motors and the detector signal are fed to an oscilloscope display unit. The photocell signals are used for synchronization and the detector signal is reconstructed in a corresponding image. The block diagram of the overall system is given in Figure 2.

The infrared radiation enters the rotating prism at the upper left, falls on the image plane, and is focused on the InSb by quartz optics. The InSb element is mounted on a Dewar flask which is filled with nitrogen. The horizontal synchronization pulse is simultaneously generated by a collimated light reflecting from the side of the rotating prism onto a photoconductor. The vertical synchronization is obtained by connecting a shutter to the gearbox that tilts the flat mirror. At an extreme position of the mirror, the shutter is open to allow the collimated light to fall on a photoconductor. A separate motor is used to adjust axially the flat mirror subsystem. This changes the focus from about 20 meters to infinity. (Manual adjustment is required to focus between 6 and 20 meters.)

The front panel of the display oscilloscope also serves as the control panel. A view of this instrument face is given in Figure 3. The main features are the focusing control (left), the temperature-range control (sensitivity on right), the mode control (which determines whether an increase in temperature produces increasing or decreasing brightness), and the isotherm control unit. When using the isotherm, the operator can select any temperature level to become solid bright. The temperature range of the isotherm is also variable in width. Bezel bolts are provided for attachment of a viewing tube and mounting of a camera. The actual image displayed on the cathode ray tube are described in the RESULTS section.

A view of the equipment in use during a training session is given in Figure 4. The Bolex 16mm movie camera, being held at the left, is specially adapted for synchronization with the display oscilloscope.

The fixed raster rate is 100 lines per frame, and images are displayed 16 per second.

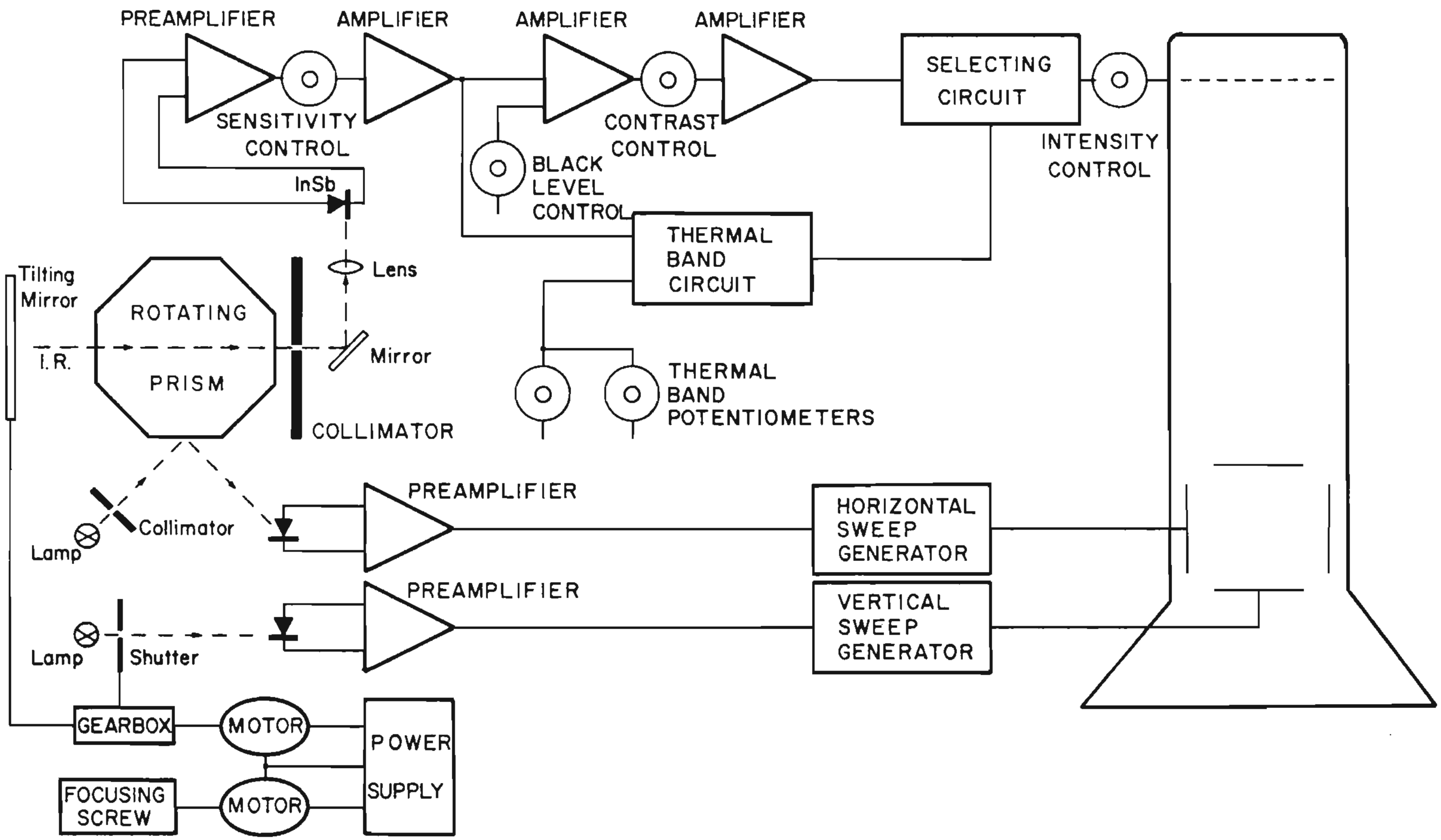


FIGURE 2: BLOCK DIAGRAM OF THE AGA THERMOVISION CAMERA SYSTEM.

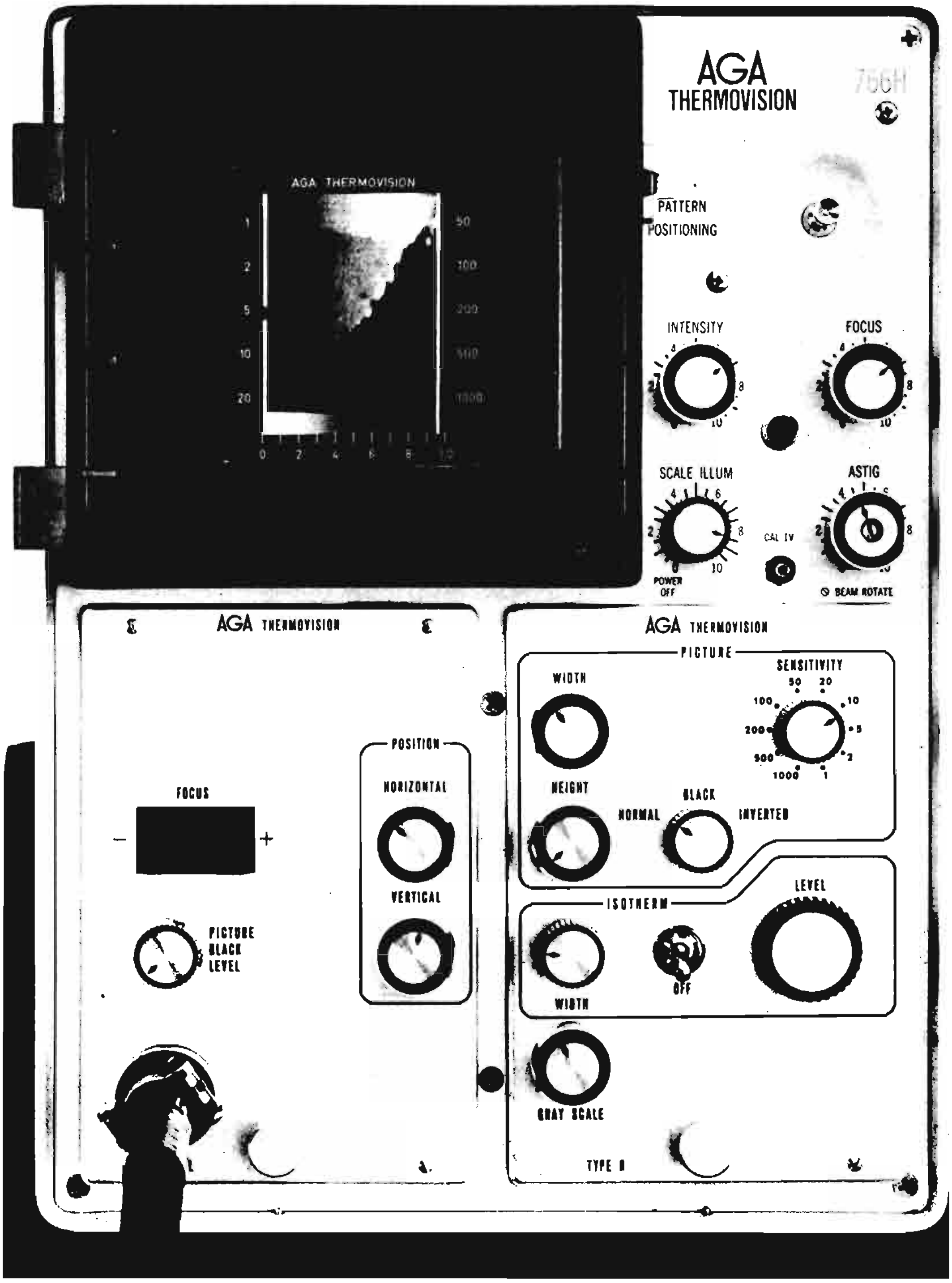


FIGURE 3. FRONT PANEL OF THE AGA DISPLAY OSCILLOSCOPE.

FIGURE 4: TRAINING SESSION ON ROOF OF HAWAII INSTITUTE OF GEOPHYSICS. THE STYROFOAM COVER ON THE OSCILLOSCOPE WAS SIMPLY TO REDUCE THE HEATING DUE TO DIRECT SUNLIGHT. STEPHEN LANGFORD ON THE LEFT; LARRY LEPLEY AT THE OSCILLOSCOPE; AND CLIFTON WARREN ON THE INFRARED CAMERA.

Greater detail on instrumentation for infrared scanning systems is available in Simon (1966), Wolfe (1965), or from the appropriate manufacturers.

Aircraft Mounting of the System

The scanner had been designed initially for military use in tanks and hence, is extremely rugged. The equipment was mounted in the Apache aircraft of the Hawaii Institute of Geophysics. As this aircraft had been FAA certified to fly without the baggage door, the large front surface mirror supplied by AGA was arranged to project from the baggage door and reflect the radiation from the ground surface to the scanner (Fig. 5). The mirror did not noticeably increase turbulence in this arrangement, because it was edgewise to the airstream. The scanner was oriented with its axis parallel to the wings and could be manually cranked to rotate about an axis parallel to the fuselage. This arrangement permitted the plane to fly along a straight line while the operator cranked up and down to adjust for the irregularity of the coastline. Another reason for the arrangement with the mirror out the baggage door is that the DeWar flask holding the liquid nitrogen could not be tilted at an angle greater than about 15°.

Since all the electronics were designed for operation from 110 volts/60 cycles per second, an inverter was required to operate off the airplane battery. Because of the cramped quarters in the aircraft and the numerous pieces of gear, it was essential that the wiring be adequate and well insulated.

A diagram showing the distribution of persons and instruments within the airplane is given in Figure 6. The co-pilot recorded the location for the start and end of each film on a topographic map. Once the run was begun, it continued until all the film in that roll had been exposed.

A non-structural modification of an Apache would make the installation of the scanner considerably safer and more convenient.

Everything had to be secured to the plane, including the human occupants,to avoid the possibility of hazards from unexpected turbulence. The appropriate safety devices, such as fire extinguishers, flares, and a life raft are, of course, mandatory.

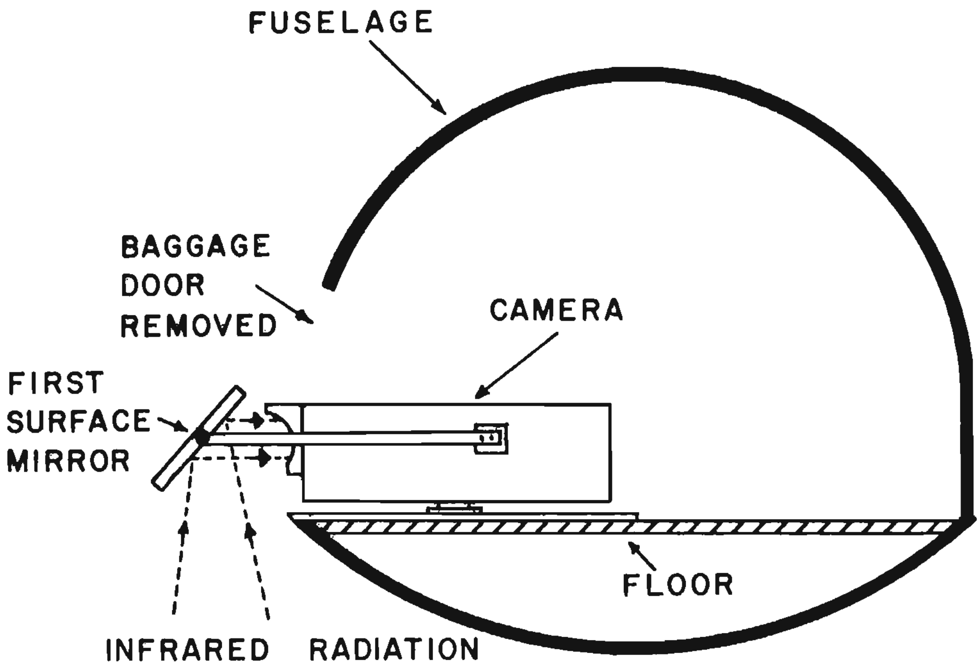


FIGURE 5: CROSS-SECTION OF APACHE AIRCRAFT AT BAGGAGE DOOR -- LOOKING AFT (not to scale)

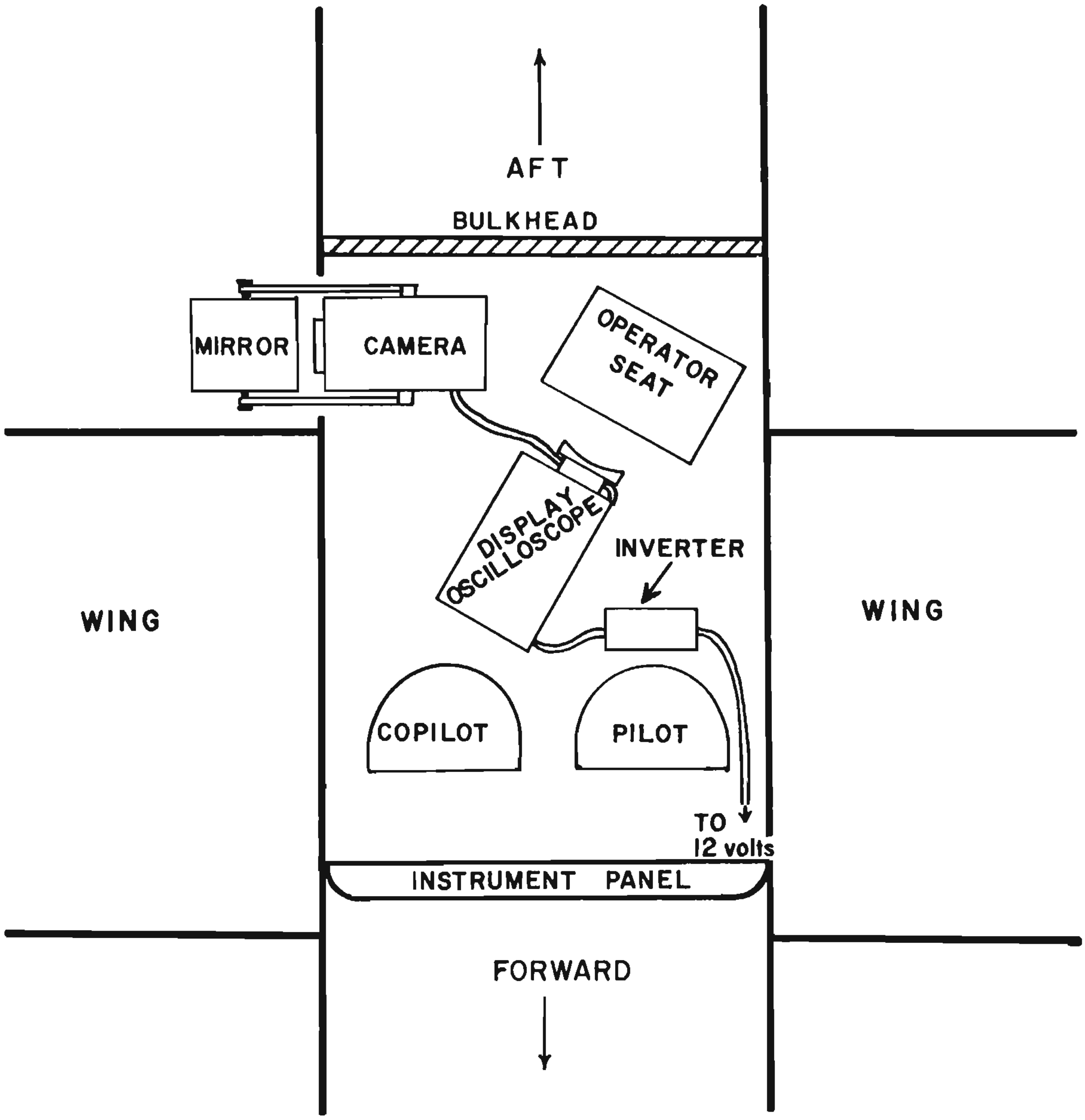


FIGURE 6: LAYOUT OF EQUIPMENT AND PERSONNEL WITHIN THE APACHE AIRCRAFT (not to scale)

Field Procedure

For surveys of the island of Hawaii the instrument was charged with liquid nitrogen at about 5:30 in the morning and the plane flown from Oahu to Hawaii. The equipment was switched on about thirty minutes after take-off to allow time for the electronics to stabilize. Film was loaded in the 35mm Minola and the camera mounted on the oscilloscope.

At the area of interest, the pilot aligned the plane along a section of coastline for the first pass and started the run. The co-pilot logged the position of the start and finish of the pictures for that roll of film. When the camera operator announced that all of the film had been used, the pilot swung out over the ocean in a large circle to permit time for film change. This entire sequence of procedures was repeated until flash from sunlight stopped the activities.

When the 16mm camera was used, it was shot along one section of the coastline. It was not practical to reload the 16mm camera during flight.

Most of the images were taken with the 35mm Minolta camera supplied with the system. This was due to the operational difficulty of loading the 16mm camera at 11,000 feet where the coldness made the film very brittle and the mind and fingers very dull.

The physical limitations imposed by the high altitude environment were due, indirectly, to the narrow angle lens available. Because of the narrow angle lens, the view is only about 1000 foot square from 10,000 feet. This was the minimum size which permitted the operator to manipulate the camera to follow the coastline. No future use of an infrared camera system should be made for coastline work unless a wide angle lens, such as will be available in 1969, is used. The additional increase in safety is very significant.

Processing and Monitoring

Upon return to Oahu, the films were developed, and contact prints made. The contact prints were reviewed for quality of the image, and prepared for cataloguing.

The environment at 11,000 feet caused the camera to operate improperly on about half the frames. This required re-shooting sections of the coastline to fill in missing areas.

The 16mm film was reviewed on a 16mm film editor or on a reader-printer which allowed prints to be made of frames for which an immediate working copy was desired.

The views obtained in this survey have been catalogued by geographic position along the southeast coast of Hawaii. In general, this is also chronologically sequential. Not until the last ten days of the field effort were the filmed images of sufficient quality to merit cataloguing. Initially, because of the great emphasis given to 35mm film, it was extremely difficult to correlate views with geographic position.

RESULTS

An image photographed from the cathode ray tube of the oscilloscope is presented in Figure 7. The name at the top is the manufacturer's advertisement. The numbers in the columns at the left indicate the temperature range between solid black and solid bright. This is a relative temperature range; it must be calibrated if absolute temperatures are desired. For calibration, the emitting surface must be at least as large as one element of ground resolution (about 11 feet on a side when flying at 11,000 feet), otherwise the radiation is averaged over that element. The range of temperature actually being used is indicated by the black indentation in the vertical bright bar. The position of this temperature range on the temperature scale is adjustable. The scale at the bottom indicates the tonal quality within the selected temperature range. This can be operated in the normal mode, in which the hottest items are solid bright, or in the reverse mode, with the hottest items solid black. The position and width of the isotherm is indicated by a solid bright area super-imposed upon the tonal scale (at about .2). Cooler water is evident along the shoreline from 100 to 200 (right-hand scale).

A master index map, designated as Master Index Map for 35mm film, to the sub-index maps of film images and a graphical direction for use are given in Section I of the Appendix. The Master Index Map for 16mm film and its sub-index maps are given in Section II. Several sub-index maps are sometimes used to indicate one-lettered areas.

It will be noted on sub-index map A-1 (for 7 July, I) that several

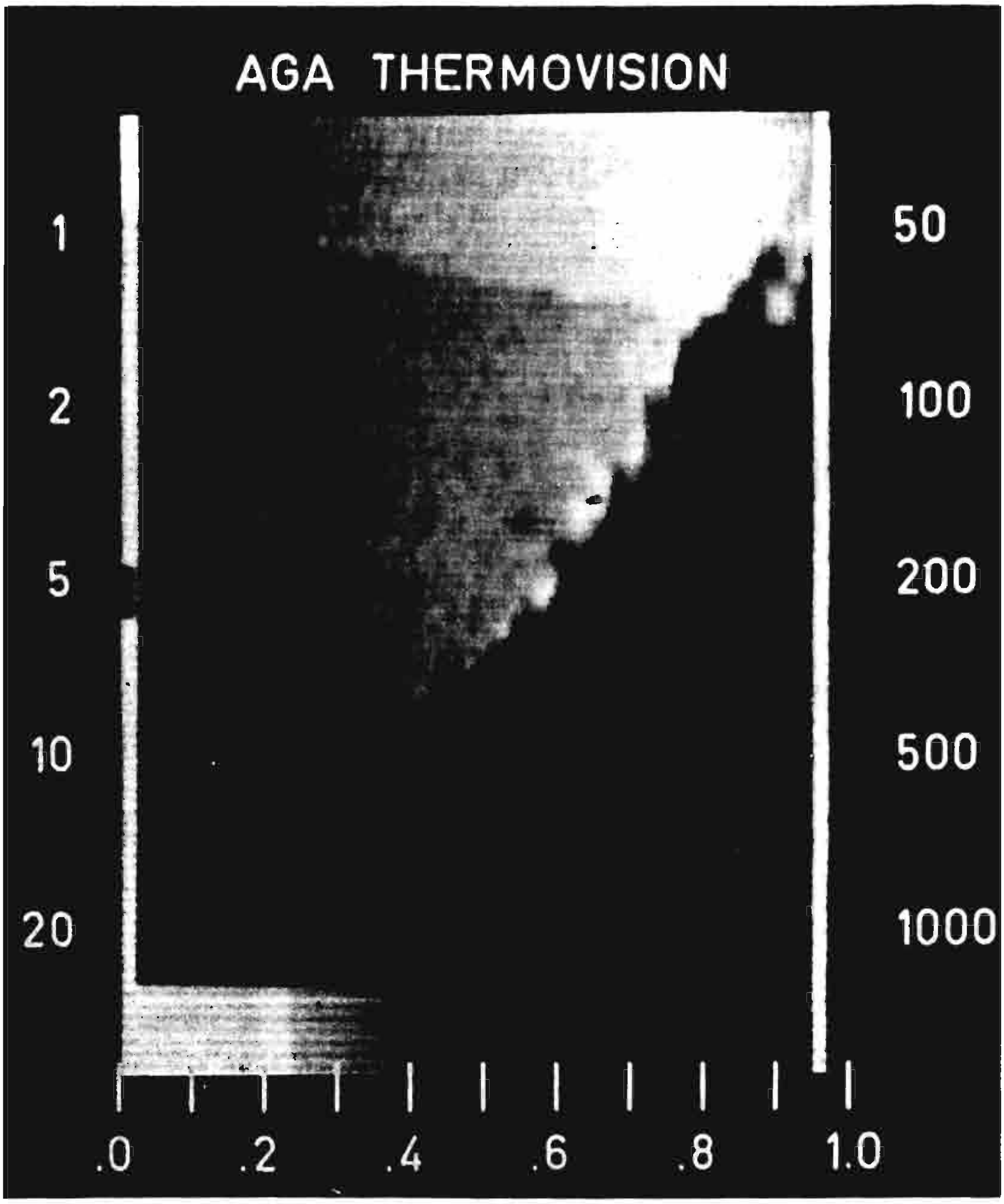


FIGURE 7: IMAGE DISPLAYED ON CATHODE RAY TUBE OF THE OSCILLOSCOPE

frames are given for the west shore of Hawaii. These were taken one day on the return flight to Oahu to finish up a roll of film.

A supplemental index map is given in Section II for a 16mm reel of film which was successfully exposed over the southeast coast of Hawaii. This coverage is restricted to the South Point and Kau District.

Not all the prints catalogued here are of equal quality. In general, the later images tended to be of better quality than those from the earlier effort.

Additional images were taken, but those indexed are considered to be of useful quality. The catalogued and non-catalogued images are available for viewing in the files of the Water Resources Research Center at the University of Hawaii.

DISCUSSION OF THE RESULTS

The thermal anomalies, considered to be potentially correlated with the outflow of cooler spring waters onto the surface of the ocean, will be brighter areas in the image prints when the Thermovision instrument is operated in reverse mode and darker areas when the instrument is operated in normal mode. The thermal anomaly is evident from the air because the fresher water is less dense than the sea water, and hence floats to the surface. If a wind is blowing or a heavy swell is running, then the mixing will noticeably reduce the salinity and temperature contrast of this surficial scum of fresher water. Because of the effects of wind and swell, comparisons of film densities to estimate the quantity of outflow are unwarranted.

The flights were conducted in early morning between 5:30 and 9:30 in order to avoid flashing reflection from the ocean surface. On the south shore at this time of day, the sunlight is from the east, often leaving the water in little gorges unheated. Consequently, where the anomaly only occurs westward of a jutting point of land, it is anticipated this may be due to lack of solar hearing in the shadows. Comparison should be made to adjacent gorges.

It is evident from the foregoing paragraph that *not all thermal anomalies are spring waters*. Consequently, any aerial infrared survey should be accompanied by a ground-truth effort. Otherwise, the thermal anomalies cannot justifiably be considered as fresh-water springs.

It was found that the summertime was a poor time for ground truth on the south coastline due to swells from storms in the South Pacific. Imagery taken in mid-winter should permit obtaining ground truth from a boat.

Sample Mosaic

Interpretation of the infrared imagery is greatly facilitated by printing the frames at some convenient size and mosaicking them to produce a replica of the shoreline corresponding to a topographic map or aerial photograph. Such a mosaic is given in Figure 8, as constructed for the Ninole Springs area--a location near Punaluu which has been widely mentioned in the literature (Stearns and MacDonald, 1949) as producing over ten million gallons of brackish water per day. This water is recorded to have a temperature as low as 64^{o}F. This figure is the most extreme infrared anomaly recorded on this coastline. The white areas along the west coast area are due to instrumentation.

A comparison of the cold-water anomalies found in this study with those found on the south coast of Hawaii by Fischer, *et al.* (1966) is made in Figure 9. Additional anomalies other than those shown in Figure 9 were noted by Fischer, *et al.*, but they were warm relative to the background, not cold. Most of these warm-water anomalies occurred in the region between Naliikakani and Apua Points, which did not yield satisfactory data in this study. There is rather good agreement on the general locations of the cold-water anomalies. However, there are differences in the specific locations which are important when a field study is initiated on the ground. Of course, some of the discrepancy is undoubtedly due to seasonal differences in the survey time. However, if it is assumed that the cold anomalies are due to fresh-water outflow, then the outflow should be relatively constant. Surface runoff would change the situation markedly.

This study concluded that some anomalies do appear between Mahuka Bay and Naliikakani Point. As discussed elsewhere, it was sometimes necessary to determine, for the anomalies found in the coastline segment as for many other similar anomalies, whether they might be due to the sun reaching the area of the anomaly after the scanning had been performed.

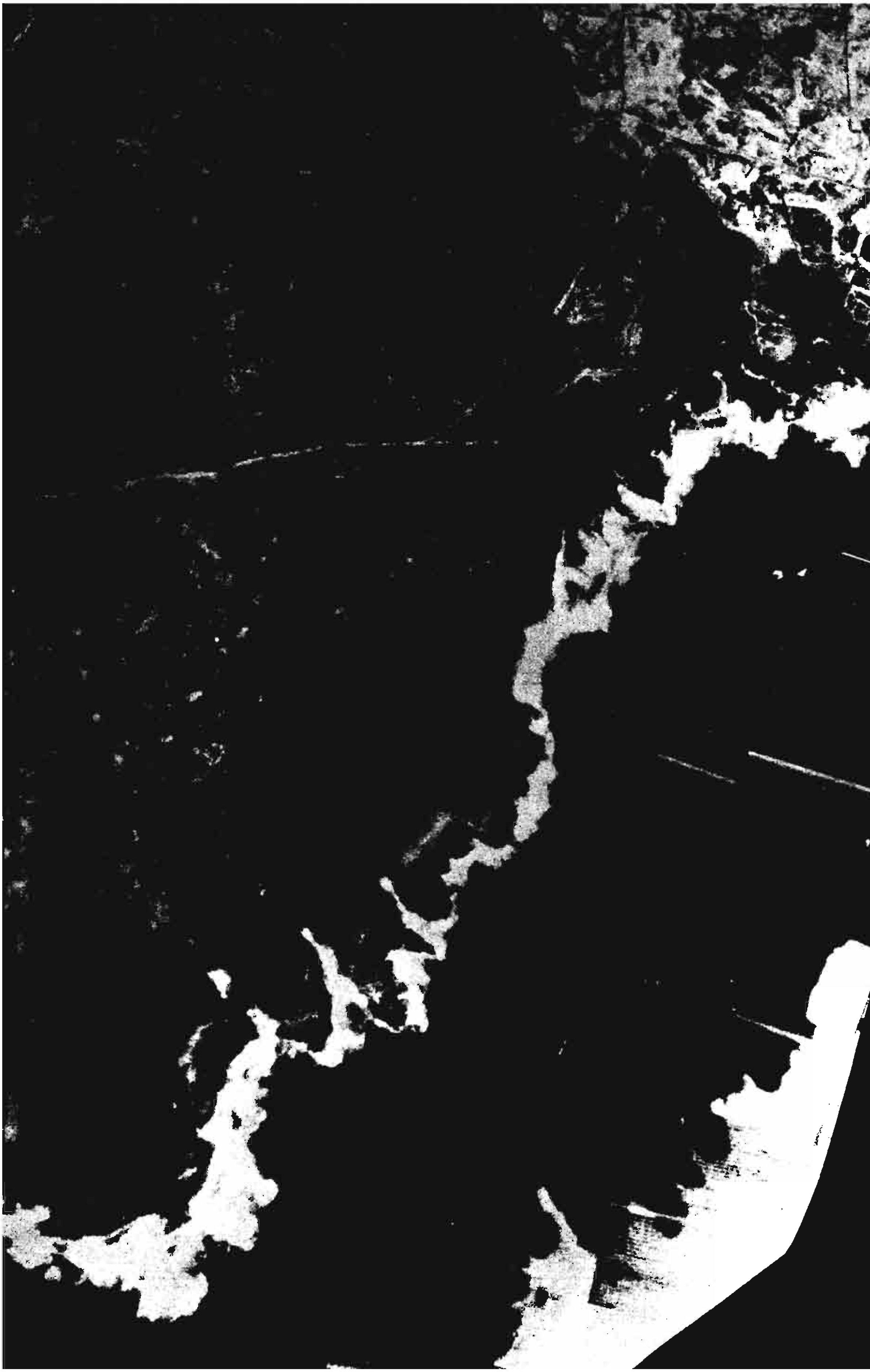
It is anticipated that future remote sensing should be directed to longer wavelengths, on either side of 3 centimeters, as indicated by a recent study (Lepley and Adams, 1968). However, the greatest need is now considered to be the development of a method and appropriate field procedures and instrumentation for estimating the quantity of outflow, once such an outflow has presumably been detected by remote sensing.

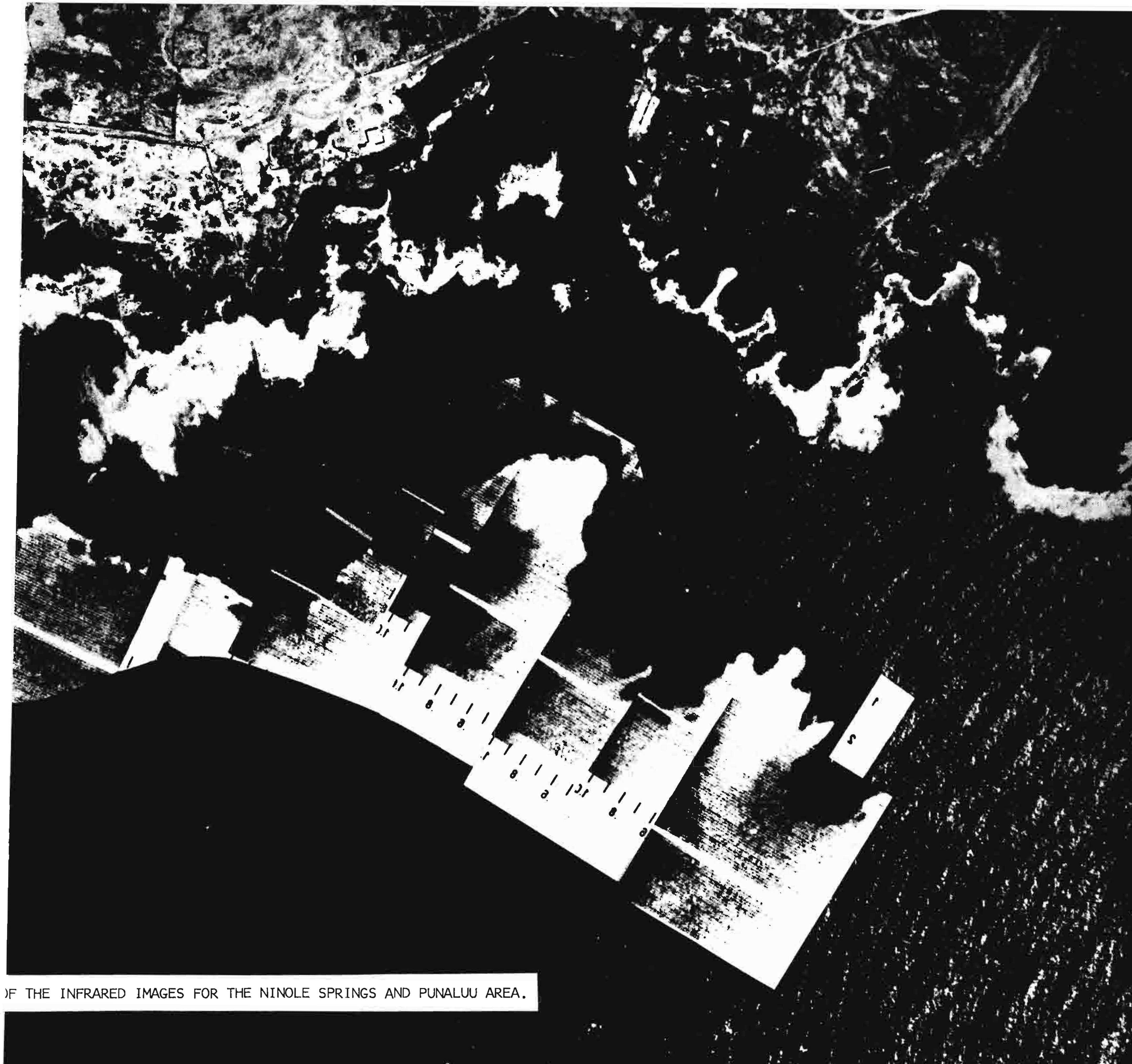
ACKNOWLEDGEMENTS

This reconnaissance effort has been successful due to the efforts of the field operators, Clifton Warren and Steven Langford, who also constructed the special camera mountings and hatch covers. The pilot on all flights was Joseph Shad. The aircraft was made available by Dr. G. P. Woollard; and the lease arrangements for the scanner were administered by Dr. D. C. Cox.

The darkroom processing wss done by Steven Langford. The cataloguing, mosaicking, and computer programming of a concommitant spectral matching study were by Roy Araki.

The tolerance and continuous cooperation of the AGA representative, Jim Patterson, helped avoid many operational difficulties and hazards.





)F THE INFRARED IMAGES FOR THE NINOLE SPRINGS AND PUNALUU AREA.

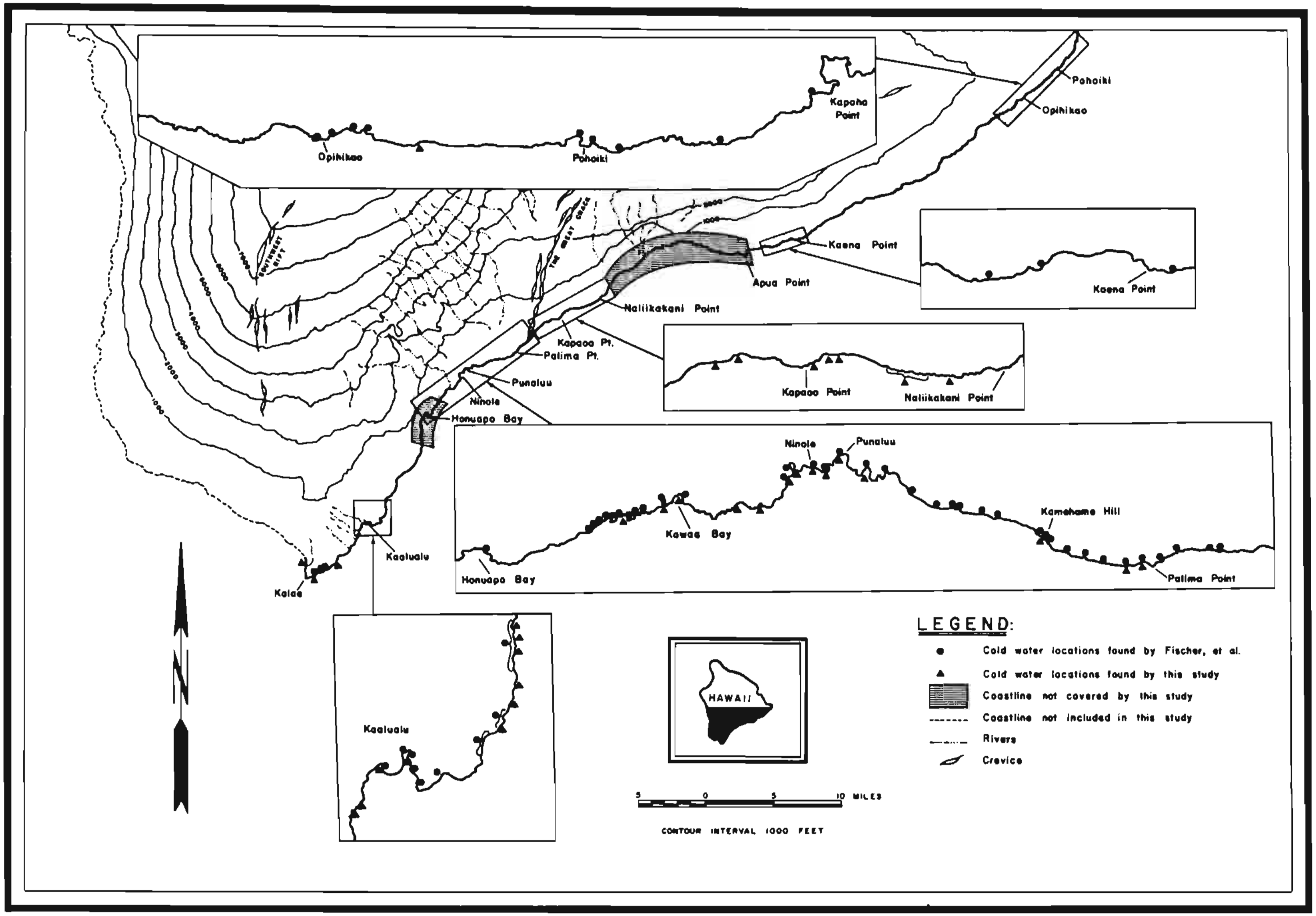


FIGURE 9: COMPARISON OF THE COLD WATER LOCATIONS FOUND IN THIS STUDY AND THOSE REPORTED BY FISCHER, *et al.* (1966).

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APPENDIX: INDEX MAPS AND GRAPHICAL DIRECTIONS FOR USE

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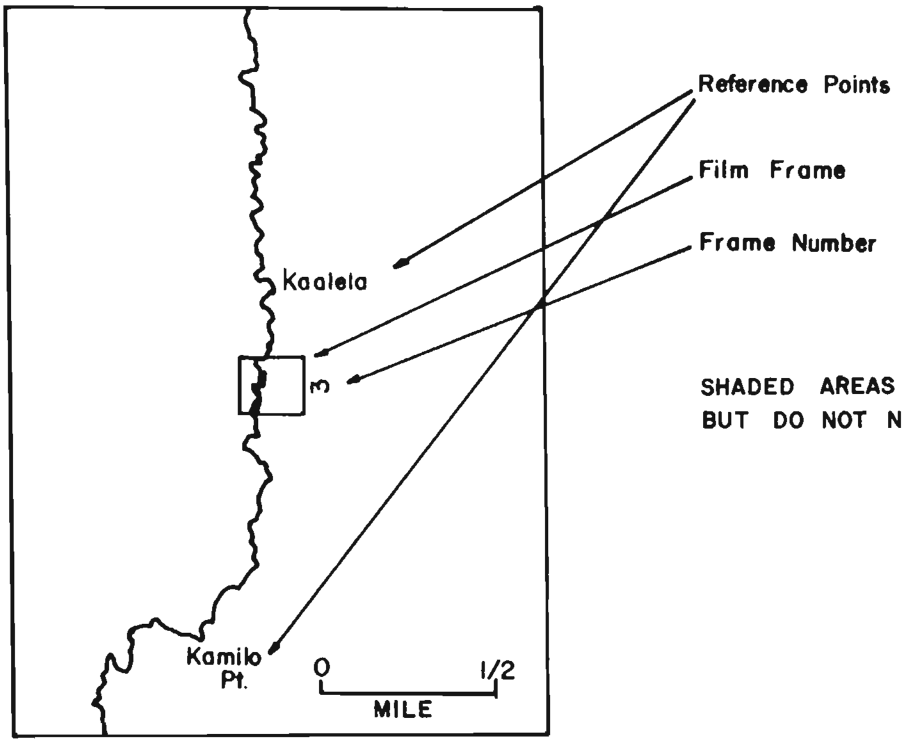
Section I: Master Index Map for 35mm Film...25

Section II: Master Index Map for 16mm Film...47

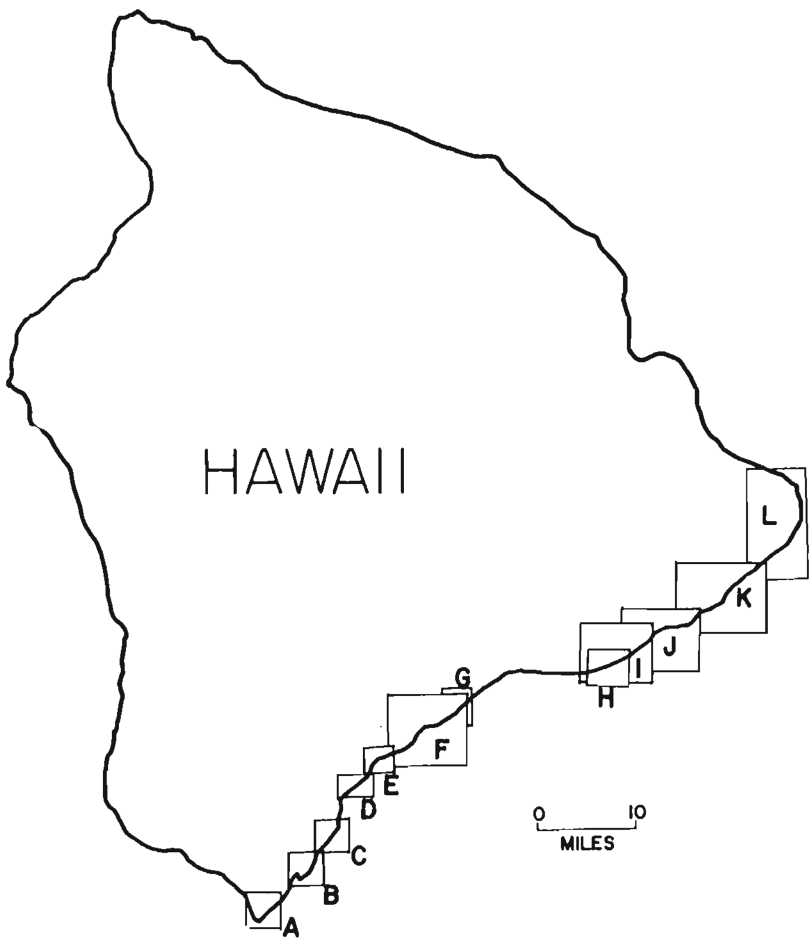
HOW TO USE MAPS



SHADED AREAS INDICATE COLD-WATER LOCATIONS, BUT DO NOT NECESSARILY INDICATE SPRINGS.

The sub-index maps are identified by the capital letters A to L. On a sub-index map, the scale and orientation are given, together with prominent place names. The sub-index, itself, is identified with a date, the number of the film roll, and a Roman numeral. The frame number within the roll of film is given by the number beside the small rectangle marked at the place along the coastline corresponding to the image view. The north arrow and a bar scale, which is in miles unless otherwise specified, are also shown. Base maps for these catalogue sketches were either the U. S. Geological Survey maps or Land Classification maps of the state of Hawaii.

SECTION I: MASTER INDEX MAP FOR 35mm FILM.



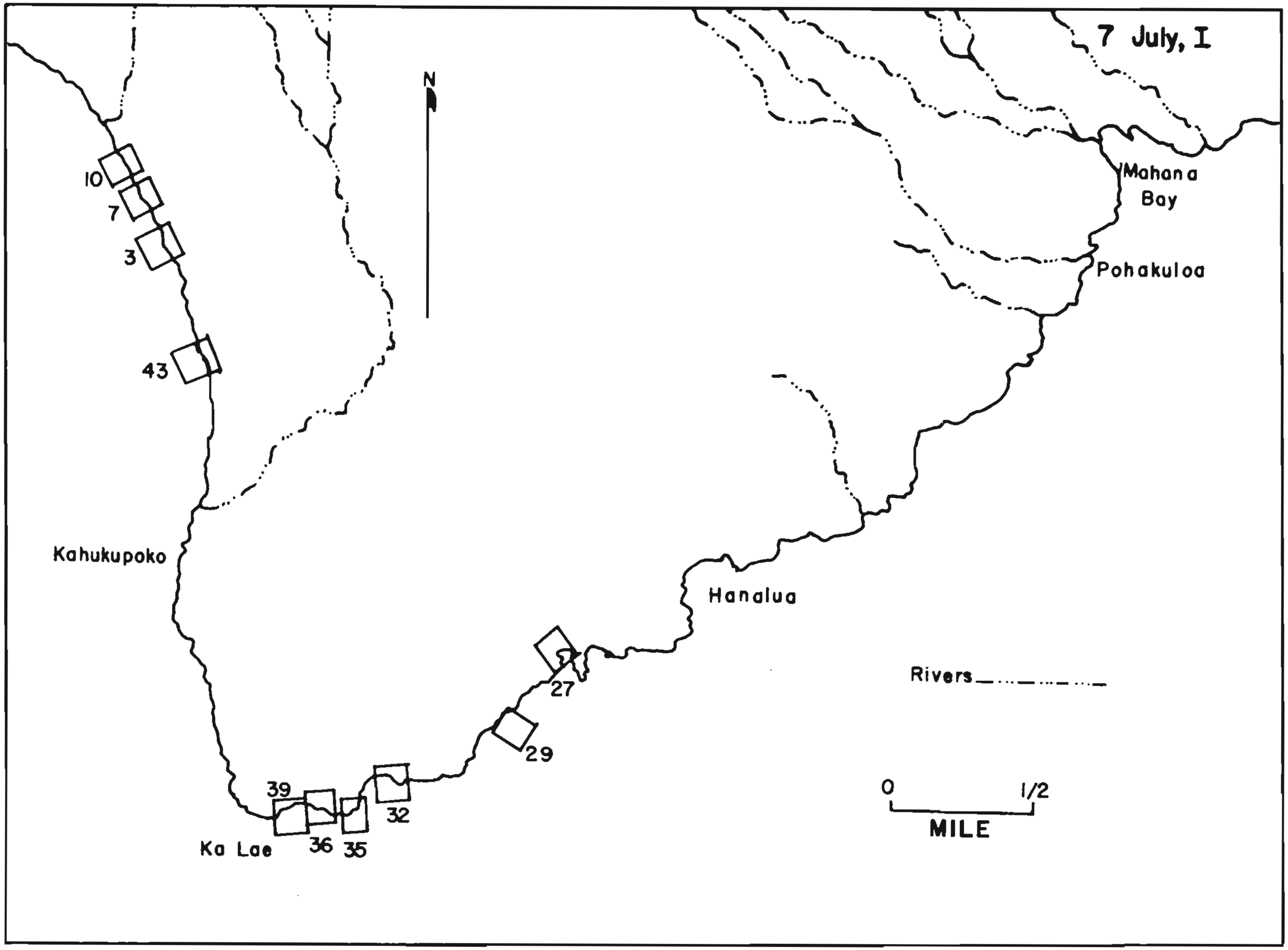
MAP REFERENCES

A, B, C, D -------- 1962 U.S. GEOLOGICAL SURVEY MAPS

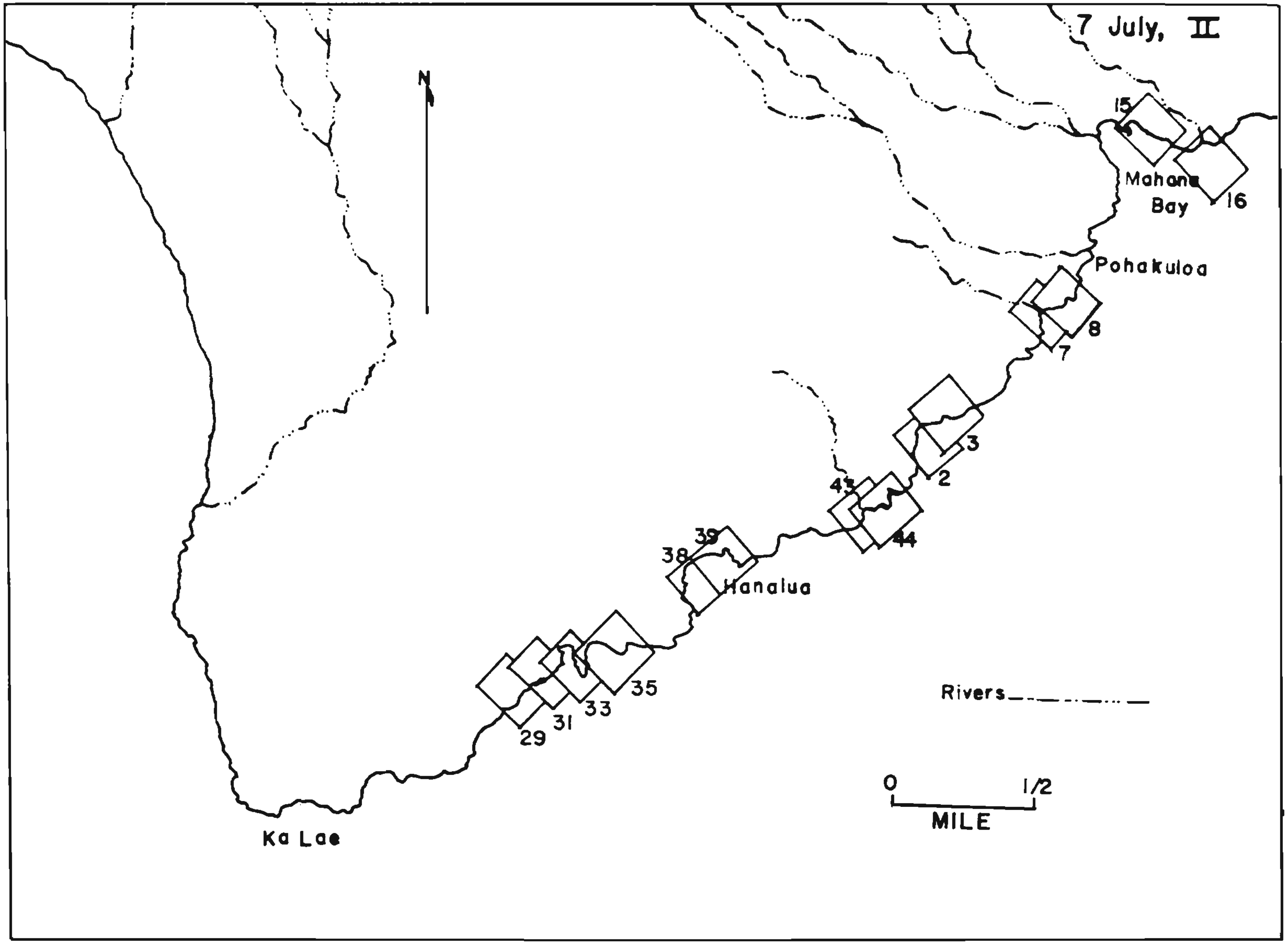
G, H ----------- 1963 U.S. GEOLOGICAL SURVEY MAPS

F, I, J, K, L ----- 1922 U.S. GEOLOGICAL SURVEY MAPS

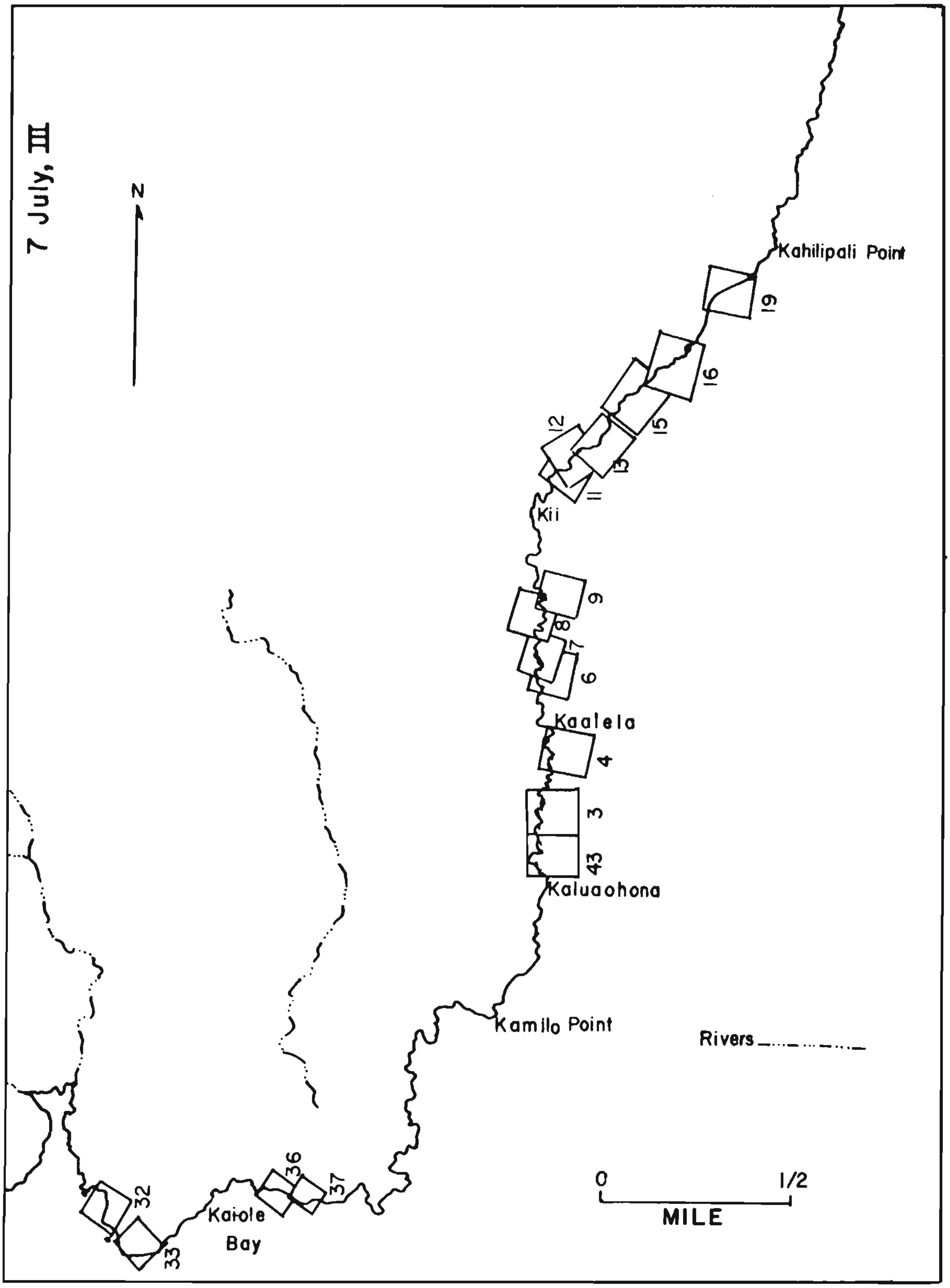
E -------------- 1963 LAND CLASSIFICATION PHOTOGAMMETRIC MAPS



SUB-INDEX MAP: A-1.



SUB-INDEX MAP: A-2.



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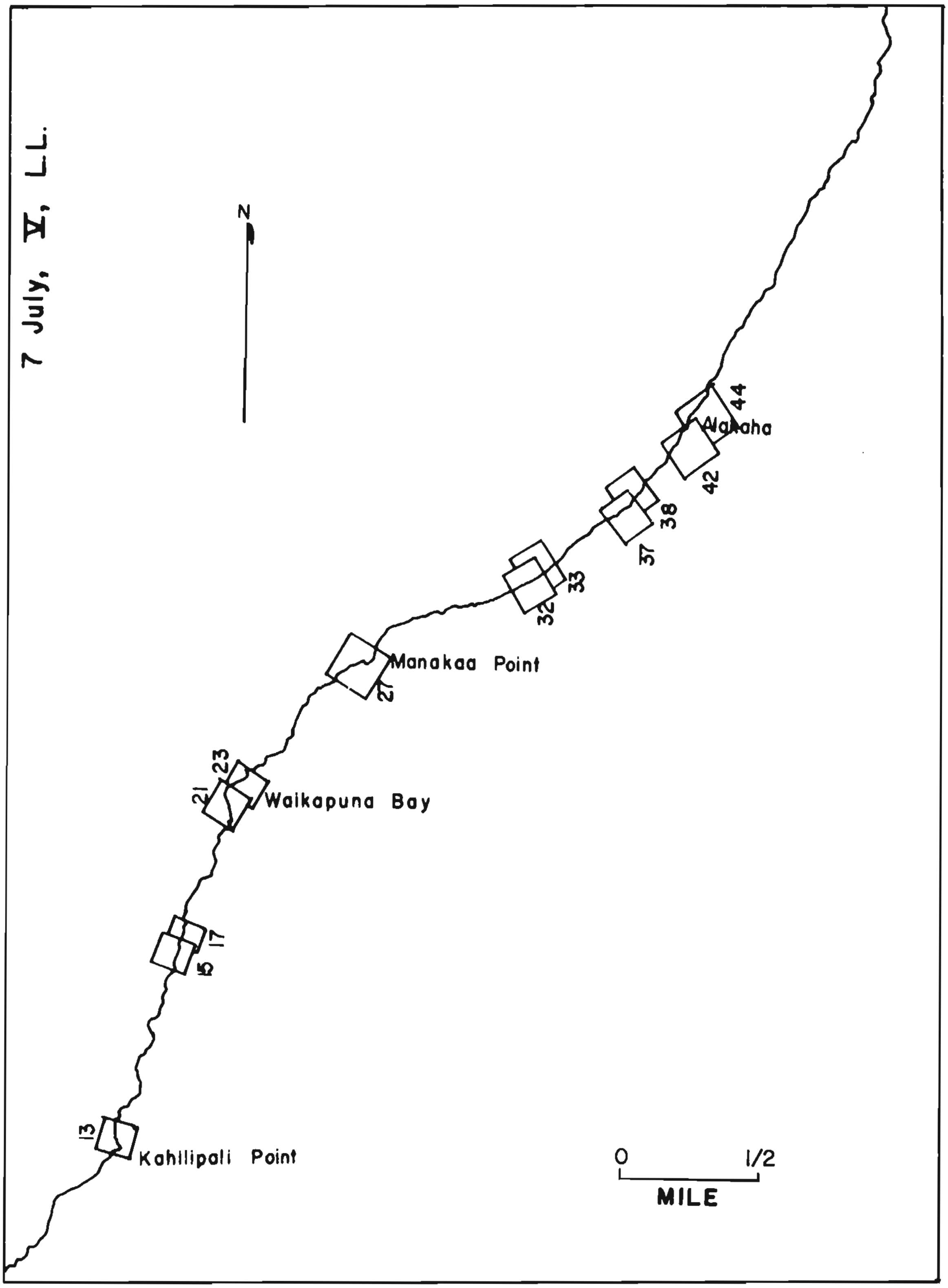

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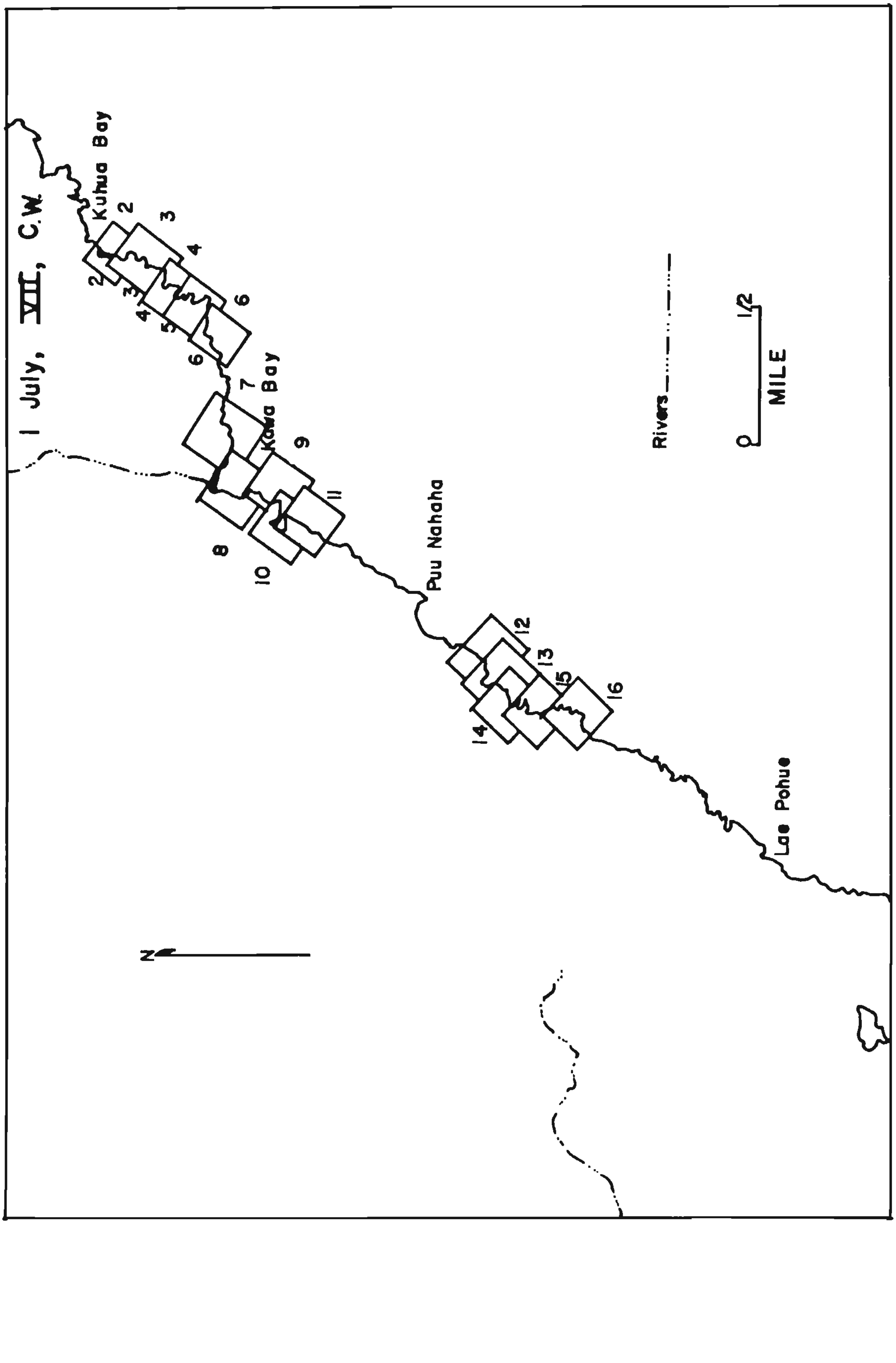

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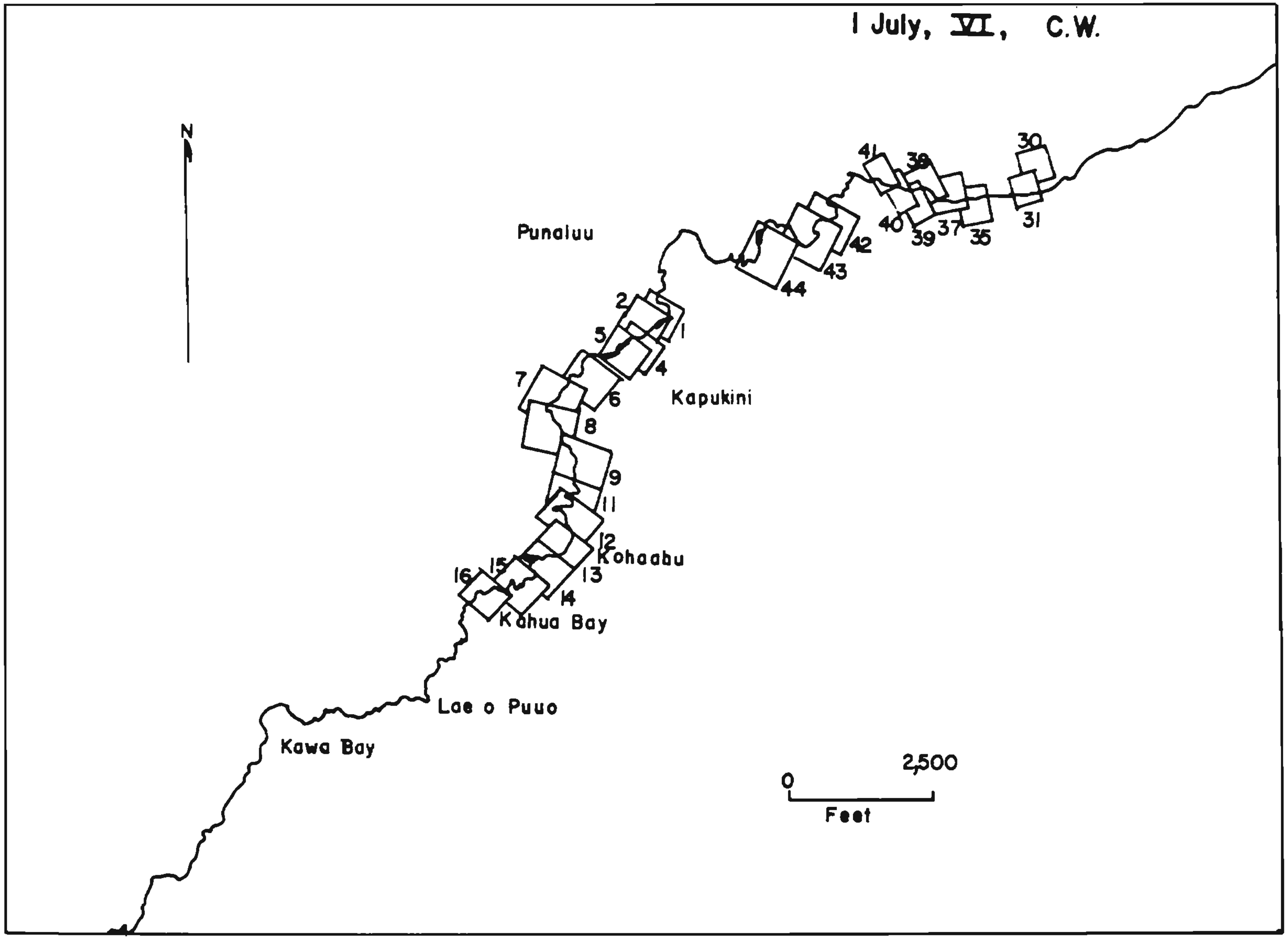
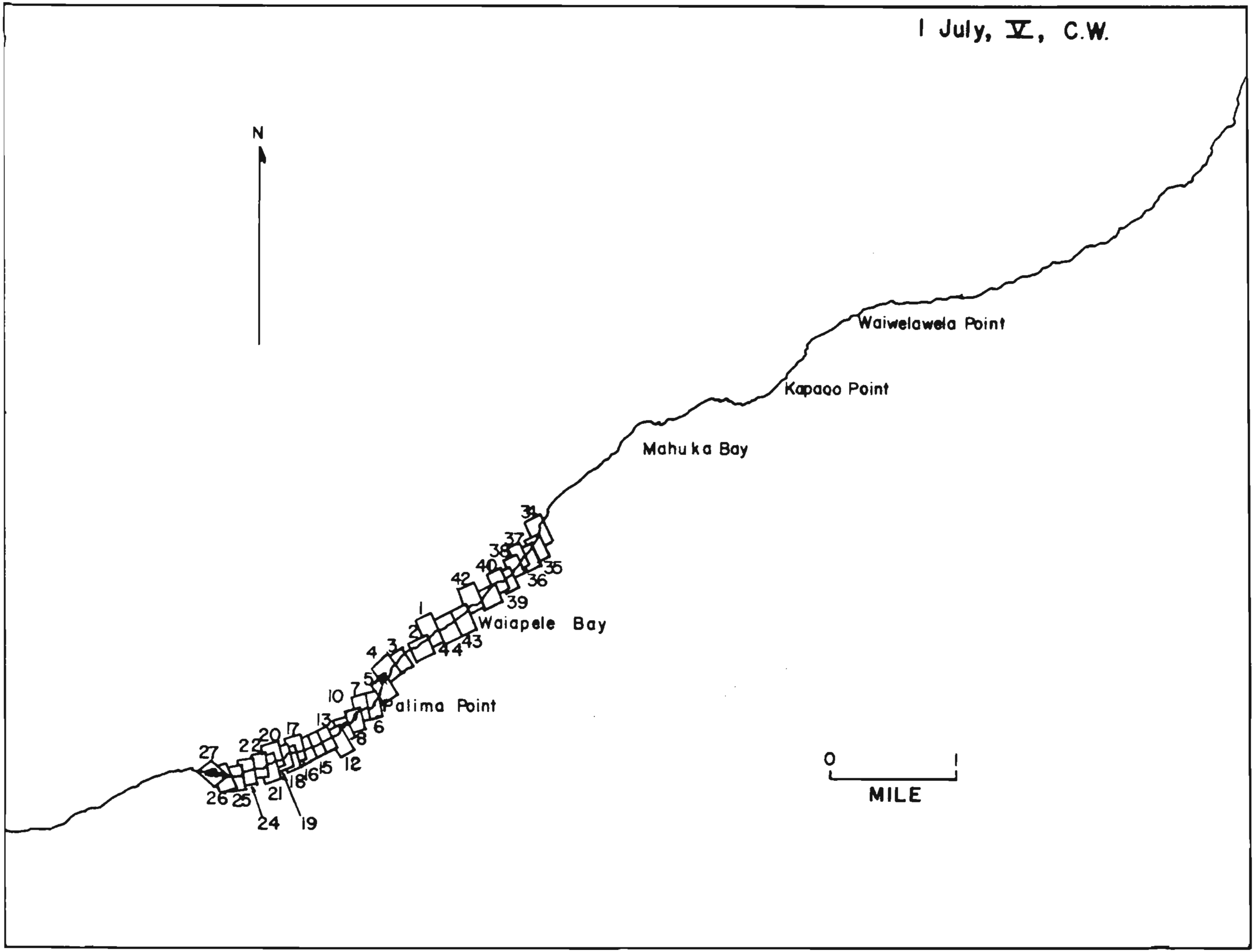
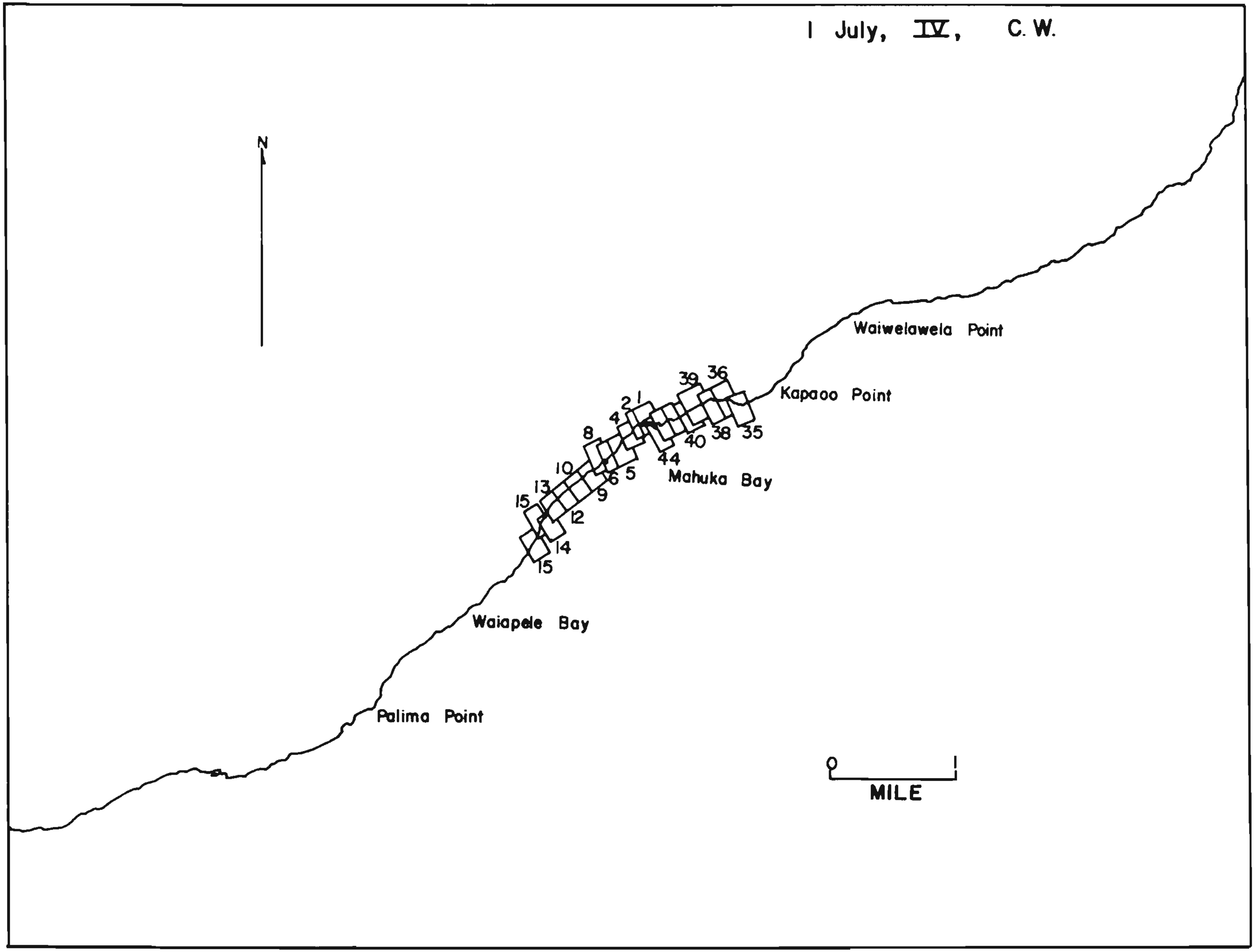


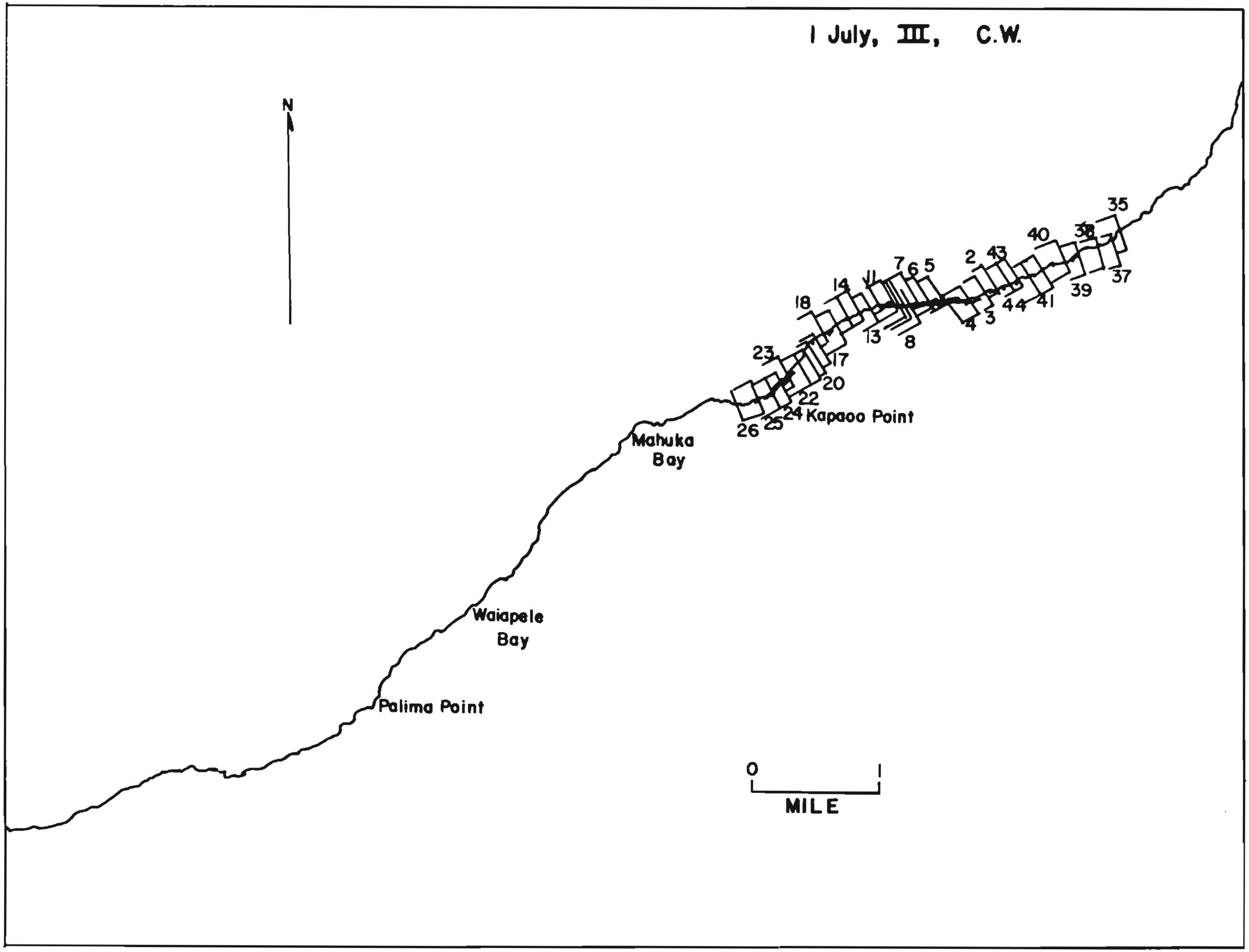
SUB-INDEX MAP: E-1.



SUB-INDEX MAP: F-1.



SUB-INDEX MAP: F-2.



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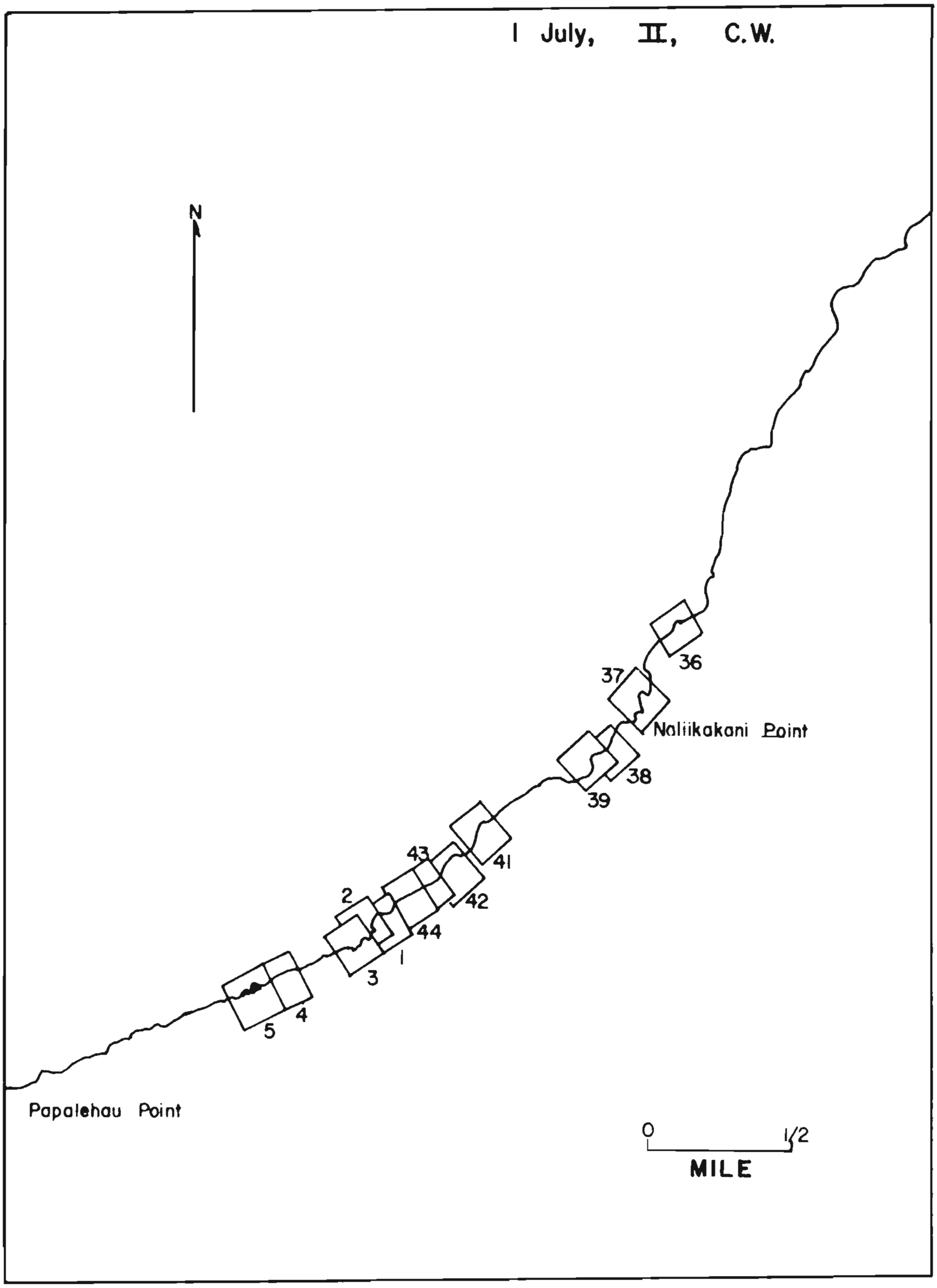
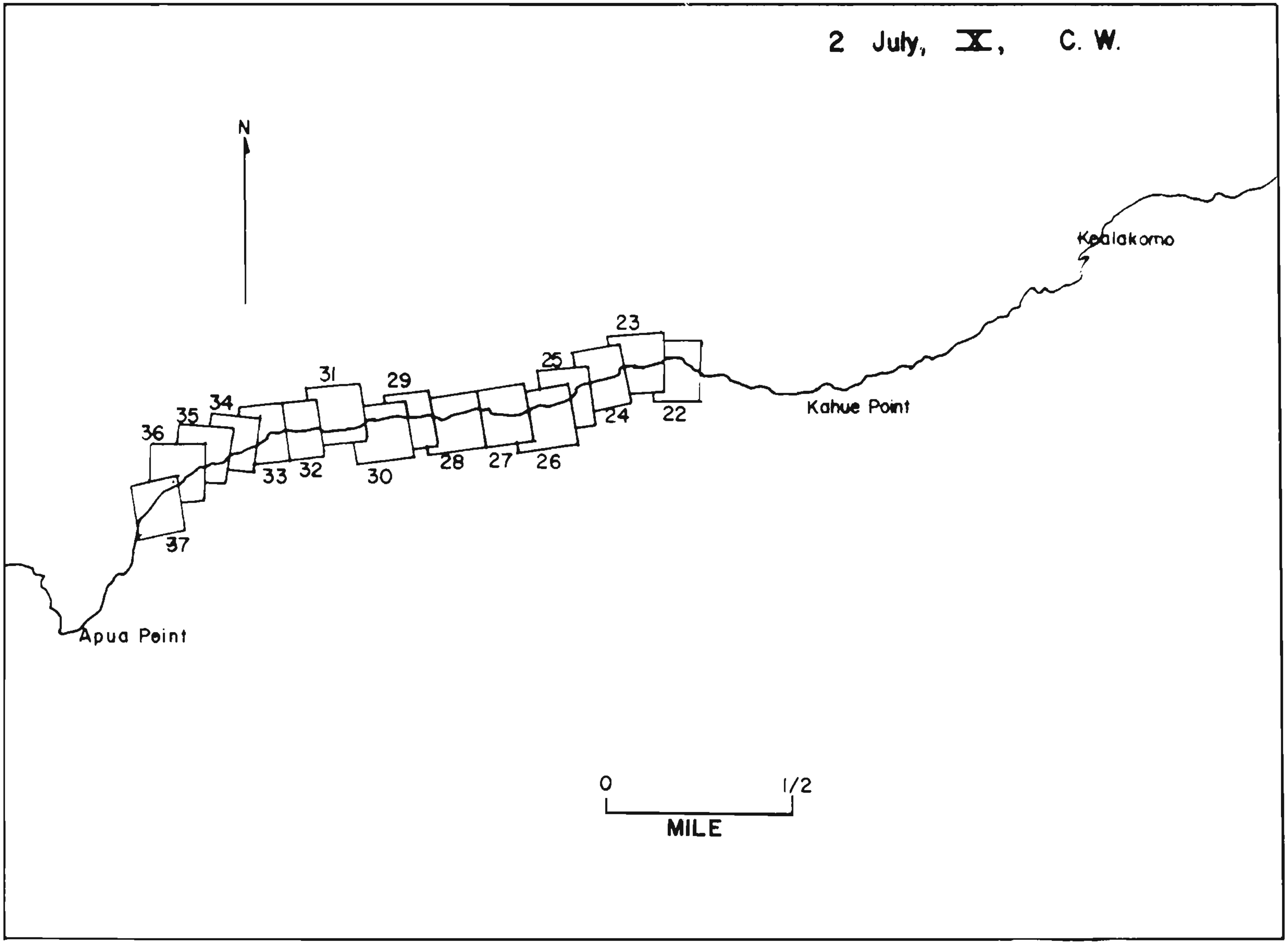
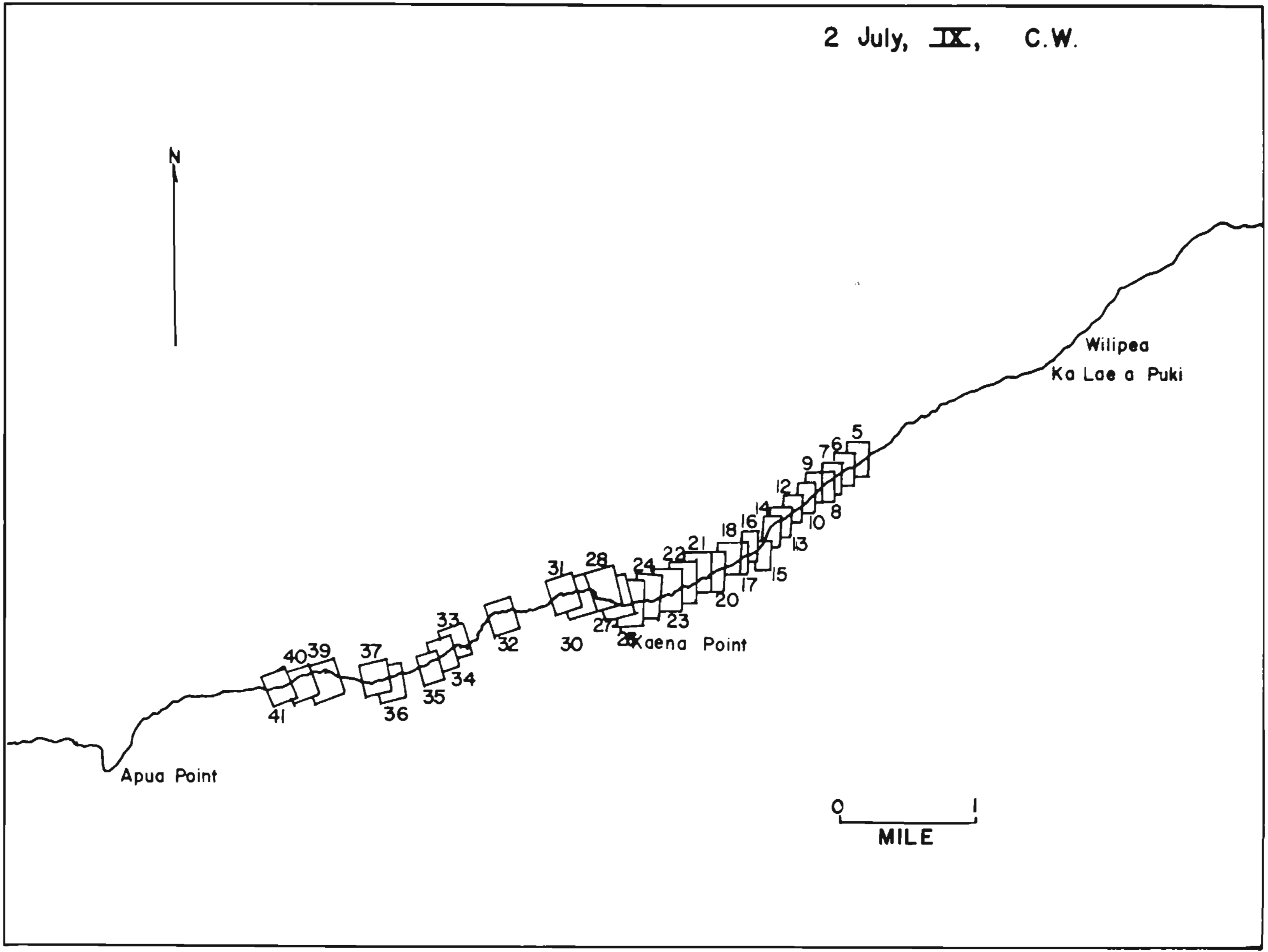


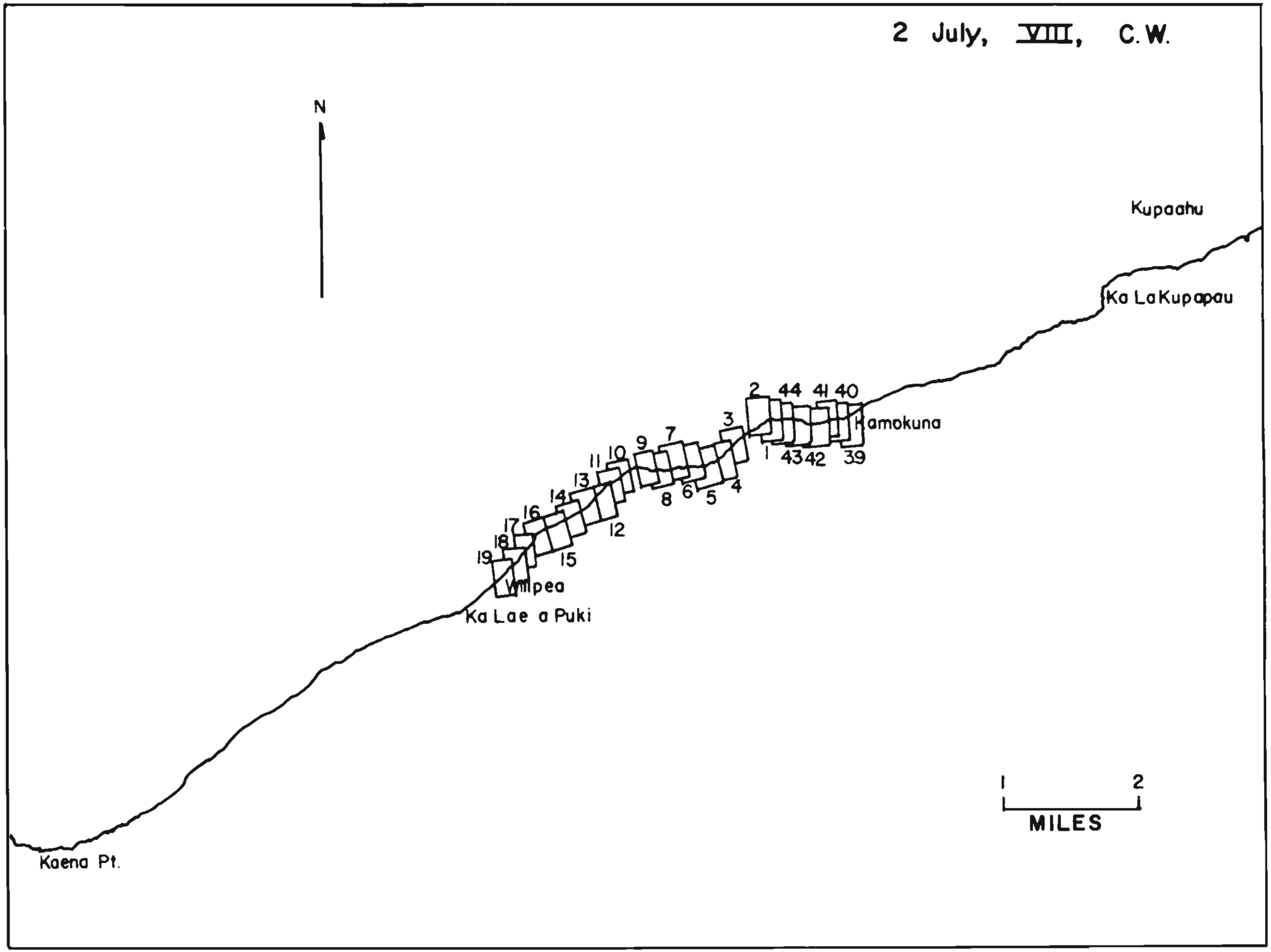
SUB-INDEX MAP: G-1.



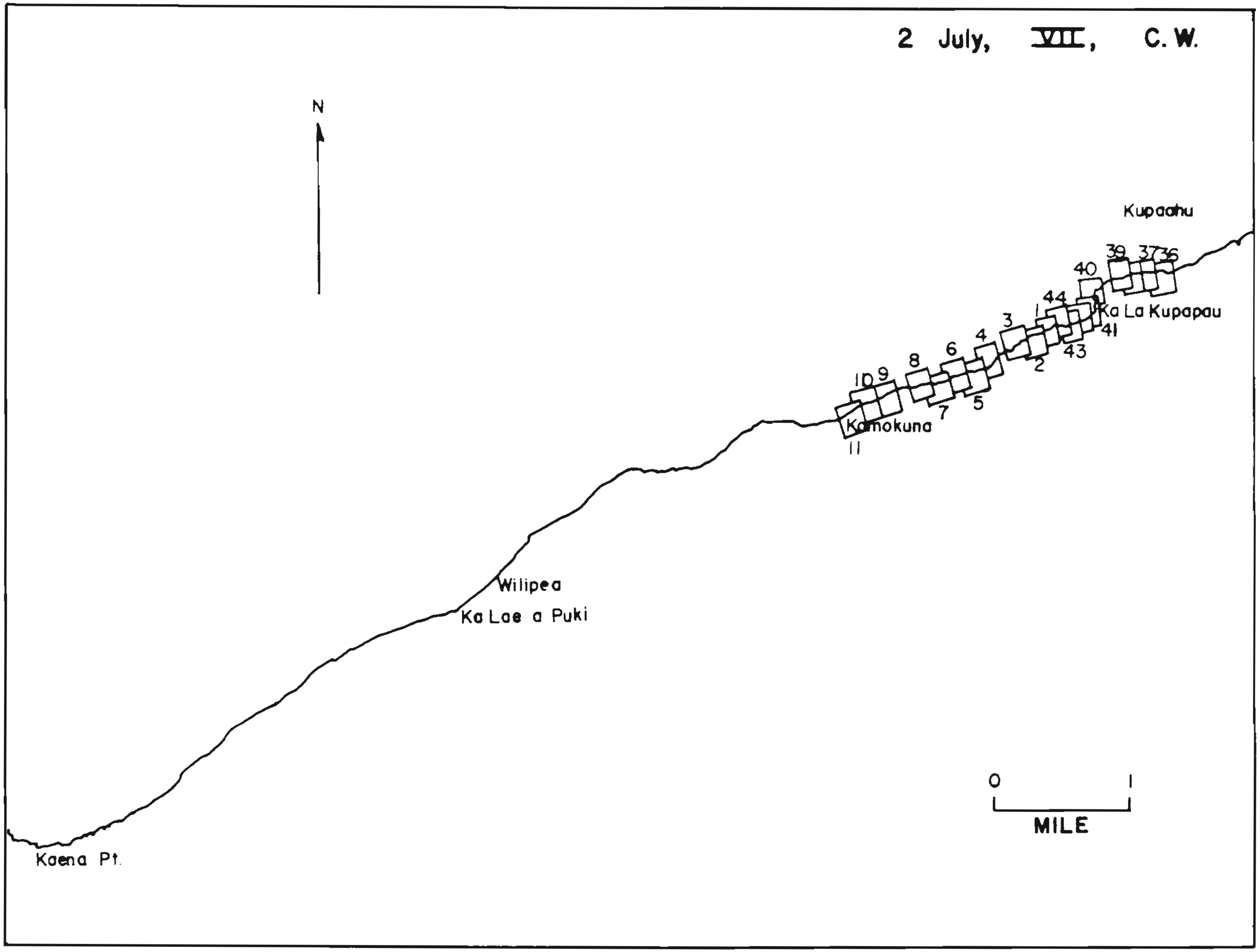
SUB-INDEX MAP: H-1.



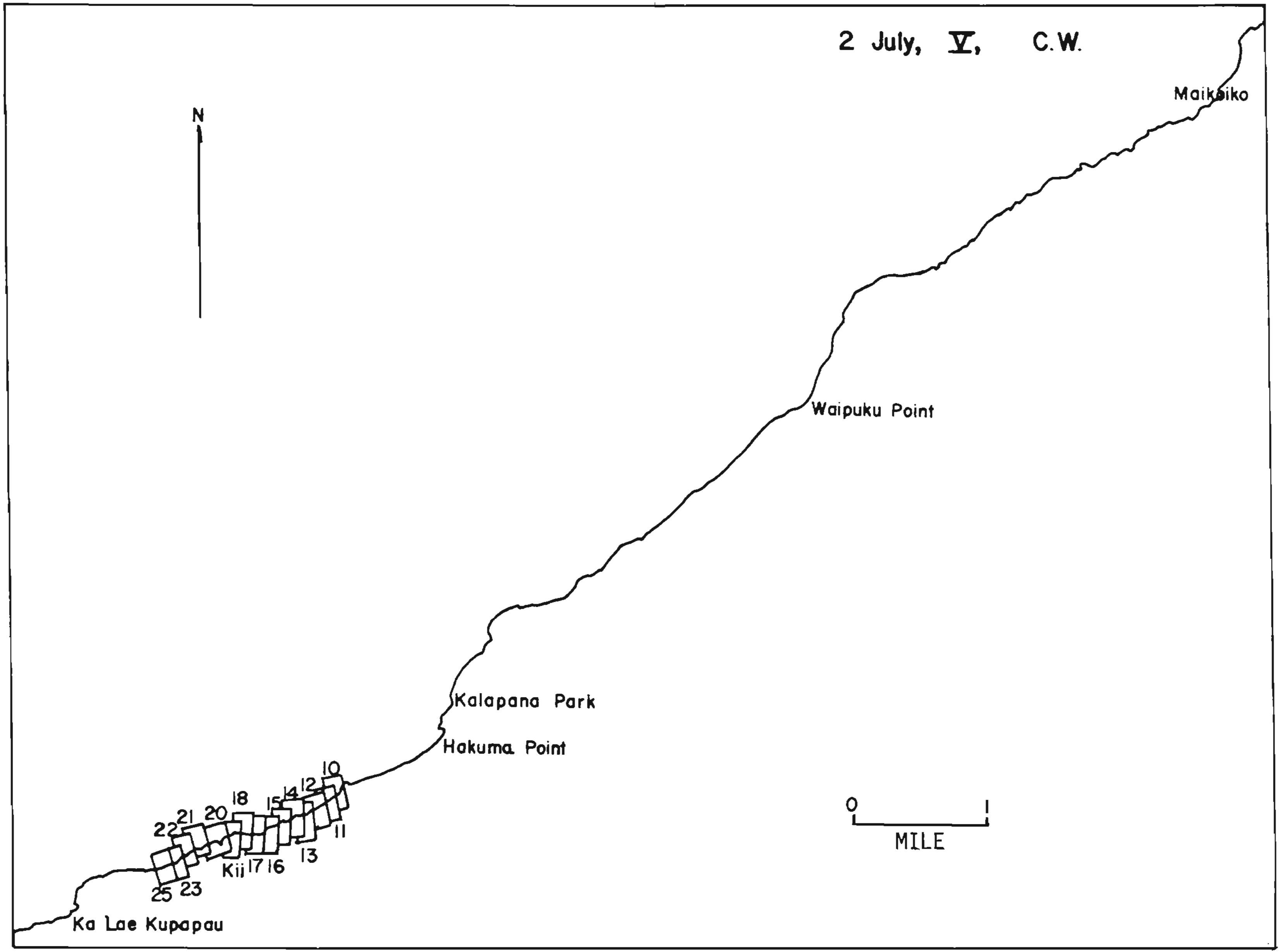
SUB-INDEX MAP: I-1.



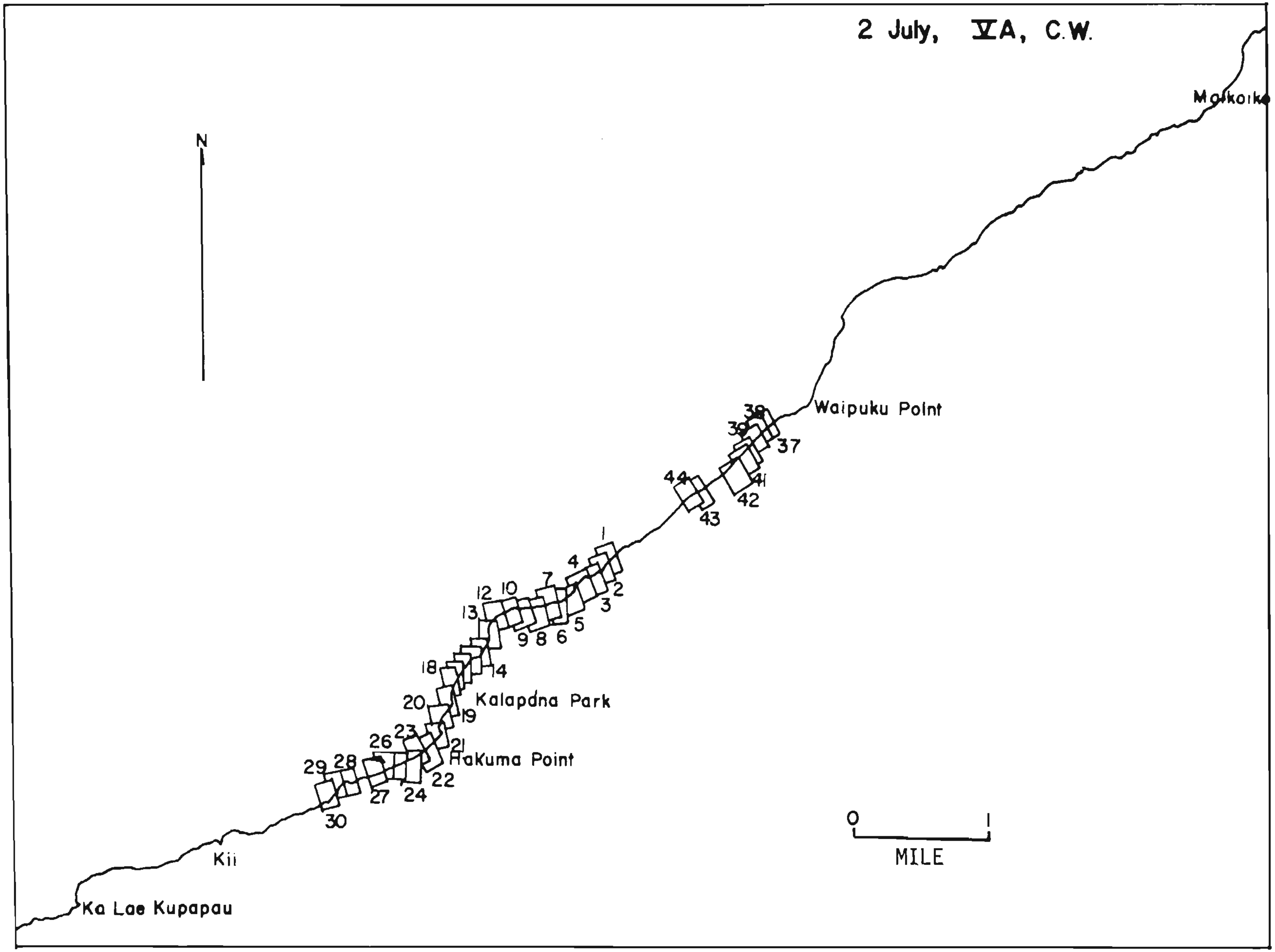
SUB-INDEX MAP: J-1.



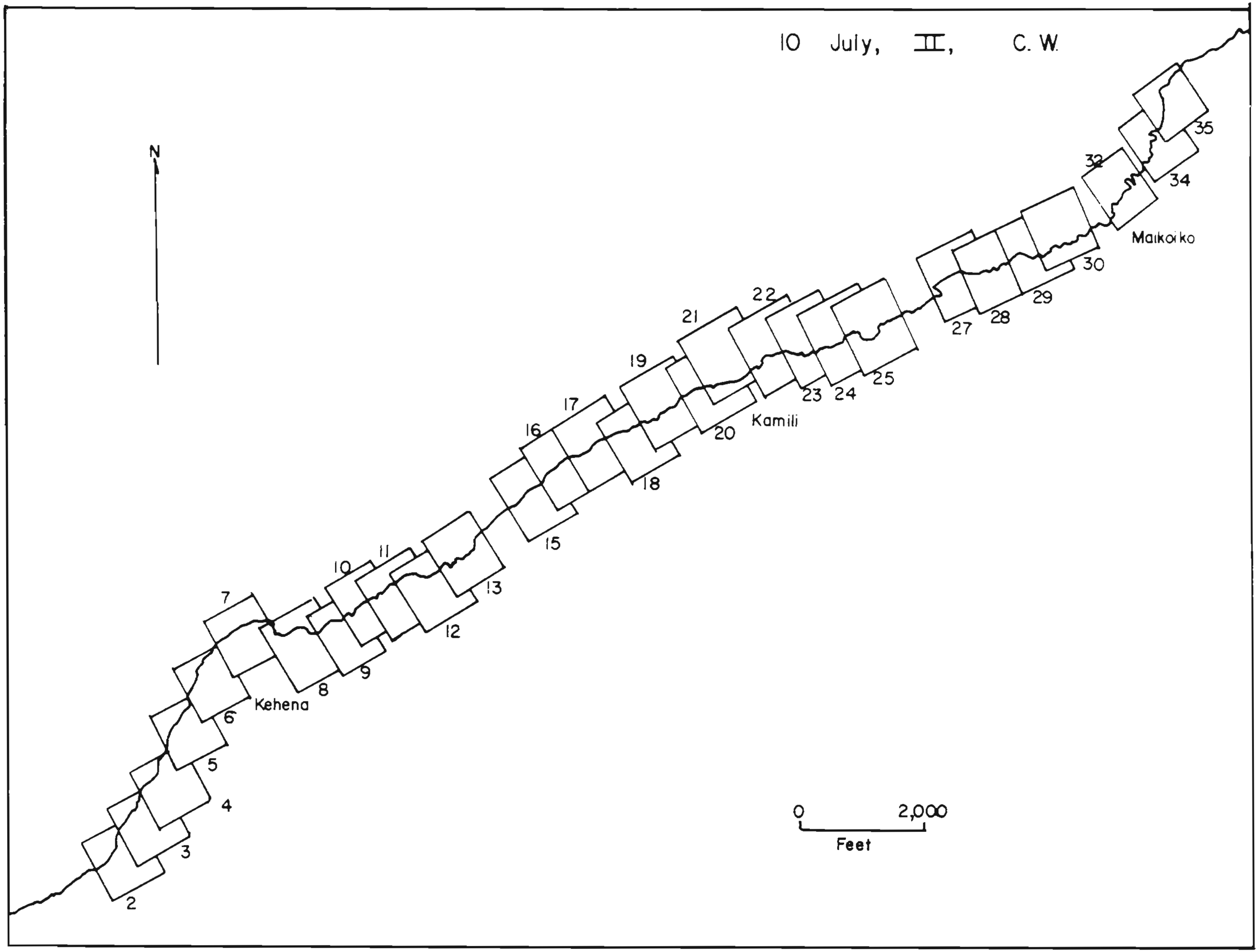
SUB-INDEX MAP: J-2.



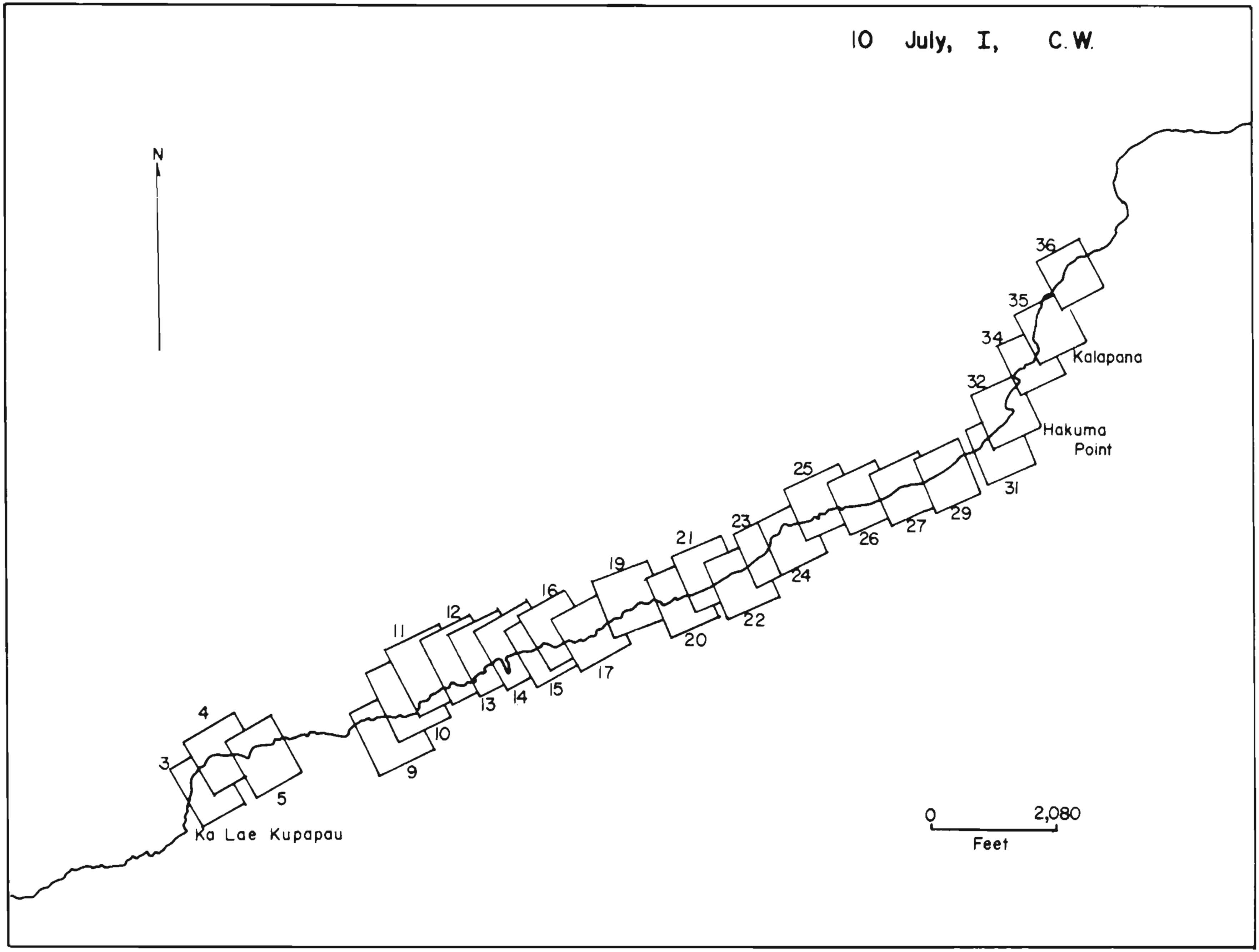
SUB-INDEX MAP: K-1.



SUB-INDEX MAP: K-2.



SUB-INDEX MAP: J/K-1.



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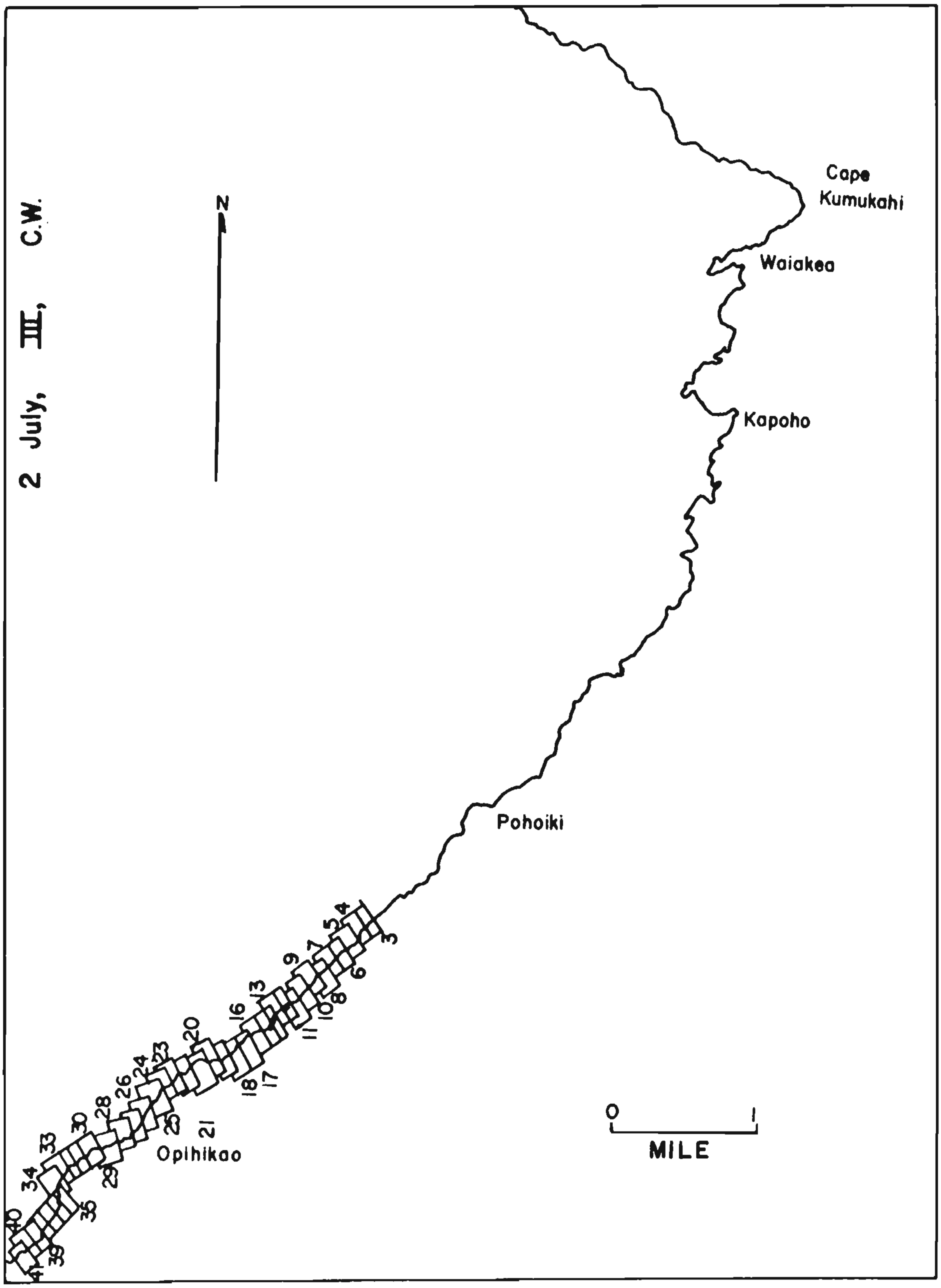
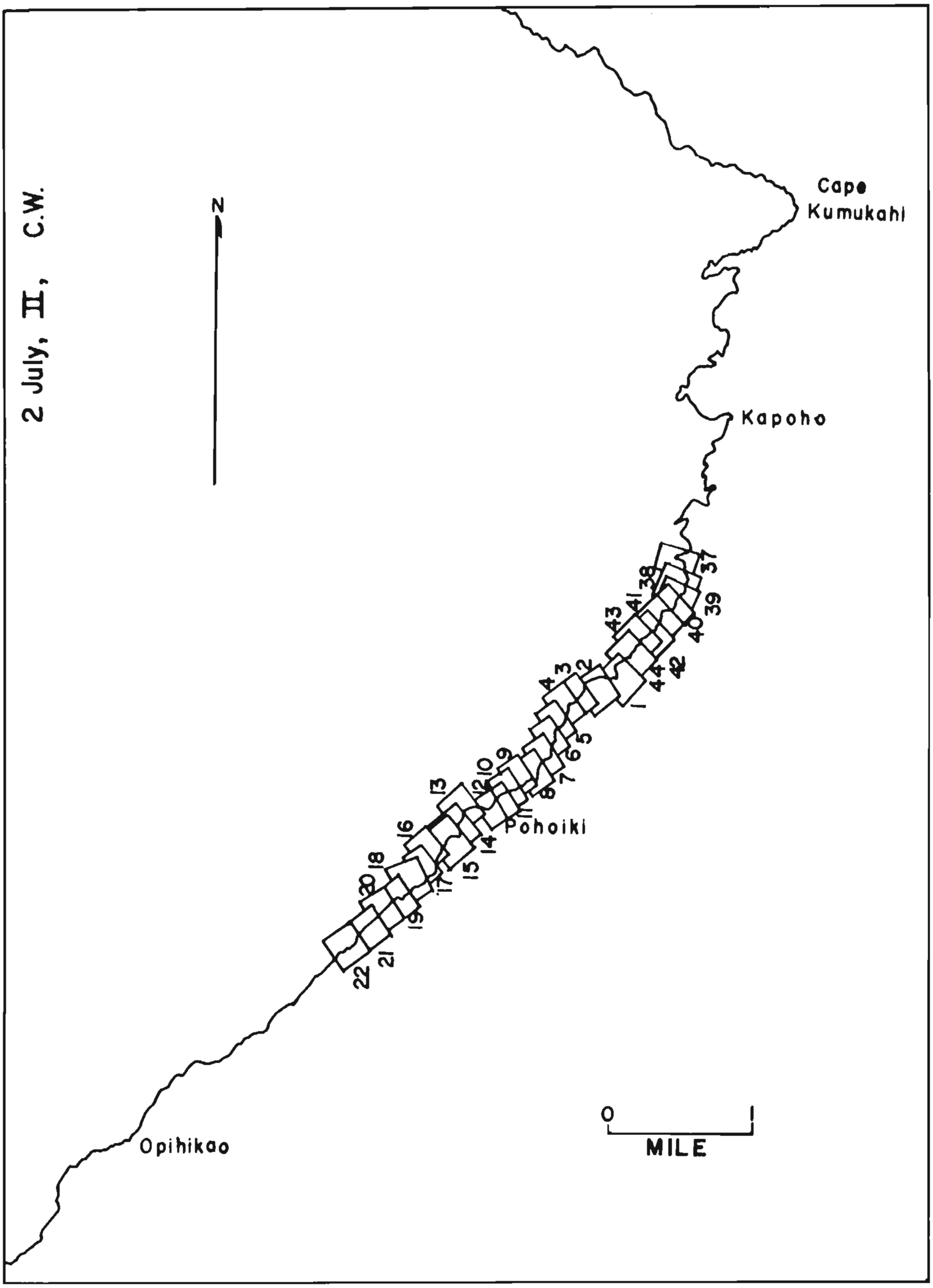
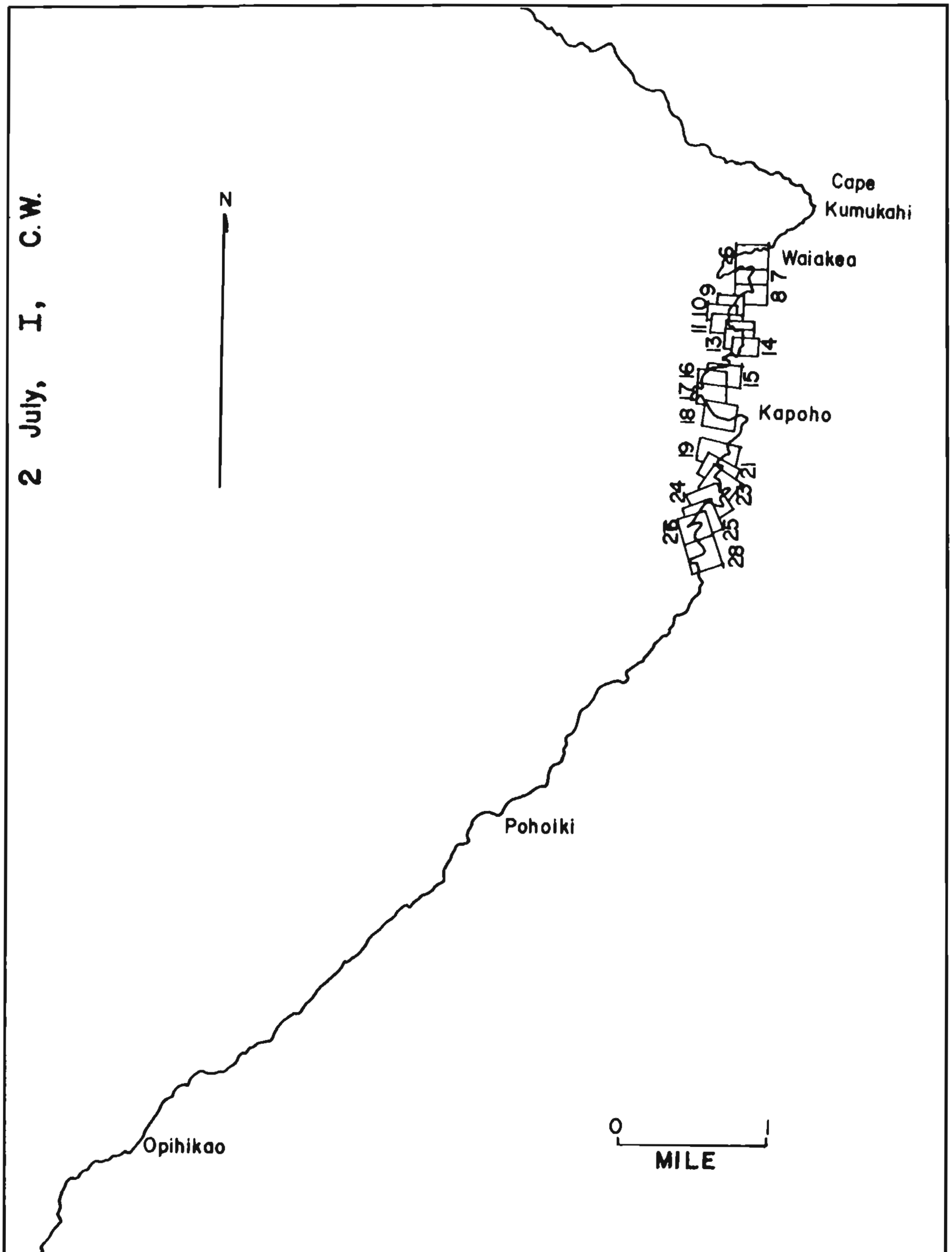


SUB-INDEX MAP: L-1.

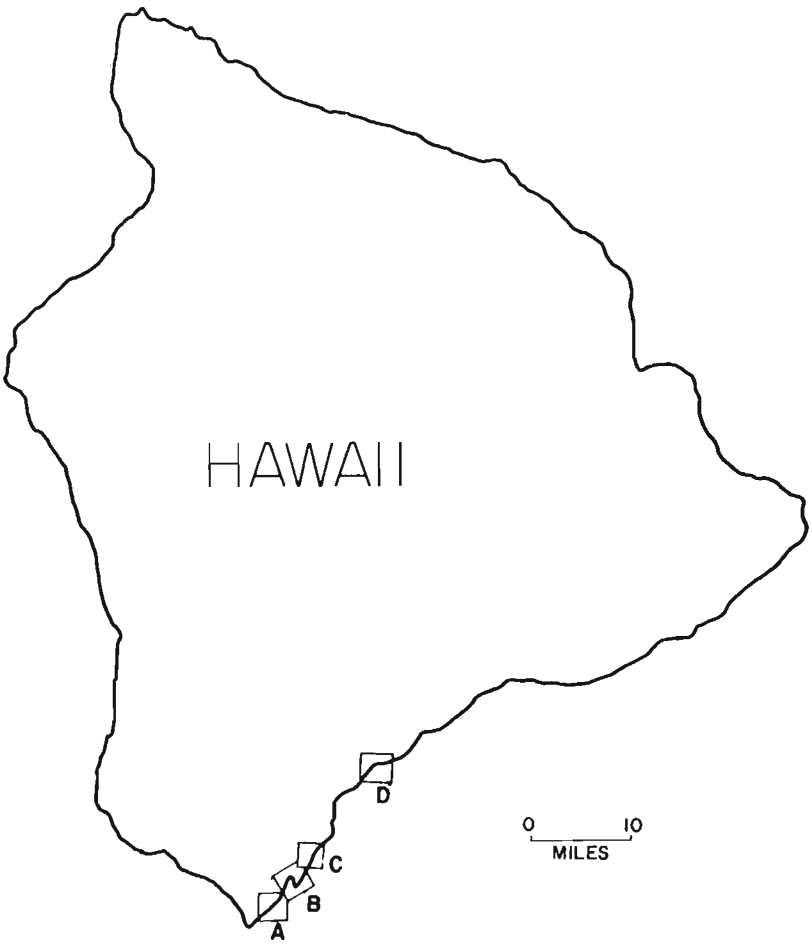


SUB-INDEX MAP: L-2.



SUB-INDEX MAP: L-3.

SECTION II: MASTER INDEX MAP FOR 16mm FILM.



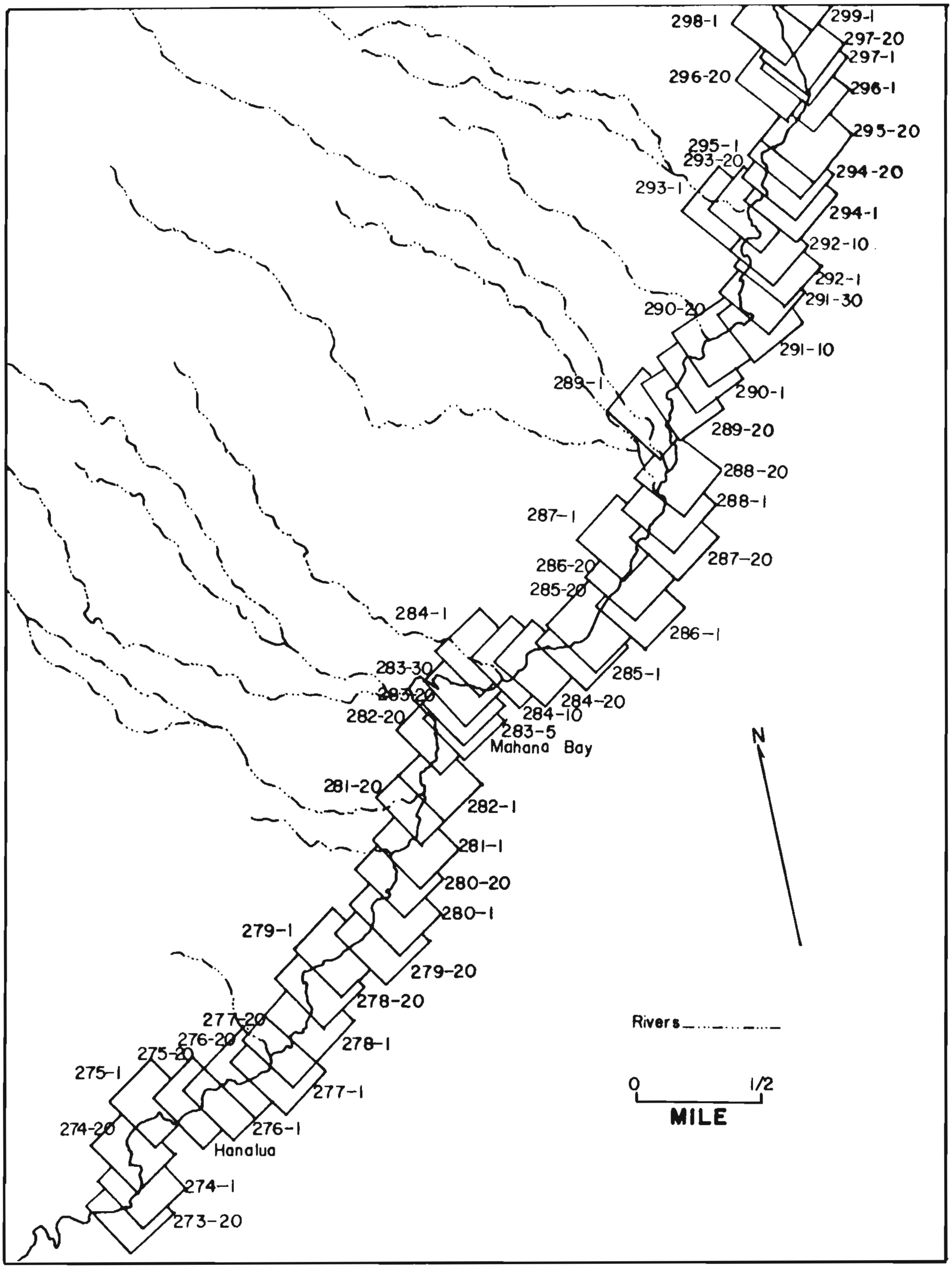
MAP REFERENCES

A ------- 1962 U.S. GEOLOGICAL SURVEY MAPS

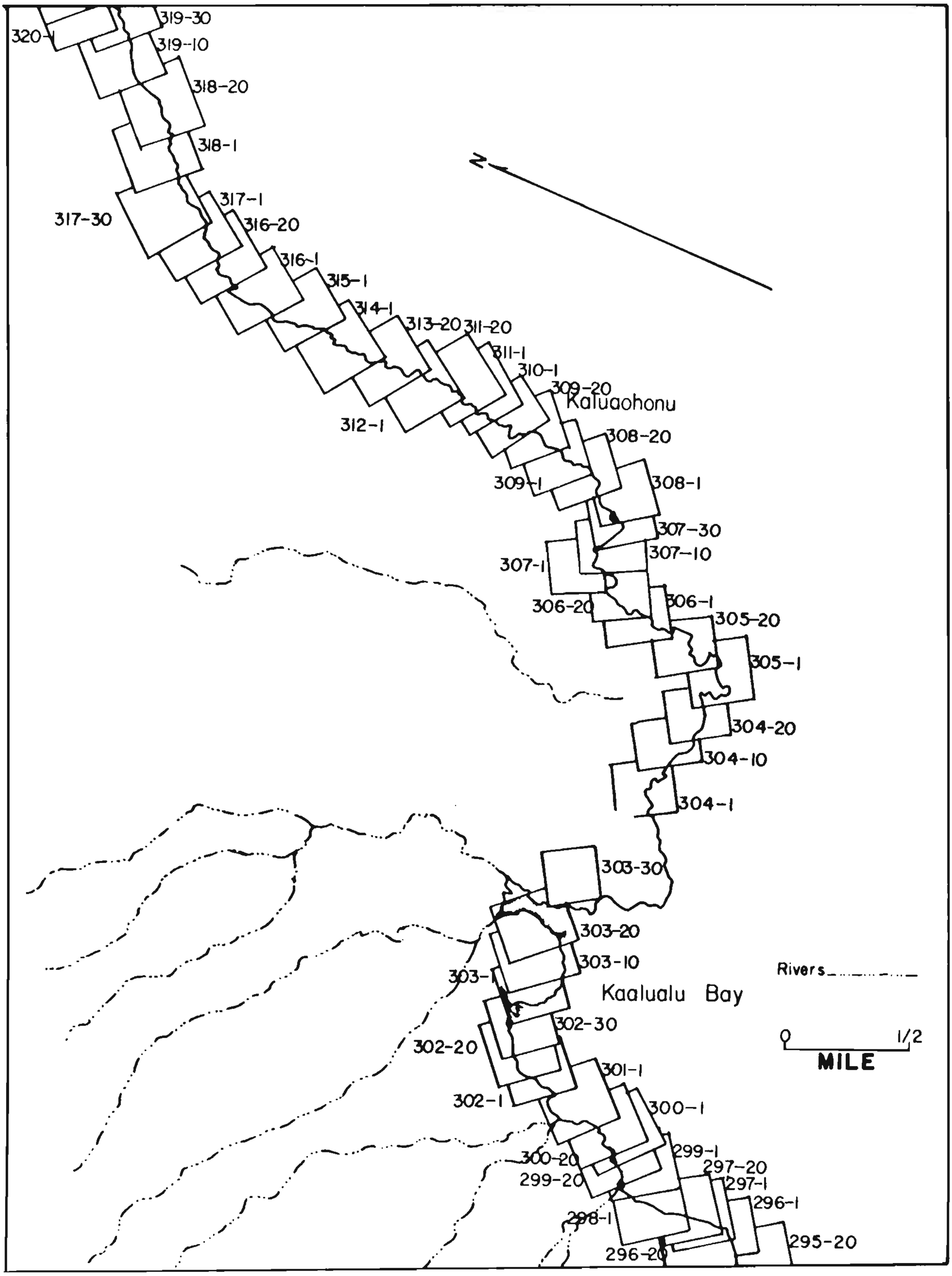
B ------- 1962 U.S. GEOLOGICAL SURVEY MAPS

C ------- 1962 U.S. GEOLOGICAL SURVEY MAPS

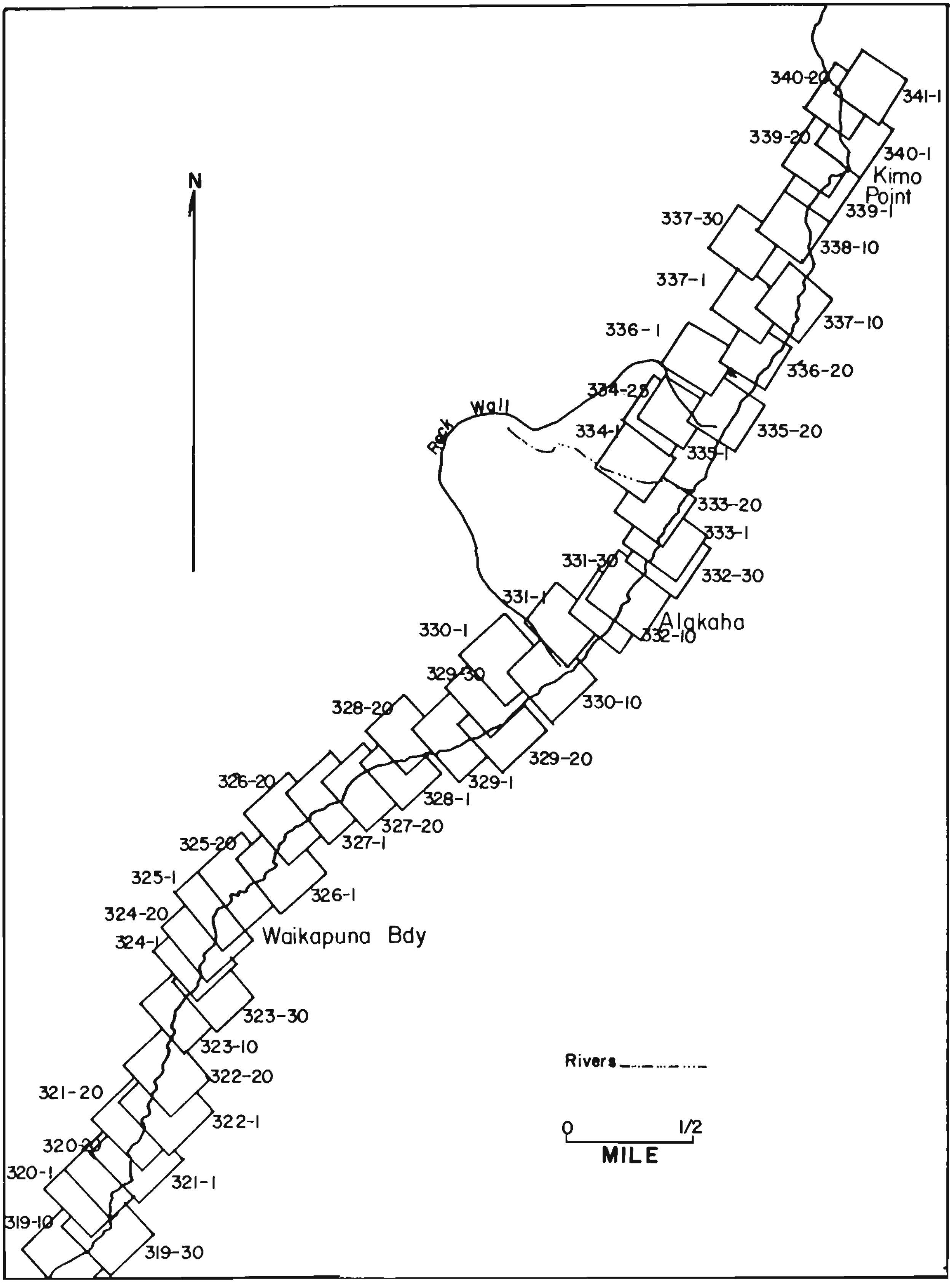
D ------- 1963 LAND CLASSIFICATION PHOTOGAMMETRIC MAPS



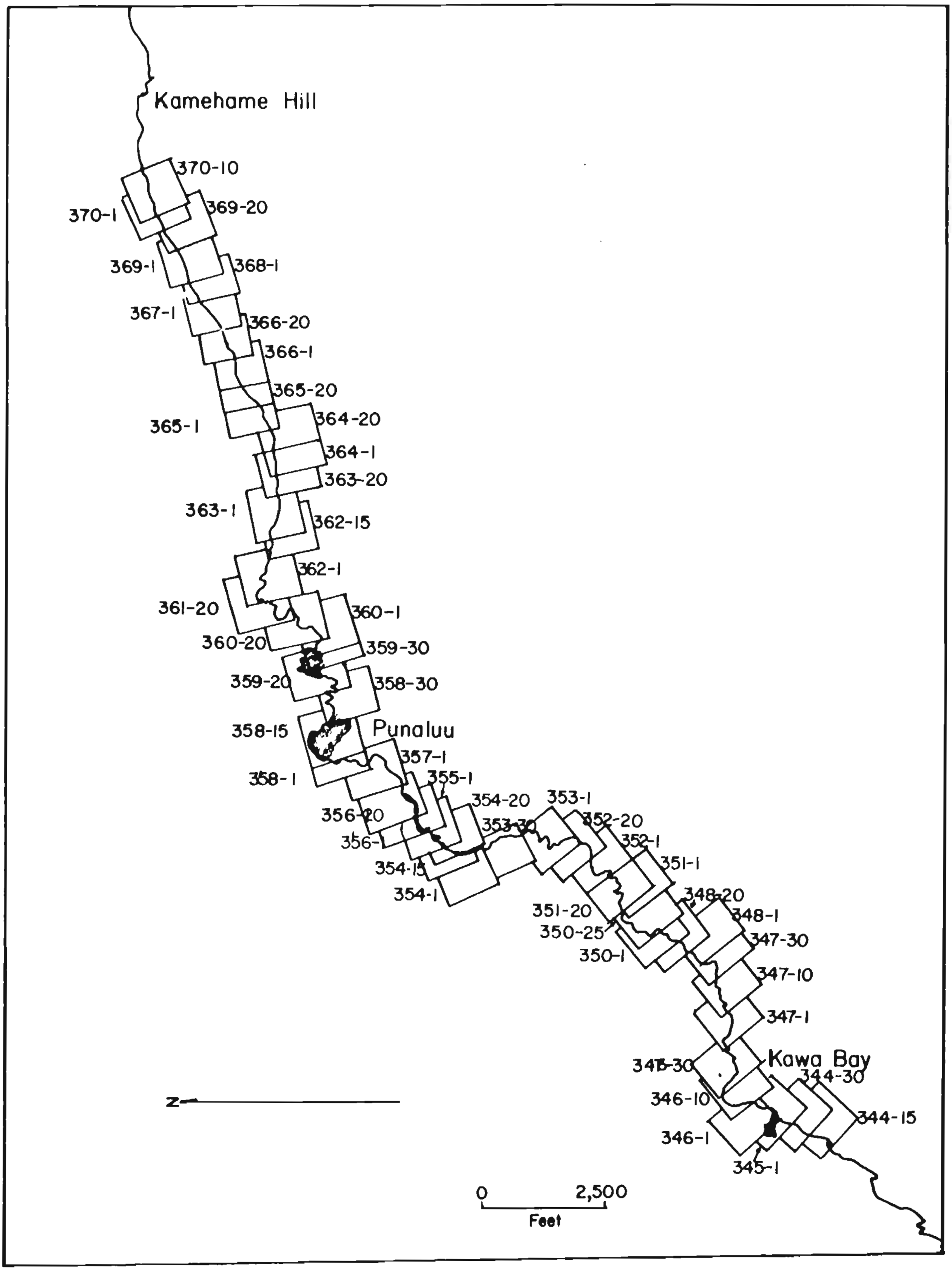
SUB-INDEX MAP: A.



SUB-INDEX MAP: B.



SUB-INDEX MAP: C.



SUB-INDEX MAP: D.