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NEARSHORE CURRENTS AND CORAL REEF ECOLOGY OF THE WEST COAST OF GUAM, MARIANA ISLANDS

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13. ABSTRACT

The Naval Oceanographic Office conducted two field investigations of the currents and coral reef ecology at Guam during winter and summer 1971. These investigations were made to assist in planning the locations of proposed sewer outfalls and to determine the level of sewage treatment required to prevent toxic levels of pollution on the beaches of Guam and ecological damage to the surrounding coral reefs.

Currents were observed with current meters, parachute drogues, and dye injections. Permanent ecological monitoring stations were installed on the reef. At these stations, the sessile organisms were identified and charted, underwater photographs were taken and photomosaics constructed, and various individual organisms were photographed close-up for documentation.

The most favorable locations for a sewer outfall in the Bile Bay area appear to be at Facpi Point and off the extreme southwestern end of Cocos Island.

The outfall at Tantapalo Point appears to be in a more favorable location than the Agat outfall.

The Agana outfall places the effluent close to areas of high recreational use. Eventual replacement of this outfall with one at the Cabras Island location should be considered.

Ague Point appears to be the ideal location for an outfall north of NCS Beach. Dye at this location consistently moved either northerly or directly out to sea.

The established ecological monitoring stations should be monitored periodically to detect the effects of continued military and civilian construction on the island. More stations should be installed to include the locations of proposed outfalls and future construction.

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NEARSHORE CURRENTS AND CORAL REEF ECOLOGY OF THE WEST COAST OF GUAM, MARIANA ISLANDS

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NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON, D.C. 20373

FOREWORD

In response to requests from the Pacific Naval Facilities Engineering Command, the Naval Oceanographic Office conducted two environmental-ecological surveys at Guam in 1971. This report publishes the results of these investigations. It not only provides answers to the problems of the requester but adds considerably to the knowledge of the currents around the island. The ecological study, in turn, provides a basis for monitoring the coral reef habitat for any changes caused by man or nature.

P. V. PURKRABEK
Captain, U.S. Navy
Commander

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I. INTRODUCTION

The Naval Oceanographic Office initiated a study of nearshore currents and coral reef ecology of the island of Guam, Mariana Islands during 1971. The study was designed to assist the Government of Guam and the U.S. Navy in planning the locations of proposed sewer outfalls and in determining the level of sewage treatment required to prevent toxic levels of pollution on the beaches of Guam and ecological damage to the surrounding coral reefs. A nearshore ecological study was initiated to provide an ecological baseline whereby changes in the coral reef communities can be detected and the causes determined, whether natural or manmade.

A. Approach

Two field investigations were scheduled to be conducted during the maximums of the summer and winter climatic conditions. The winter survey was made during the period 4 February through 3 March, and the summer survey was conducted from 19 August through 15 September.

Nearshore currents were investigated through the use of arrayed and bottom-mounted current meters and drogue and dye tracking. A coral reef ecological investigation was initiated in the vicinity of present and proposed ocean outfalls and at other selected sites. A general ecological investigation of the coral reefs was made during the initial (winter) survey. During the summer survey, eight ecological survey areas (quadrats) were established. Figure 1 shows a summary of the work conducted during the two field investigations.

B. Previous Investigations

Nearshore currents in the vicinity of Agat and Agana were briefly investigated by the Pacific Islands Engineers (1951) during 1946 and 1949 with the use of surface drifters. Their studies, which covered 1- and 2-day periods during the months of February, March, April, May, June, July, August, and September, revealed westerly currents at both locations.

The Marine Laboratory of the University of Guam conducted a detailed study of the Agana outfall from September 1969 to September 1970 (Jones and Randall, 1971). Their investigations included a currents study of Agana Bay and the Agana reef flat and an ecological study in the immediate vicinity of the Agana outfall. Their current meter and drogue data indicated a predominance of southwest currents that varied in relation to the tidal phase.

Tracey et al. (1964) reviewed the literature on the scientific studies of Guam. The major emphasis of these studies was on terrestrial and marine geology.

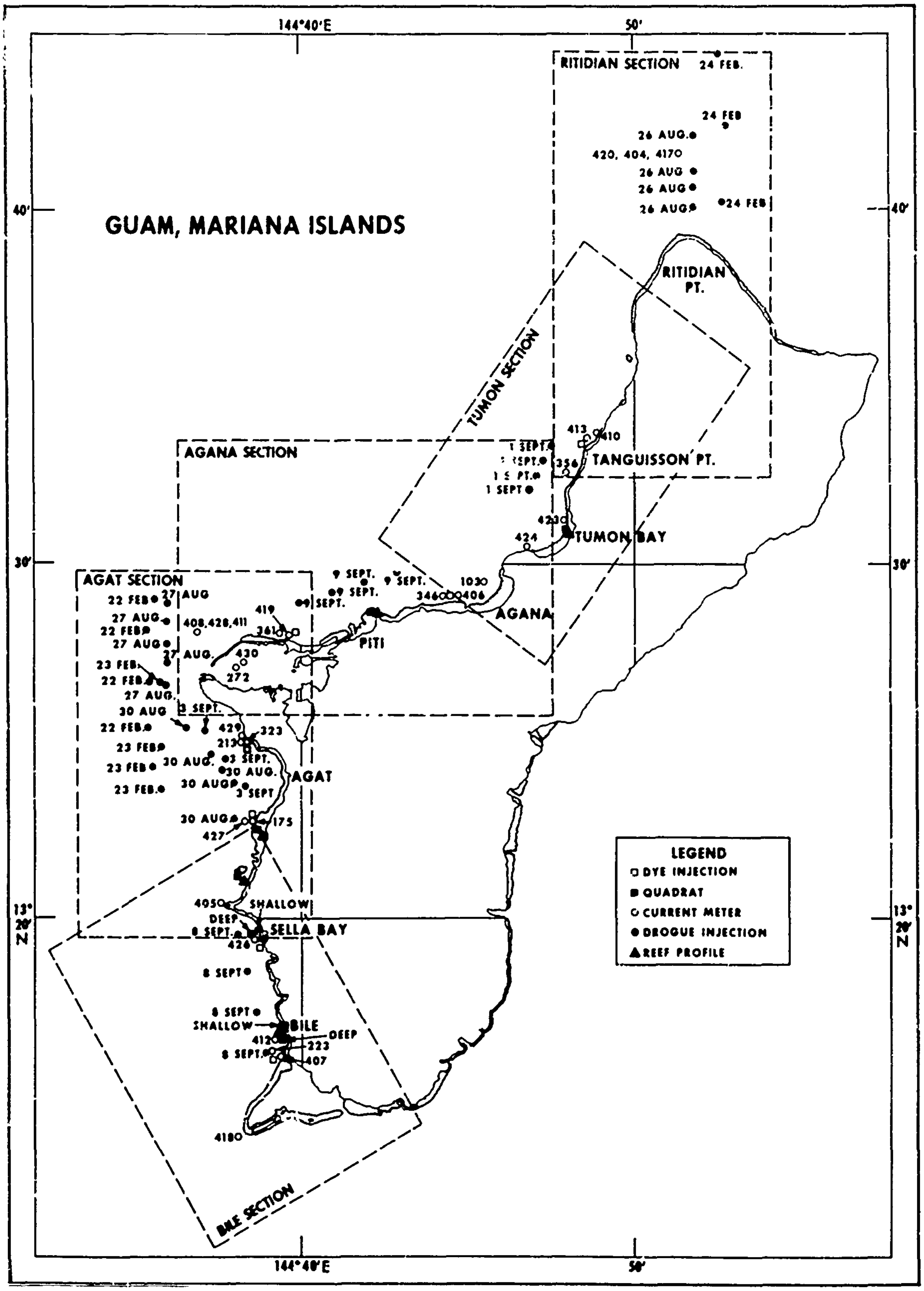


Figure 1. Summary of survey operations conducted during two field investigations February - March 1971 and August - September 1971.

Coastal marine geological studies of Guam that have ecological application have been conducted by Johnson (1964), Emery (1962), and Tracey et al. (op. cit.). The paper by Tracey et al. presents a brief discussion of the western fringing reefs of Guam.

Of immense value to the ecological portion of this study was the work done by Cloud (1959) at Saipan, Mariana Islands; an island environmentally similar to Guam. Cloud presents a detailed description of the reef and discusses the shoal-water ecology.

II. METHODS AND PROCEDURES

A. Currents

To determine the probable route of pollutants, water currents along the coast of Guam were observed using dye injections, parachute drogues, and recording current meters.

At selected areas along the coast, rhodamine (types W.T. and B) and fluorescein dyes were injected by either wading to the outer reef flat and dumping liquid dye or by dropping solidified dye cake arrays from a helicopter. The pattern of dye dispersal was then photographed and charted from a helicopter to determine surface water transport for the period during which the dye patches were observed. Tidal and meteorological data were obtained for the dye dispersal periods to discover their influence on surface water movement.

Parachute drogues were deployed at various locations to determine surface water movements. Each drogue consisted of an 8-foot (2.4-meter) aluminum pole (with flag) inserted through a styrofoam float. An 8-foot (2.4-meter) diameter parachute was tethered at 5 feet (1.5 meters). The drogues were tracked by radar range and bearing fixes. Richardson-type, film-recording current meters were installed on bottom stands and deep water arrays. These meters used a Savonius rotor for speed sensing and a vane that aligns with the current for direction. The data obtained from the meters were coded on photographic film and were decoded and placed on magnetic tape for computer processing. The computer provided a separation of each current vector into north and east components and an average of the 10 vectors obtained during each 50-second sampling period. The data were then machine plotted to provide a graphic display of all the data for the study period. Machine plots included current speed and direction histograms and frame number versus speed and direction. Progressive vector diagrams were constructed for selected data segments. Table 1 summarizes the current meter implants and presents maximum and modal speeds for each meter.

Table I. Summary of current meter installations at Guam in 1971.

Station	Location Lat. (N)	Location Long. (E)	Meter Number	Data Period Start (LCT)	Data Period End (LCT)	Method	Water Depth (Ft.)	Meter Depth (Ft.)	Speed Recorded (knots) Maximum	Speed Recorded (knots) Modal
Cocos	13°13'50"	144°38'10"	418	1145,28 Aug	1325, 9 Sep	Bottom Stand	95	90	0.65	0.03
Merizo	13°16'15"	144°39'25"	407	1230,21 Aug	1250, 9 Sep	Bottom Stand	40	35	0.77	0.09
Bile	13°16'36"	144°39'06"	223	1110, 7 Feb	1330, 3 Mar	Buoyed	200	50	0.30	0.06
Bile	13°16'45"	144°39'30"	412	1318,21 Aug	1108, 9 Sep	Bottom Stand	50	45	0.23	0.04
Sella	13°19'35"	144°38'40"	426	1247,28 Aug	1037, 9 Sep	Bottom Stand	50	45	0.40	0.05
Facpi	13°20'30"	144°37'45"	405	1430,21 Aug	1020, 9 Sep	Bottom Stand	55	50	0.99	0.11
Agat	13°23'18"	144°38'30"	175	1100,11 Feb	1310, 2 Mar	Bottom Stand	35	30	0.19	0.00
Agat	13°23'35"	144°38'50"	427	1520,21 Aug	0916, 9 Sep	Bottom Stand	49	44	0.32	0.04
Tantapalo	13°24'57"	144°38'25"	323	1130,11 Feb	1350, 2 Mar	Bottom Stand	65	60	0.34	0.03
Tantapalo	13°25'00"	144°38'18"	213	1745, 7 Feb	1945, 9 Feb	Buoyed	270	50	1.00	0.12
Tantapalo	13°24'50"	144°38'25"	429	1015,22 Aug	0900, 9 Sep	Bottom Stand	65	60	0.55	0.05
Apra	13°27'00"	144°38'00"	272	1600, 5 Feb	0600, 8 Feb	Buoyed	125	110	0.50	0.05
Apra	13°27'10"	144°38'40"	430	1415,23 Aug	0255,26 Sep	Bottom Stand	130	125	0.08	0.00
Orote	13°28'20"	144°37'09"	408	1550, 3 Sep	1350,14 Sep	Buoyed	2,775	539	0.89	0.14
Orote	13°28'20"	144°37'09"	428	1310, 3 Sep	1350,14 Sep	Buoyed	2,775	1,349	0.64	0.07
Orote	13°28'20"	144°37'09"	411	1320, 3 Sep	1510,14 Sep	Buoyed	2,775	2,740	0.33	0.07
Cabras	13°28'00"	144°39'24"	361	0010,25 Feb	1430, 2 Mar	Bottom Stand	40	35	0.59	0.25
Cabras	13°28'05"	144°39'45"	419	1120,22 Aug	1110,12 Sep	Bottom Stand	55	50	0.29	0.08
Agana	13°29'06"	144°45'30"	346	0800,16 Feb	1350,19 Feb	Bottom Stand	35	30	0.88	0.15
Agana	13°29'12"	144°45'30"	103	1610, 6 Feb	1525, 2 Mar	Buoyed	300	50	0.50	0.05
Agana	13°29'15"	144°44'40"	406	1210,22 Aug	1230,12 Sep	Bottom Stand	65	60	0.36	0.10
Ypao	13°30'40"	144°46'55"	424	1110,24 Aug	1230,12 Sep	Bottom Stand	120	115	0.27	0.06
Fafai	13°31'20"	144°47'50"	423	1456,22 Aug	1320,12 Sep	Bottom Stand	100	95	0.35	0.00
Tanguisson	13°32'36"	144°47'48"	356	1305, 6 Feb	1145,12 Sep	Buoyed	300	50	0.74	0.07
Tanguisson	13°33'25"	144°48'25"	413	1410,22 Aug	2020,22 Aug	Bottom Stand	50	45	0.27	0.13
Hilaan	13°33'50"	144°48'50"	410	1330,24 Aug	1720,12 Sep	Bottom Stand	75	70	0.40	0.04
Ritidian	13°41'42"	144°51'38"	420	1017,25 Aug	1247,13 Sep	Buoyed	1,200	89	0.99	0.25
Ritidian	13°41'42"	144°51'38"	404	1120,25 Aug	1410,13 Sep	Buoyed	1,200	200	0.92	0.15
Ritidian	13°41'42"	144°51'38"	417	1510,25 Aug	1430,13 Sep	Buoyed	1,200	1,165	1.97	0.56

B. Coral Reef Ecology

During the winter survey, preliminary ecological data were collected in the vicinity of present and proposed sewage outfalls and at Sella Bay. Utilizing snorkling and SCUBA apparatus, oceanographers extensively photographed and described eight reef areas. The results of these efforts are presented in the interim report of the initial field survey (Naval Oceanographic Office, 1971).

Based on analysis of the data from the winter survey, eight locations were selected for installation of permanent ecological monitoring stations (quadrats). These quadrats were selected to be representative of various reef environments in areas of expected pollution as well as control areas not likely to be subjected to pollution.

Each quadrat is 10 meters (32.8 feet) square and is divided into nine smaller squares, 3.3 meters (10.8 feet) to a side. Concrete blocks permanently mark the corners of the quadrat.

The sessile organisms located within the quadrat were identified and charted on underwater slates. Using underwater photogrammetric techniques, the entire quadrat was photographed and a photomosaic constructed. From the underwater chart and the photomosaic, a chart of each quadrat was constructed showing the distribution and types of bottom organisms.

In addition, various individual organisms within each quadrat were selected for close-up photographic documentation.

III. RESULTS AND DISCUSSION

A. Currents

Guam lies directly in the path of the North Equatorial Current, which sets westward across the central Pacific between 8° and 15° N. The average surface speed ranges from 0.3 to 0.8 knot (.15 to .40 m/sec), but speeds of 2 knots (1.0 m/sec) can be reached during strong winds. Surface current directions of the North Equatorial Current vary from the NW quadrant during winter to the SW quadrant during summer. The presence of this major ocean current sweeping past the island is undoubtedly an important factor controlling nearshore currents, especially along the east coast of Guam and at its northern and southern extremities.

Tides at Guam are semidiurnal with considerable diurnal inequality. The mean range is 1.7 feet (.51 meter) and the diurnal range (difference in height between mean higher high water and mean lower low water) is 2.4 feet (.72 meter). Tides are a major current producing force especially in shallow water and in restricted channels or straits. Because of the large diurnal inequality, the differences in heights between highs and lows must be considered as well as the times of highs and lows when comparing tides and currents at Guam.

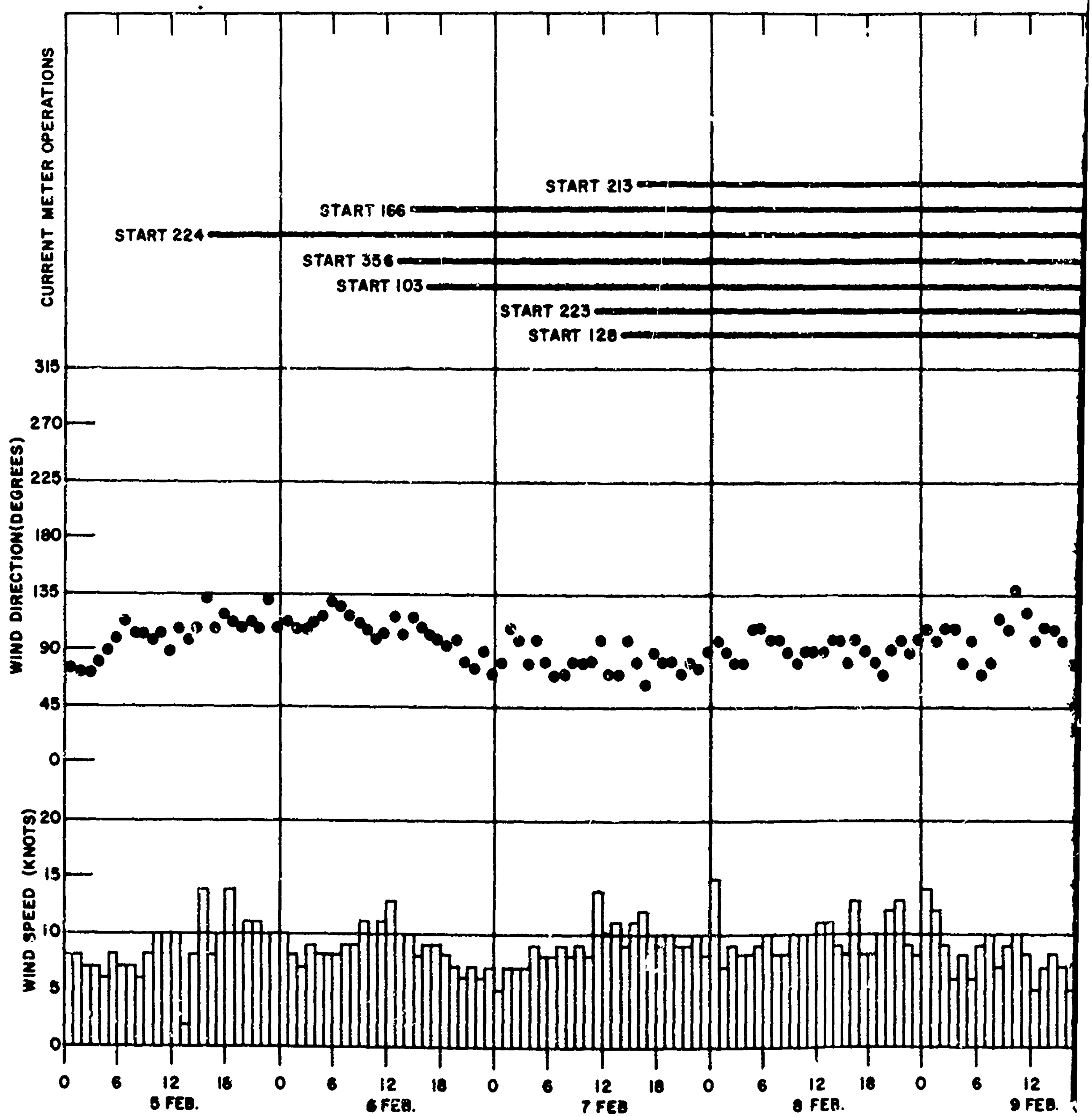
Winds are an important factor influencing surface currents. Strong winds tend to mask the effects of other current-producing forces. Guam lies in the belt of northeast tradewinds. Tradewind flow is dominant during all seasons, but it is especially pronounced during the winter season (January through May). During the summer season (July through October) the effect of the tradewinds is somewhat diminished, and winds from every direction are not uncommon. Typhoons are most frequent during the summer season, and although they are common in the vicinity of Guam, none affected the area during the periods of data collection. Figure 2 shows the speed and direction of winds observed at the Naval Air Station, Agana during the periods of the two field surveys. Figure 3 presents a comparison of wind roses for historical data to wind roses of data for the survey periods. This comparison reveals considerable similarity between the historical data and observed winds during 1971.

To simplify the presentation and discussion of current data, the west coast of Guam has been divided into five sections as shown in figure 1.

1. Bile Section

This section includes the southern tip of the island to as far north as Facpi Point. The coastline between Facpi Point and Cocos Lagoon is well sheltered from the dominant northeast tradewinds and from the direct influence of the North Equatorial Current. As might be expected, the current meter data and dye observations show that, with the exception of the southernmost meter, currents in the section were primarily controlled by tides and local winds.

A single current meter (#223) was installed in this section during the winter survey. It was placed at the 50-foot (15.2-meter) depth on an array in 200 feet (61 meters) of water off Bile Bay, a proposed site for an ocean outfall. Figure 4 presents current speed and direction histograms from this meter. The current direction histogram portrays a dominant easterly flow. An analysis of this easterly flow is illustrated in figure 5, which portrays a short segment of the current meter data in the form of a progressive vector diagram. This diagram was constructed by aligning hourly current vectors so that the origin of each vector is at the end of the previous vector. A progressive vector diagram can be regarded as a chart showing the path of a water particle as if it were continuously subject to the current at the meter location. The actual situation may be much different, as the water particle is subject to different and unknown currents as soon as it leaves the meter location.


CURRENT METER OPERATIONS
START 213
START 166
START 224
START 356
START 103
START 223
START 128
WIND DIRECTION (DEGREES)
315
270
225
180
135
90
45
0
WIND SPEED (KNOTS)
20
15
10
5
0
0 6 12 18 0 6 12 18 0 6 12 18 0 6 12 18 0 6 12
5 FEB.
6 FEB.
7 FEB
8 FEB.
9 FEB.

B

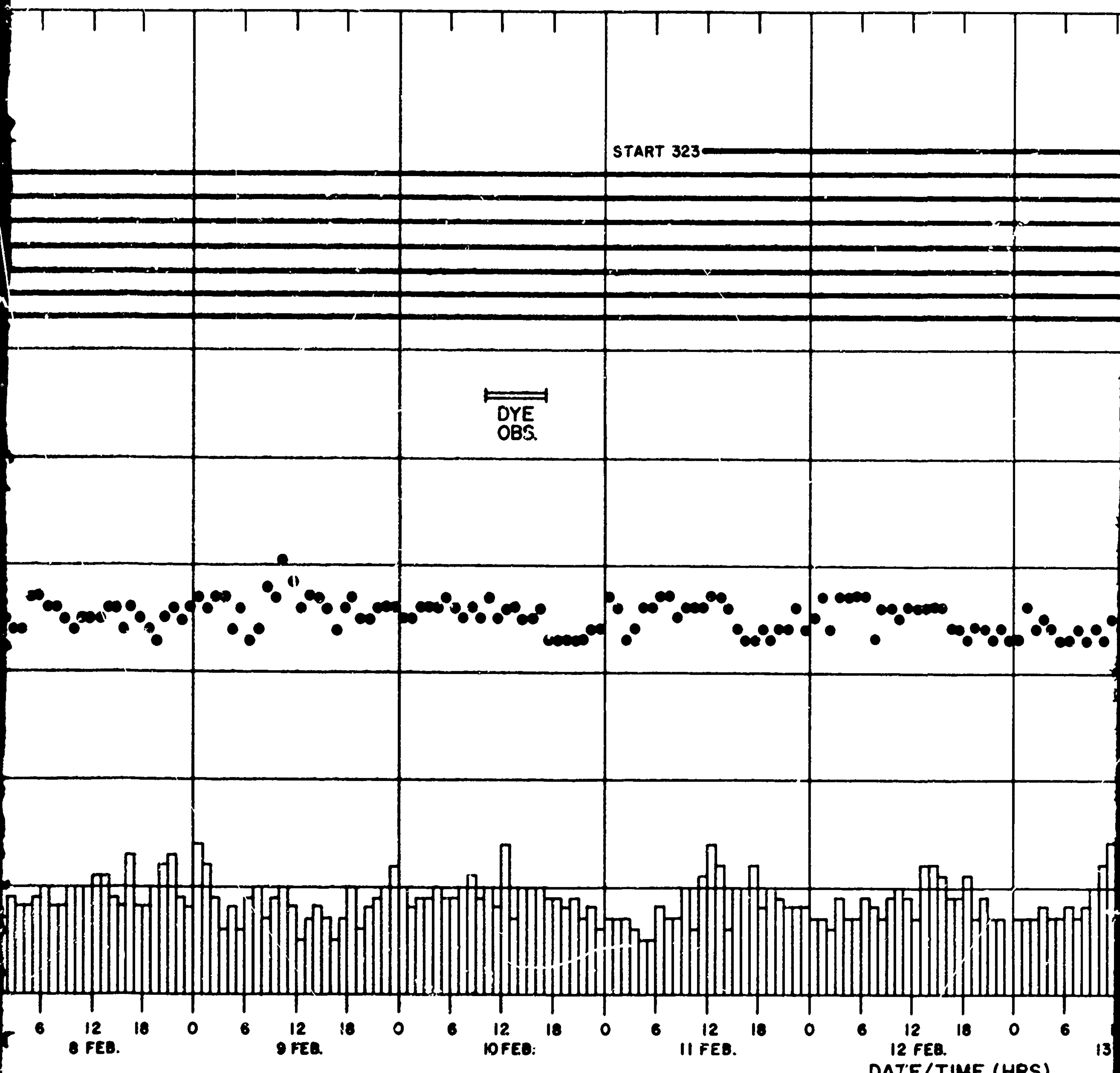
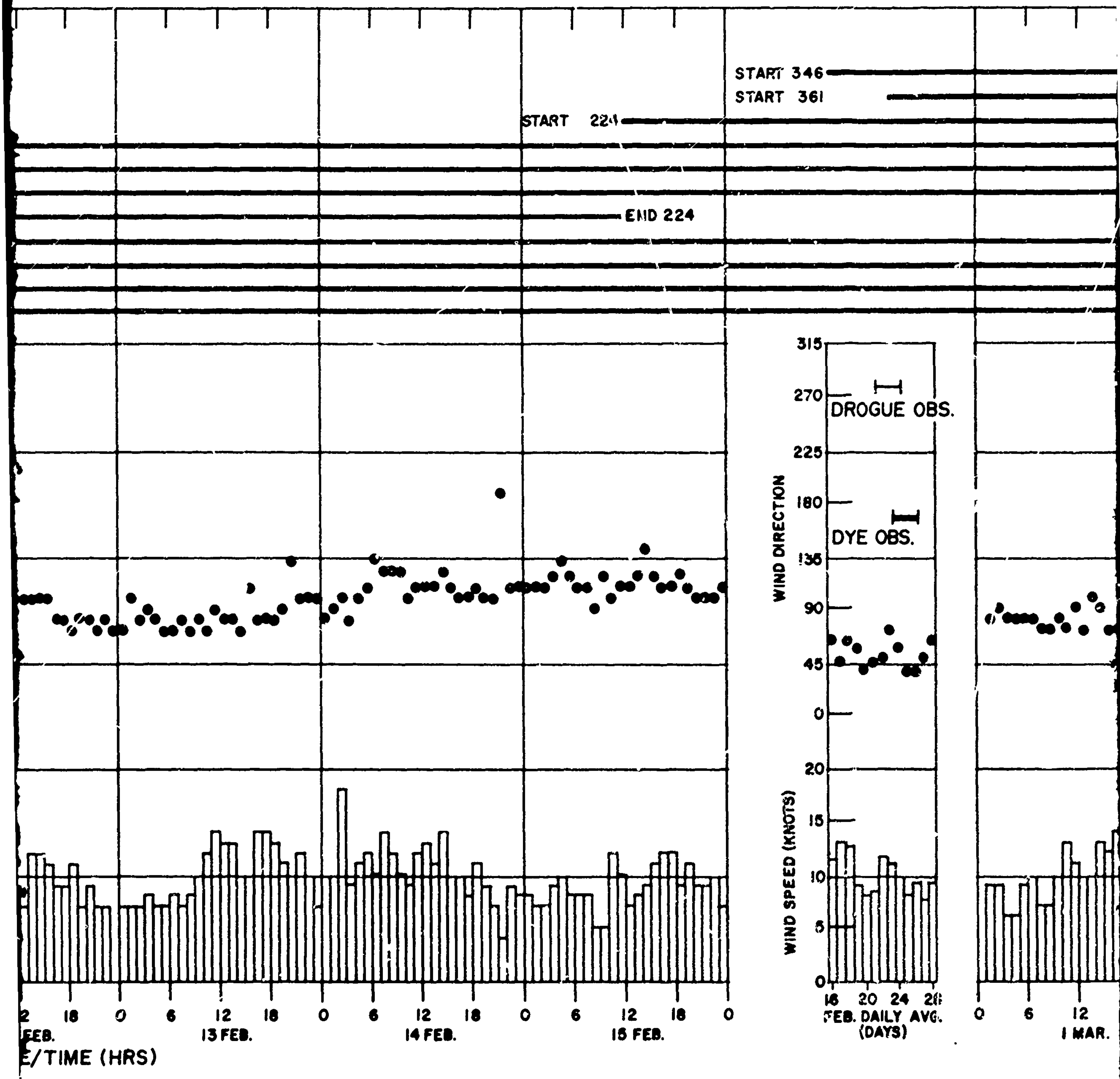
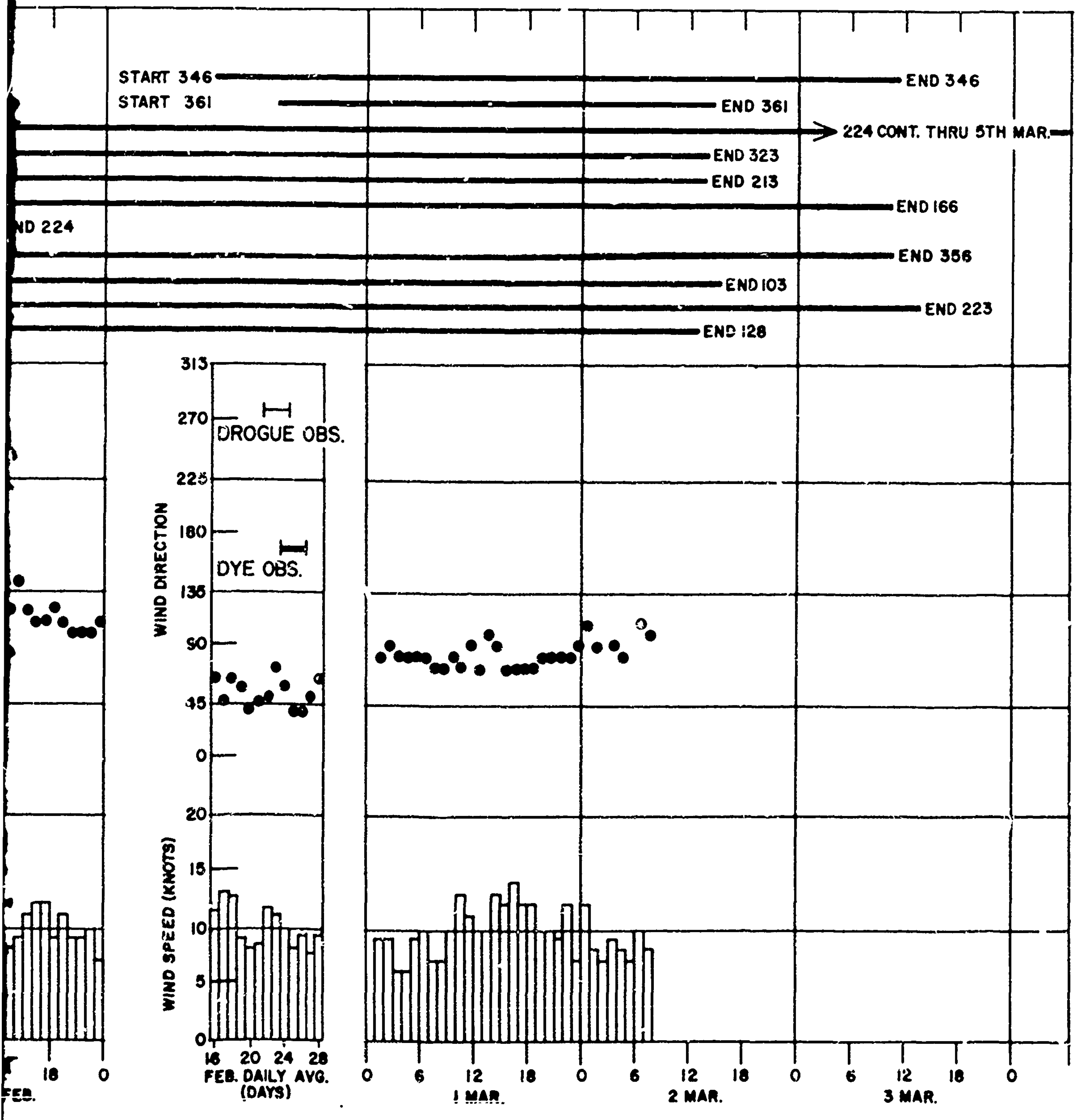


Figure 2. Speed and direction of winds observed at the Naval Air Stat
periods and dye and drogue observation dates for the two fi

C



t the Naval Air Station, Agana showing current meter implant
dates for the two field investigation periods.


START 346
START 361
END 346
END 361
224 CONT. THRU 5TH MAR.
END 323
END 213
END 166
ND 224
END 356
END 103
END 223
END 128
DROGUE OBS.
DYE OBS.
WIND DIRECTION
313
270
225
180
135
90
45
0
WIND SPEED (KNOTS)
20
15
10
5
0
16 20 24 28
FEB. DAILY AVG.
(DAYS)
18 0
FEB.
0 6 12 18 0 6 12 18 0 6 12 18 0
1 MAR.
2 MAR.
3 MAR.

A

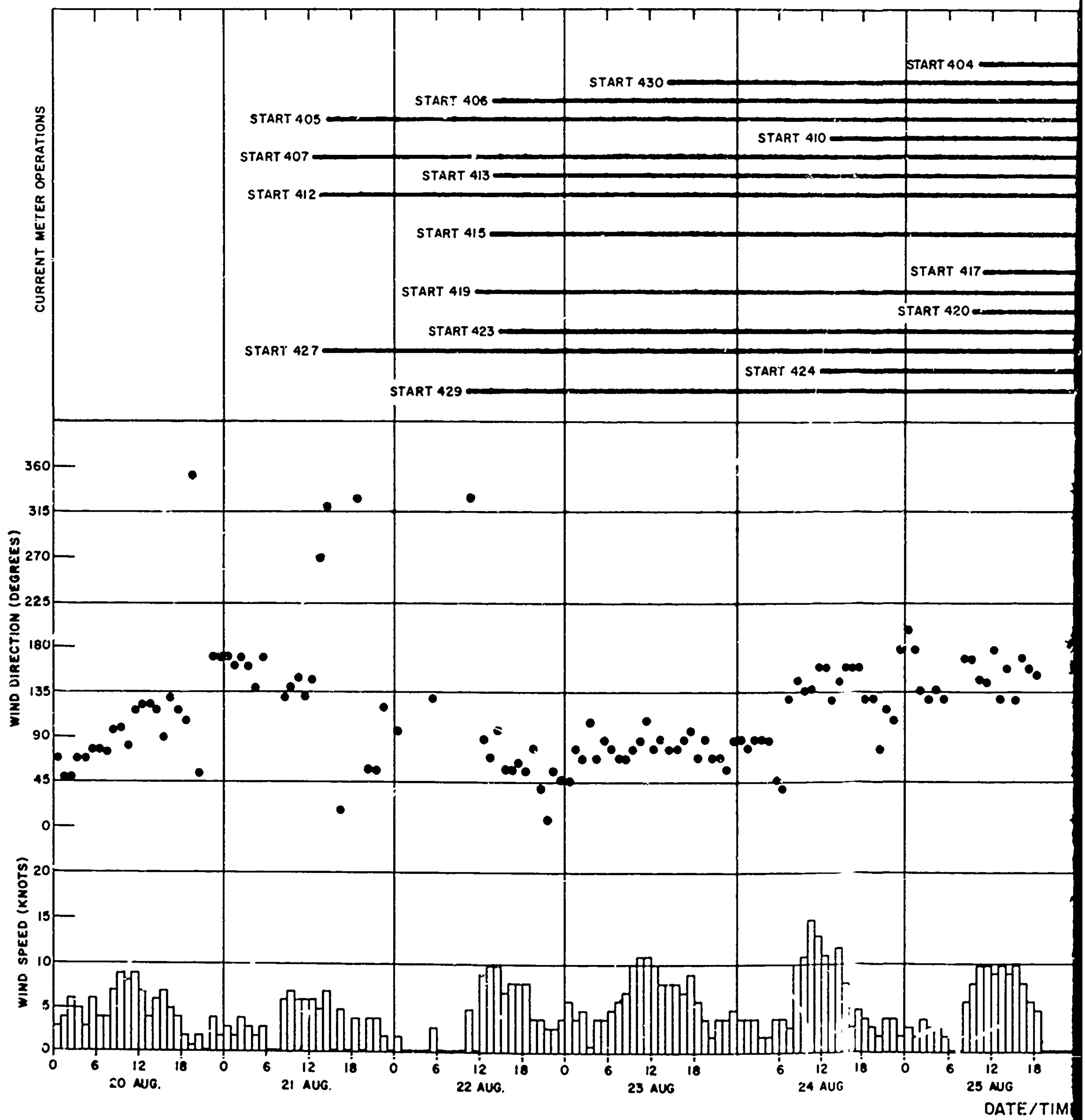


Figure 2. C

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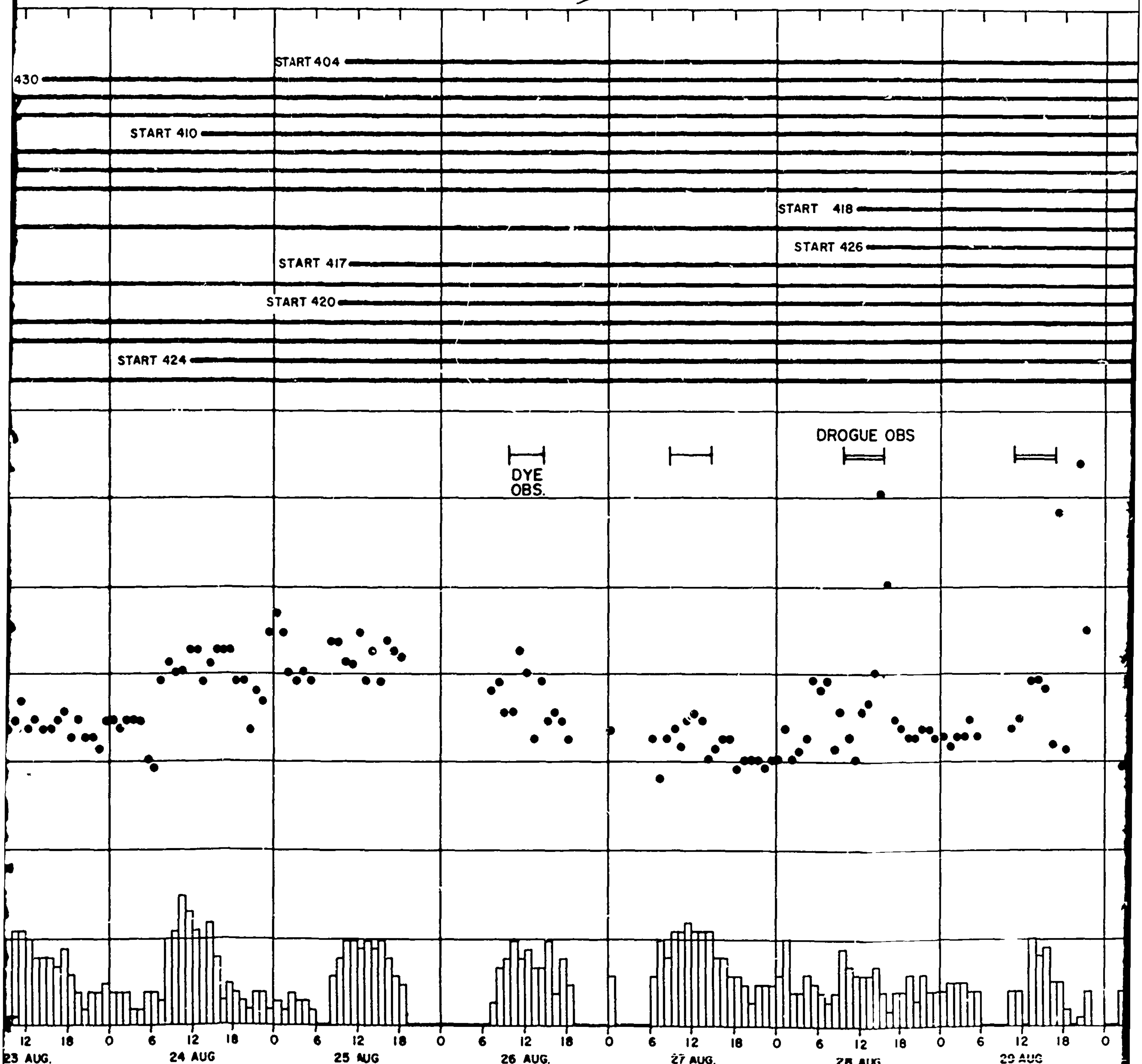
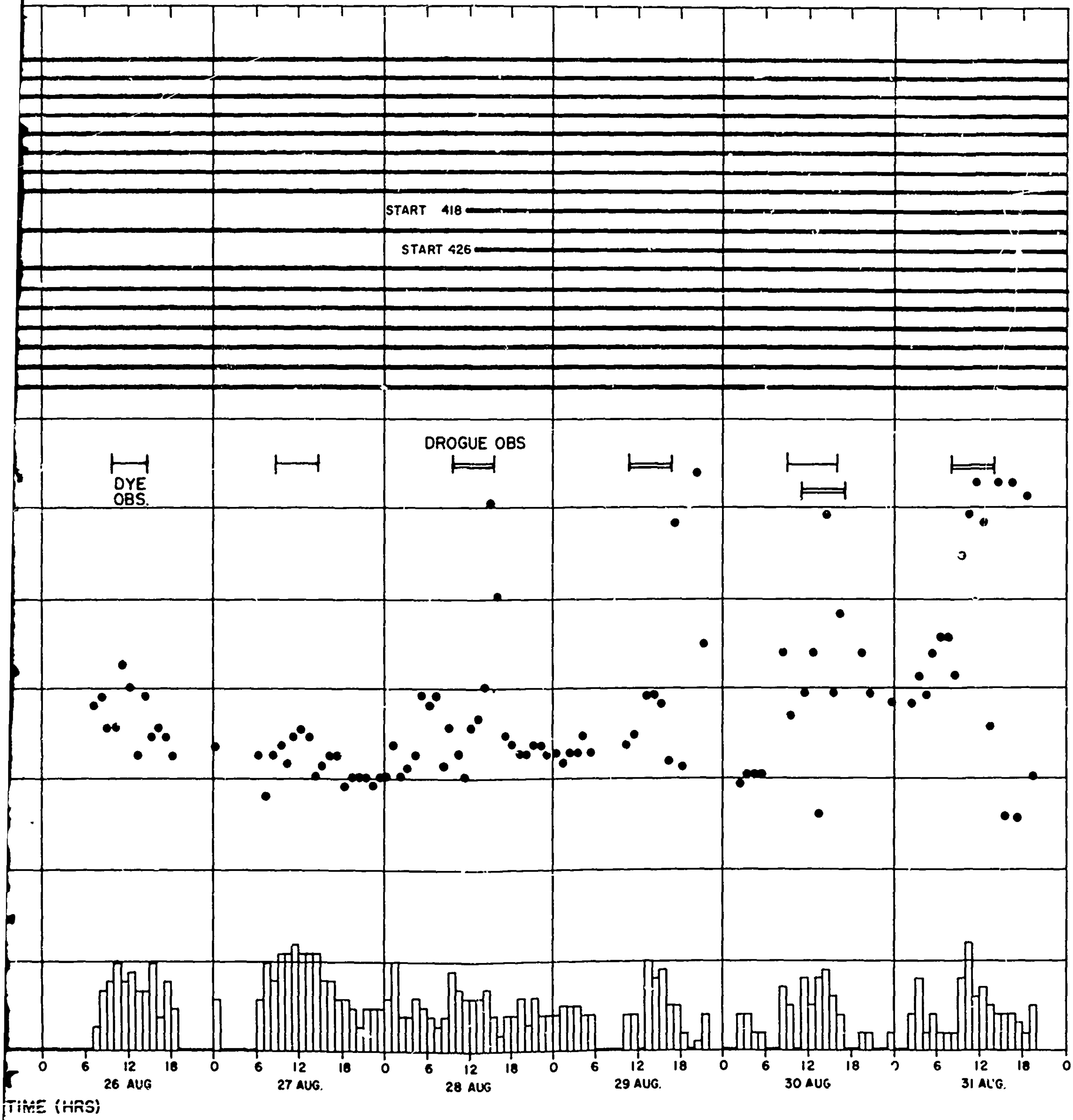


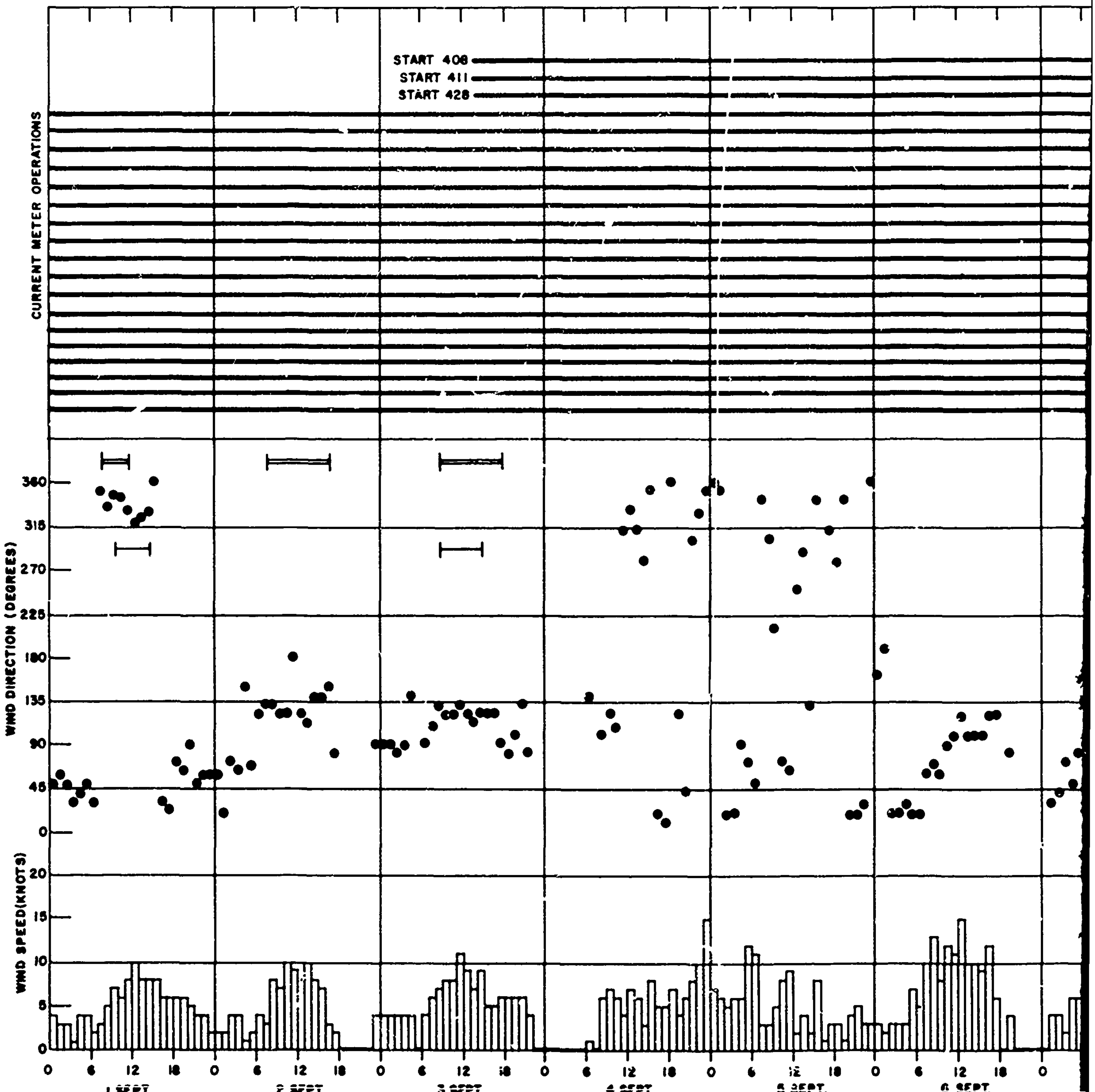
Figure 2. Continued



START 418
START 426
DROGUE OBS
DYE OBS.
0 6 12 18 0 6 12 18 0 6 12 18 0 6 12 18 0 6 12 18 0 6 12 18 0
26 AUG
27 AUG.
28 AUG
29 AUG.
30 AUG
31 AUG.
TIME (HRS)

Continued

A


START 408
START 411
START 428
CURRENT METER OPERATIONS
WIND DIRECTION (DEGREES)
360
315
270
225
180
135
90
45
0
WIND SPEED (KNOTS)
20
15
10
5
0
0 6 12 18 0 6 12 18 0 6 12 18 0 6 12 18 0 6 12 18 0 6 12 18 0
1 SEPT.
2 SEPT.
3 SEPT.
4 SEPT.
5 SEPT.
6 SEPT.

B

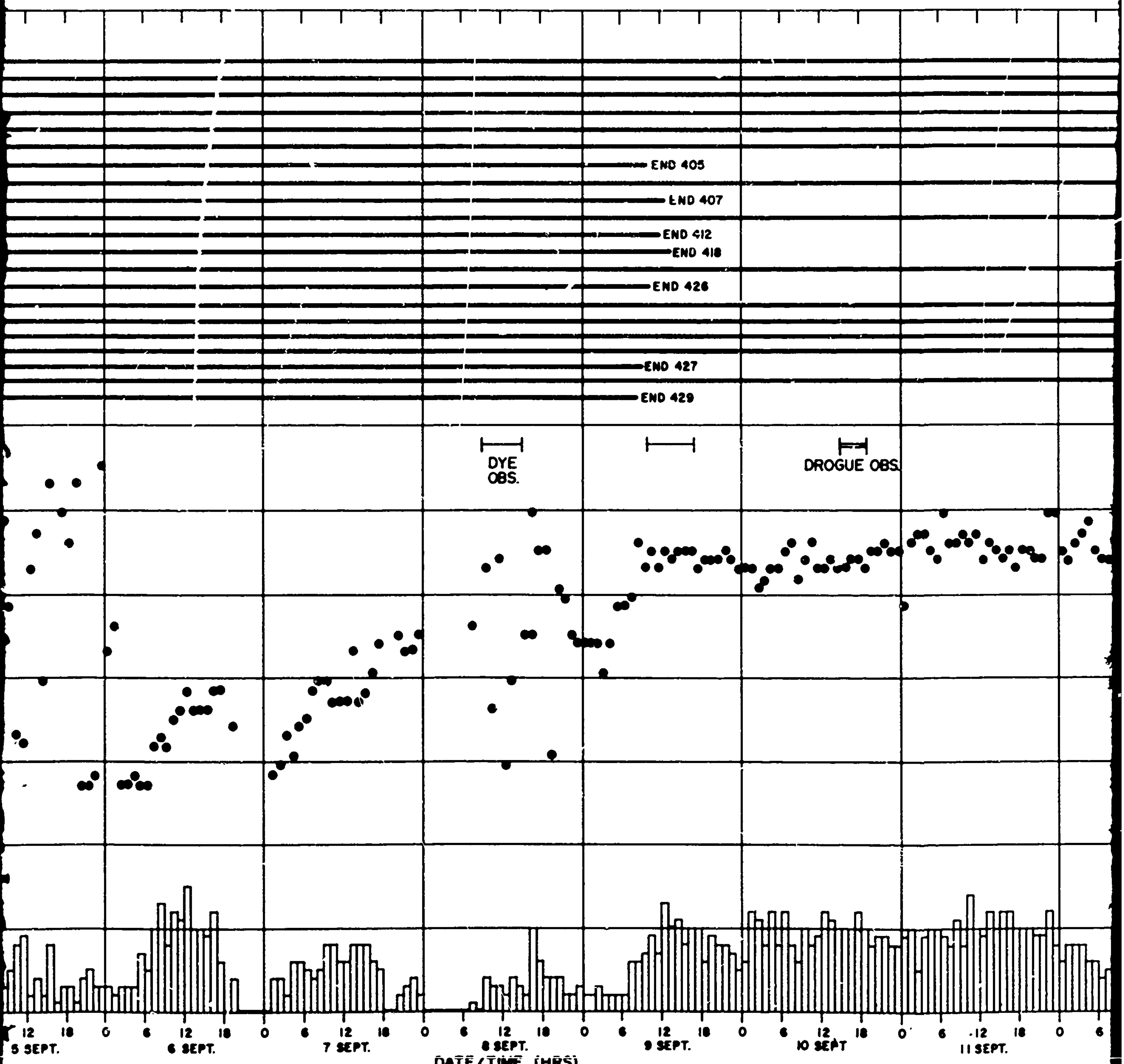


Figure 2. Continued

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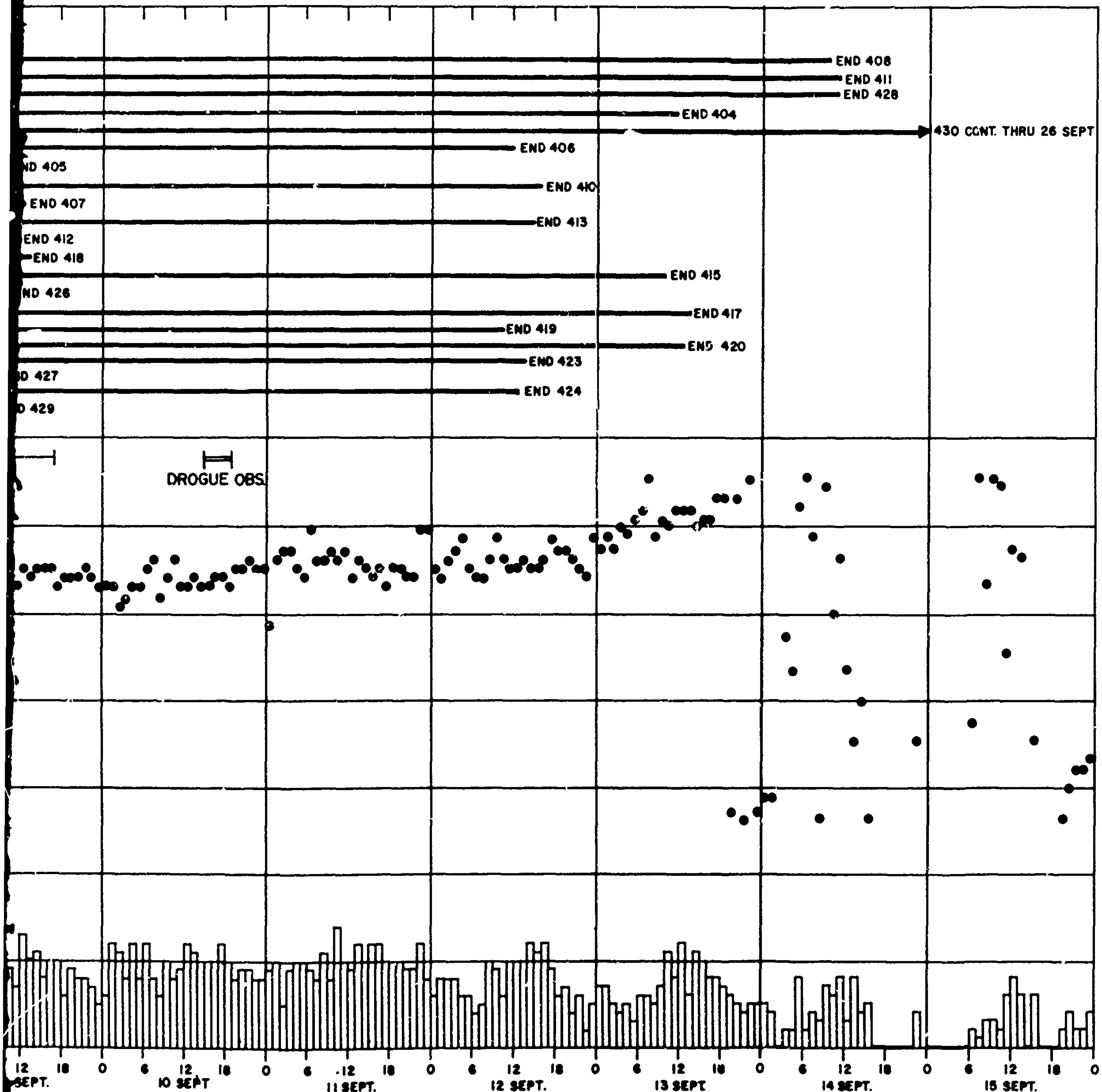

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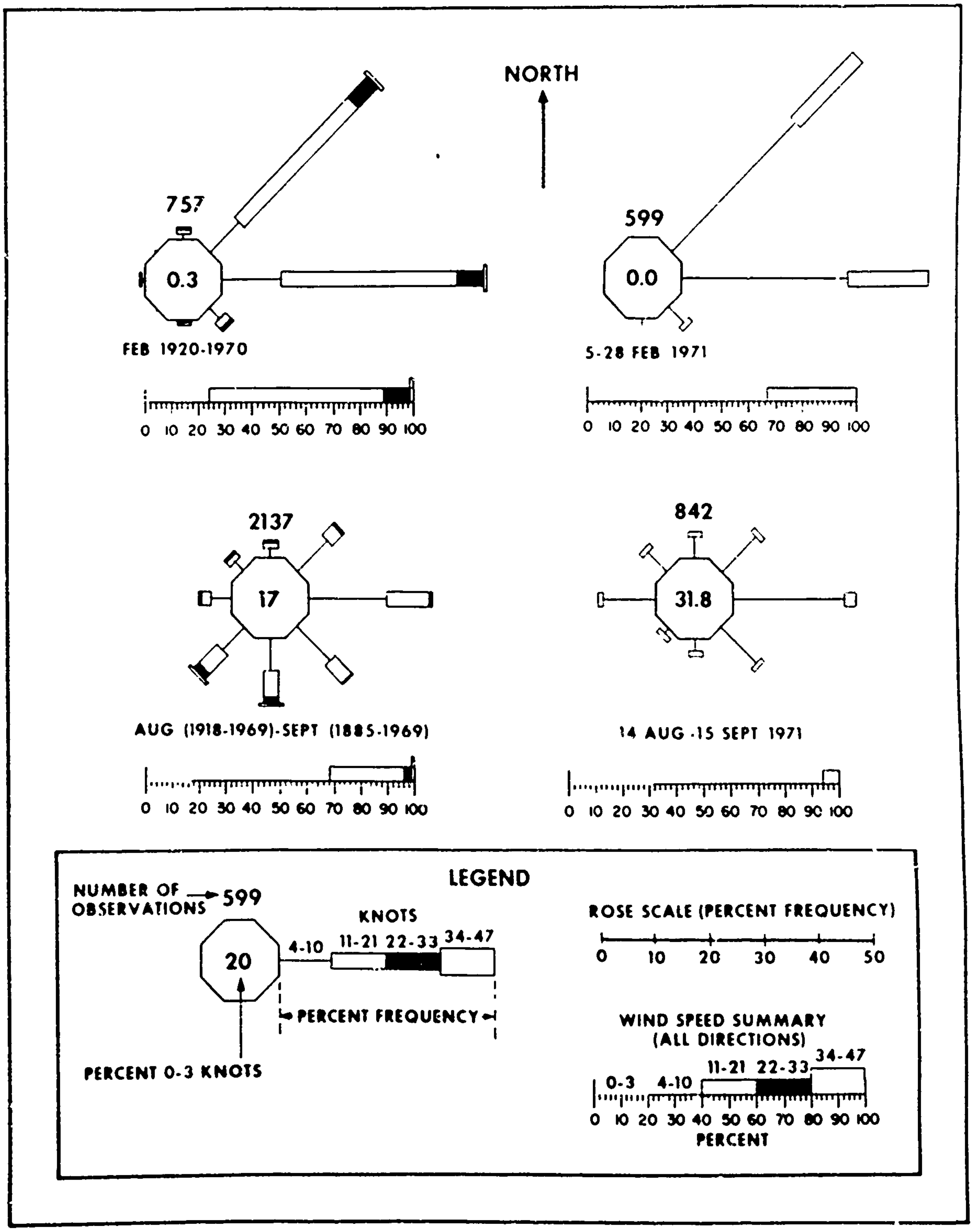


Figure 3. Wind roses of historical data and 1971 data.

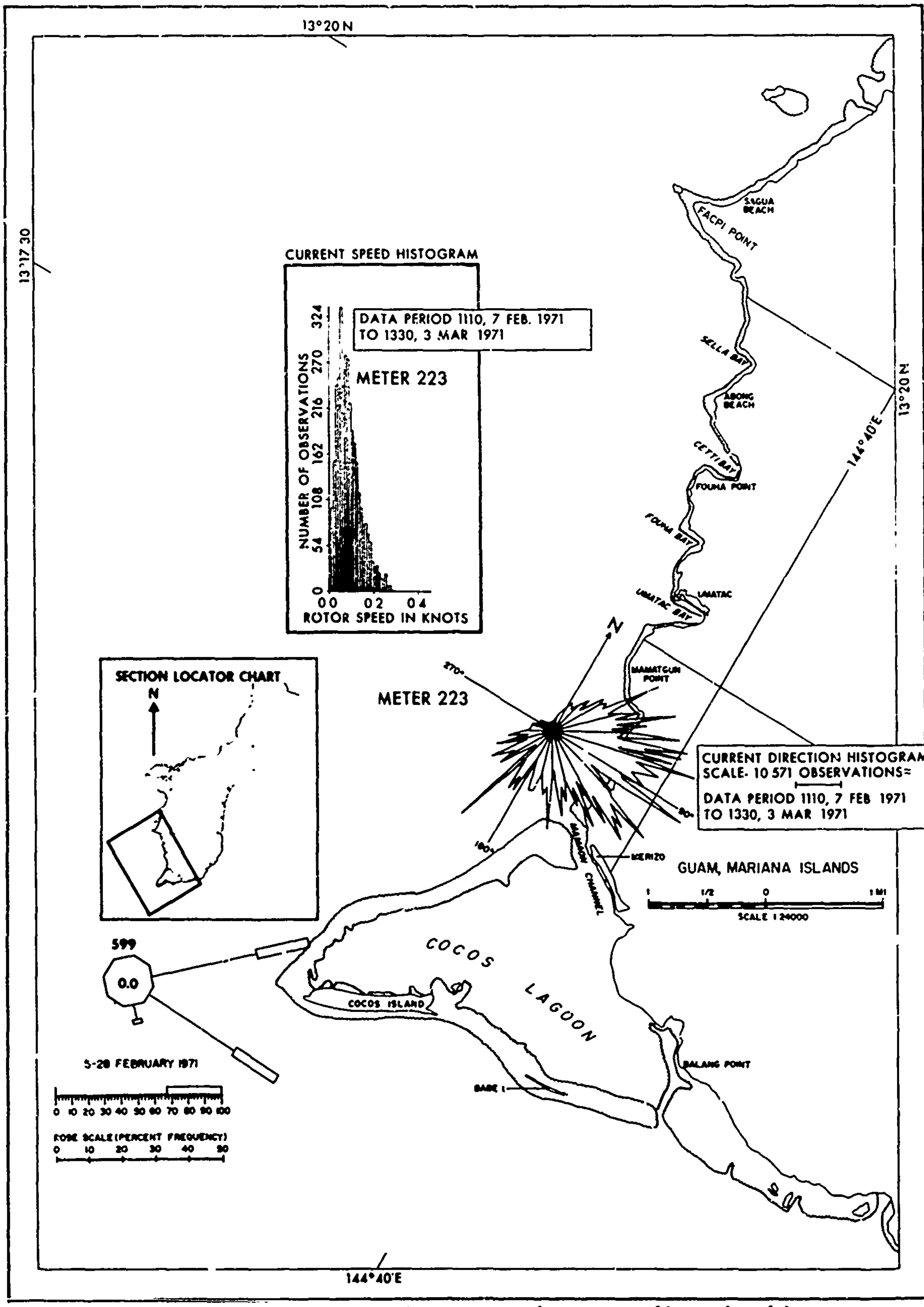


Figure 4. Current speed histogram and current direction histogram for the Bile Section in winter including meter #223 and a wind rose for the data period.

Figure 6 shows that currents at meter #223 progressed primarily in a series of northeast and southeast excursions. This can be interpreted as a steady easterly flow superimposed on a periodic north-south current. The exact character and origin of the periodic current is indefinite. Major changes in direction occurred at 4- to 8-hour intervals similarly to the tidal changes; however, correlation of these changes with tidal highs and lows is poor. The periodic current probably results from a combination of tidal and local meteorological effects. The steady easterly drift is interpreted as part of an eddy current created by the strong flow through Mamaon Channel. The presence of a similar eddy on the south side of the channel is evident from the dye dispersal study conducted on 3 September (fig. 20).

Five current meters were installed in this section during the summer survey. Their locations and the resultant data are plotted in figure 7. Meter #412 was installed in Bile Bay on a bottom stand in 50 feet (15.2 meters) of water. The meter recorded very slight currents ranging in speed from 0 to 0.23 knot (0 to .115 m/sec). The greatest number of observations was of currents flowing north and south-southwest. Figure 8 presents a short segment of the data plotted as progressive vectors. Any correlation of currents with tidal highs and lows is questionable; however, there is some evidence of a slightly stronger and more consistent flow before and after the major low tides. The progressive vectors illustrate the rate at which a pollutant would be carried away from Bile Bay, if it were continuously subjected to the currents recorded at meter #412. Over the 3-day period the net transport was slightly less than 2 nautical miles (3.22 km).

Dye studies conducted in the Bile Bay area confirm the pattern of sluggish water movement (figs. 9 through 20). In all cases, dye released near the shore spread out along the coast rather than moving out of the Bay. Dye released in Bile Bay remained in the area and was visible for exceptionally long periods of time. Dye released at 0905 hours on 31 August (fig. 17) was still present as a large patch 3-1/2 hours later. A similar situation existed during the winter dye dispersal studies (figs. 9 through 13) in which dye remained in the area for up to 4 hours. Dye observations roughly paralleled the data recorded at the current meter, indicating that the current meter record is fairly representative of water movement in the entire bay.

Current meter #407 was installed at the 40-foot (12.2-meter) depth at the entrance to Mamaon Channel during the summer survey. This site was selected to determine the exchange of the waters of Bile Bay with Cocos Lagoon, an important recreational area, and to what extent pollutants originating in the bay would affect Cocos Lagoon. Current speeds ranged up to 0.77 knot (.39 m/sec) with a relatively large number of observations over 0.5 knot (.25 m/sec). The direction plot shows that currents were bidirectional, but that the predominant flow was easterly. Current directions generally changed in concert with tidal cycles as

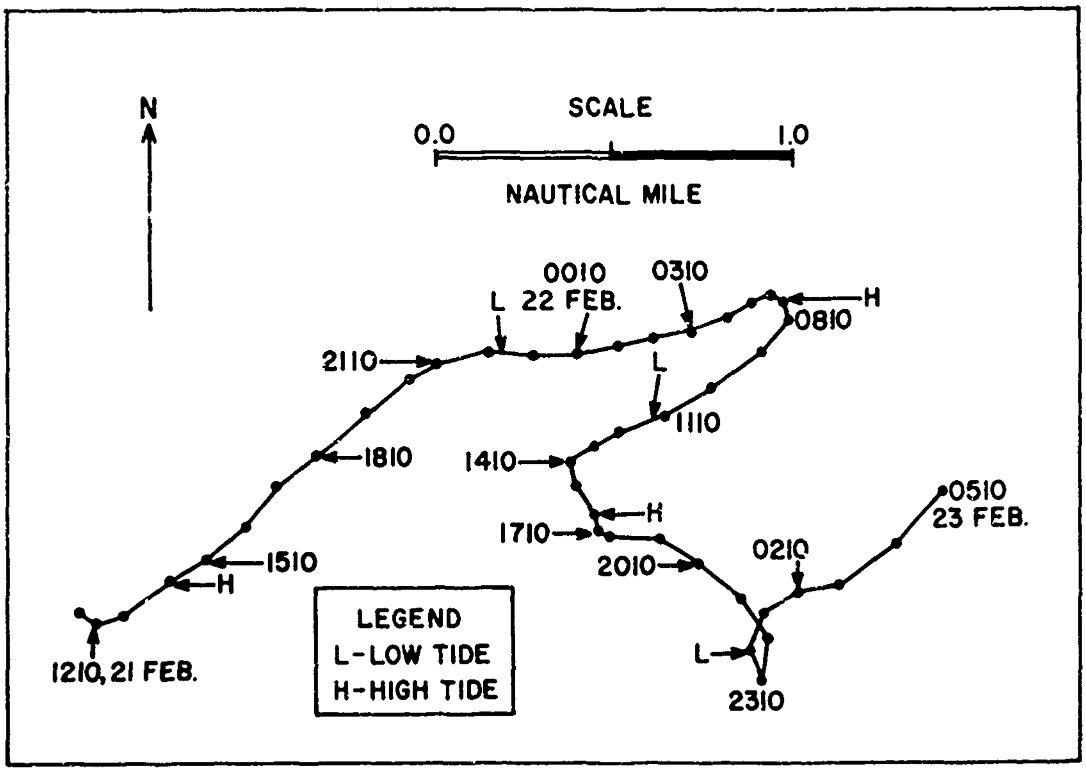


Figure 5. Progressive vector diagram of current from meter #223, 1210, 21 February to 0510, 23 February 1971.

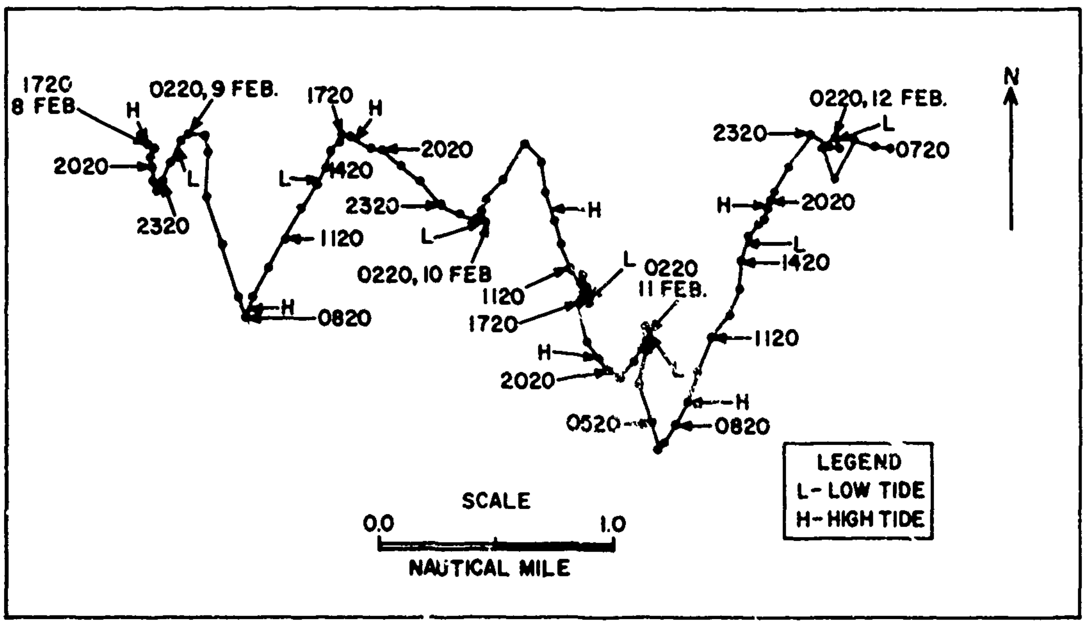


Figure 6. Progressive vector diagram of current from meter #223, 8 - 12 February 1971.

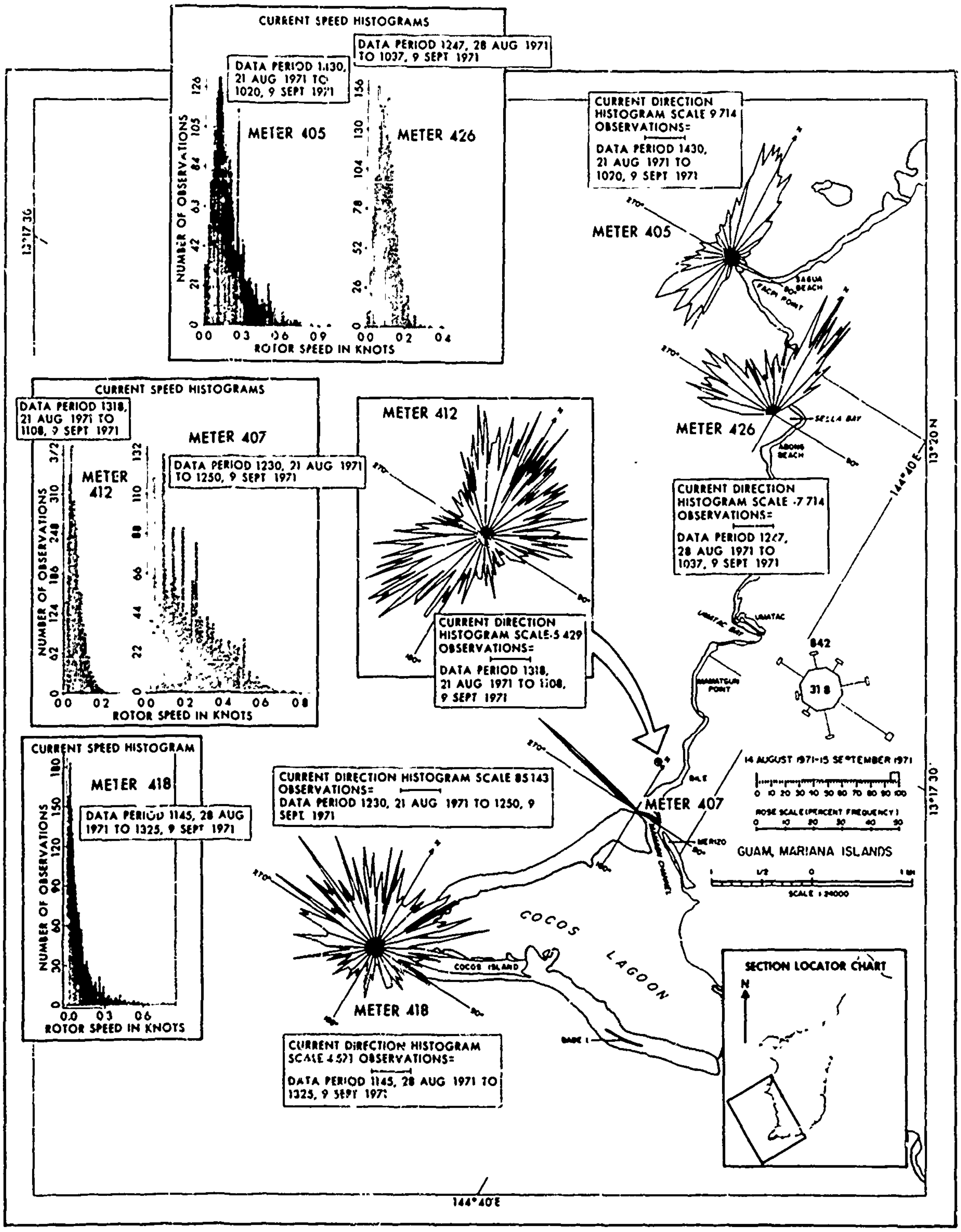


Figure 7. Current speed histograms and current direction histograms for the Bile Section in summer including meters #405, #426, #412, #407, and #418 and a wind rose for the data period.

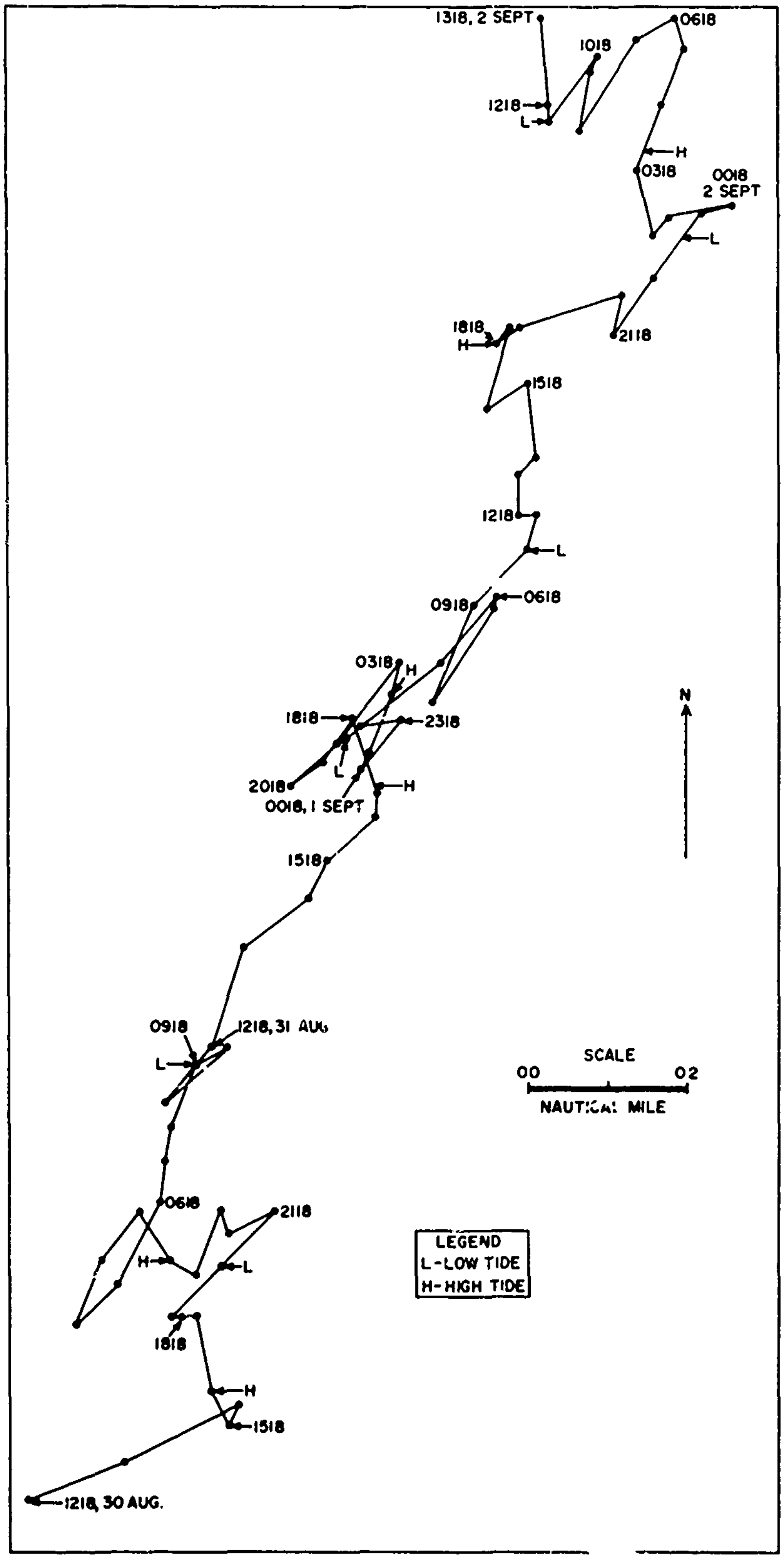


Figure 8. Progressive vector diagram of current from meter #412, 1218, 30 August to 1318, 2 September 1971.

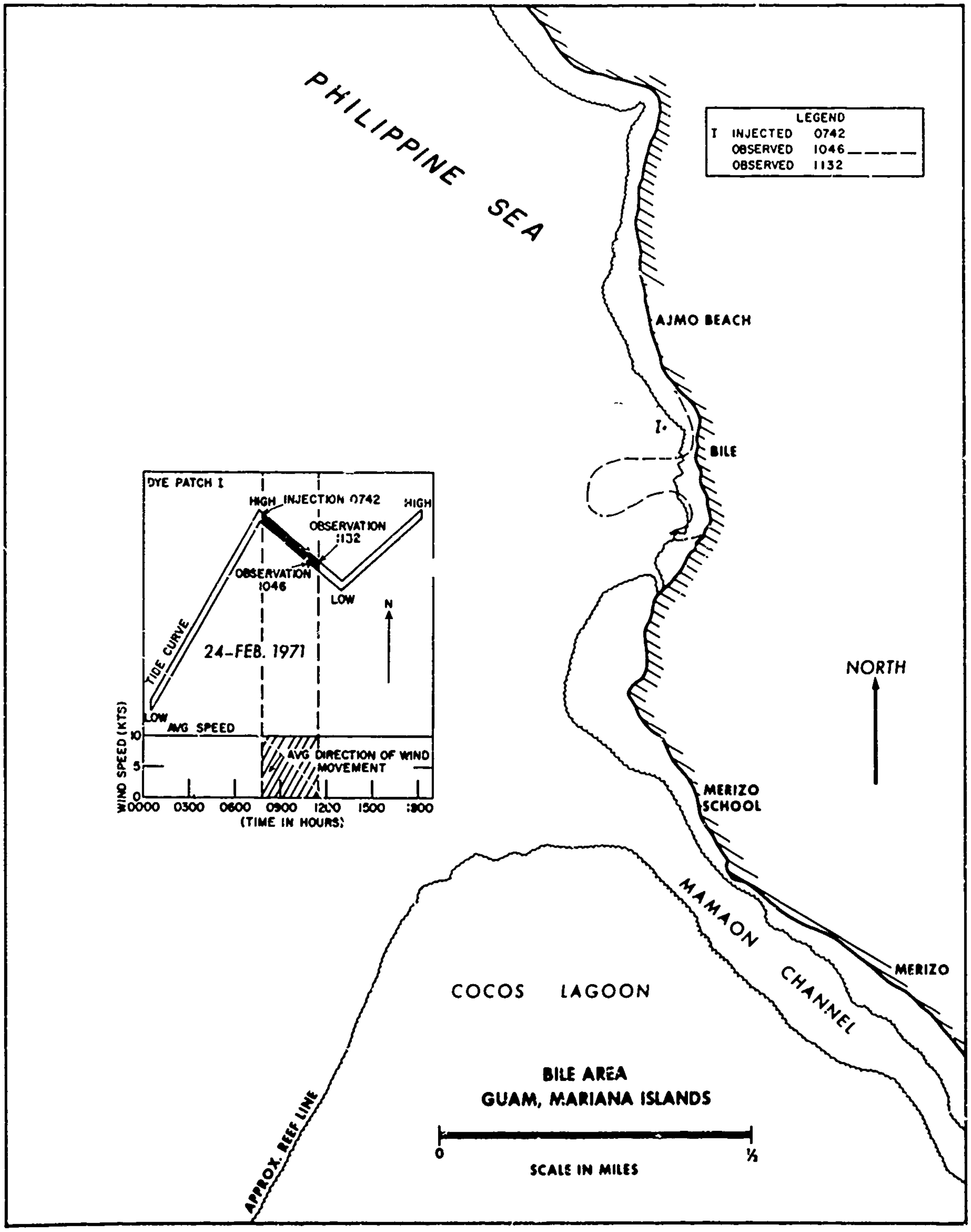


Figure 9. Dye movement at Bile Bay on 24 February 1971.

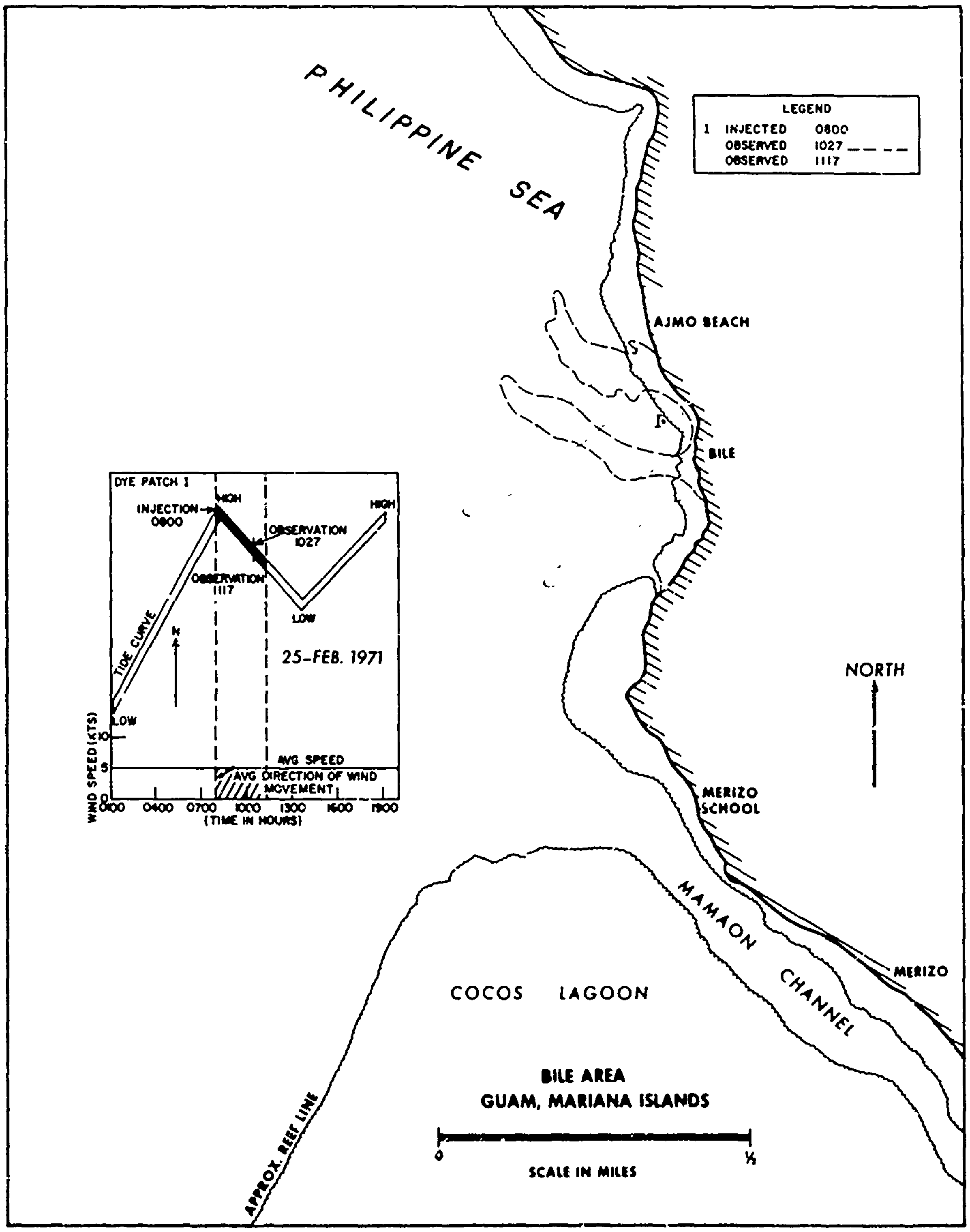


Figure 10. Dye movement at Bile Bay on 25 February 1971, A.M.

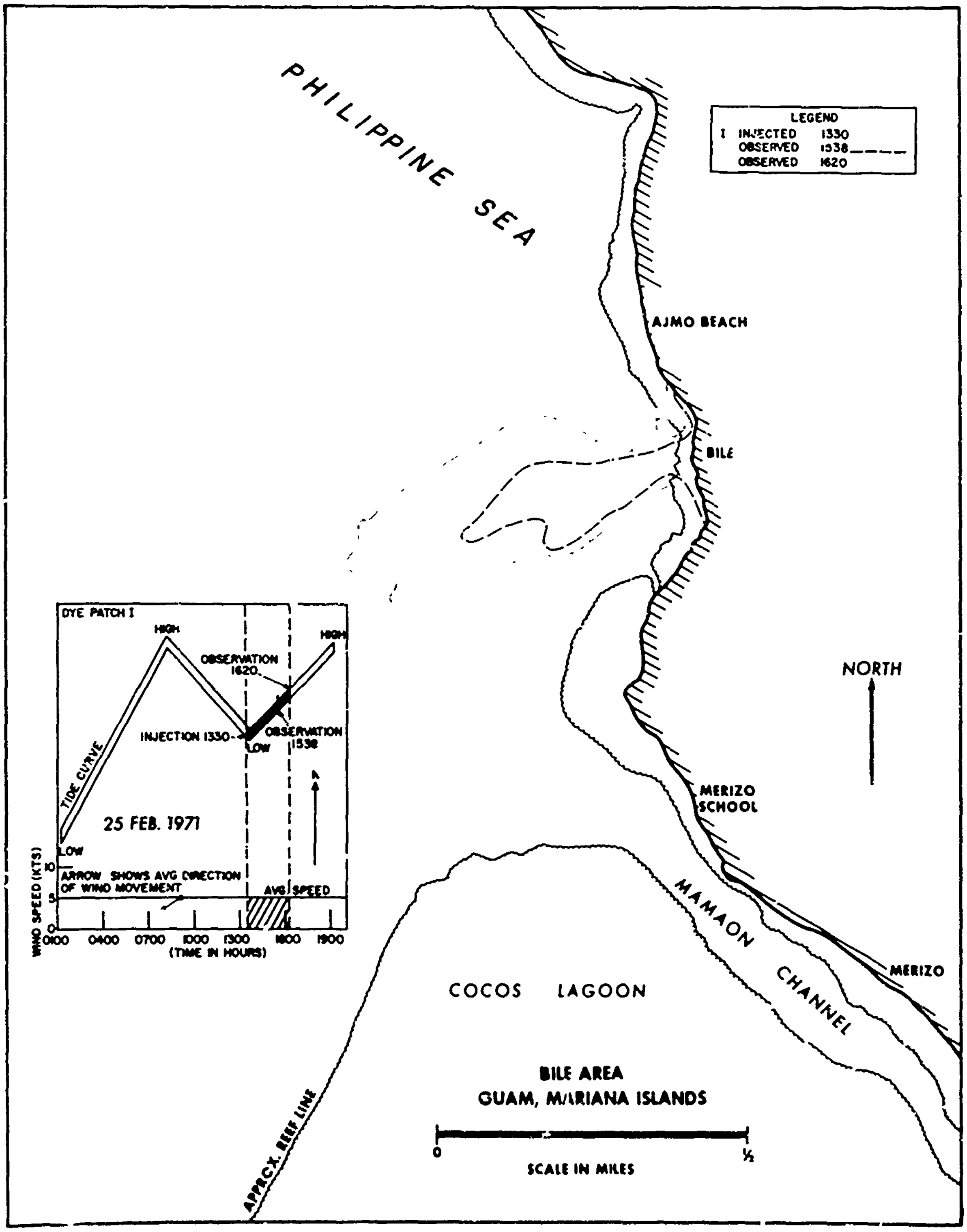


Figure 11. Dye movement at Bile Bay on 25 February 1971, P.M.

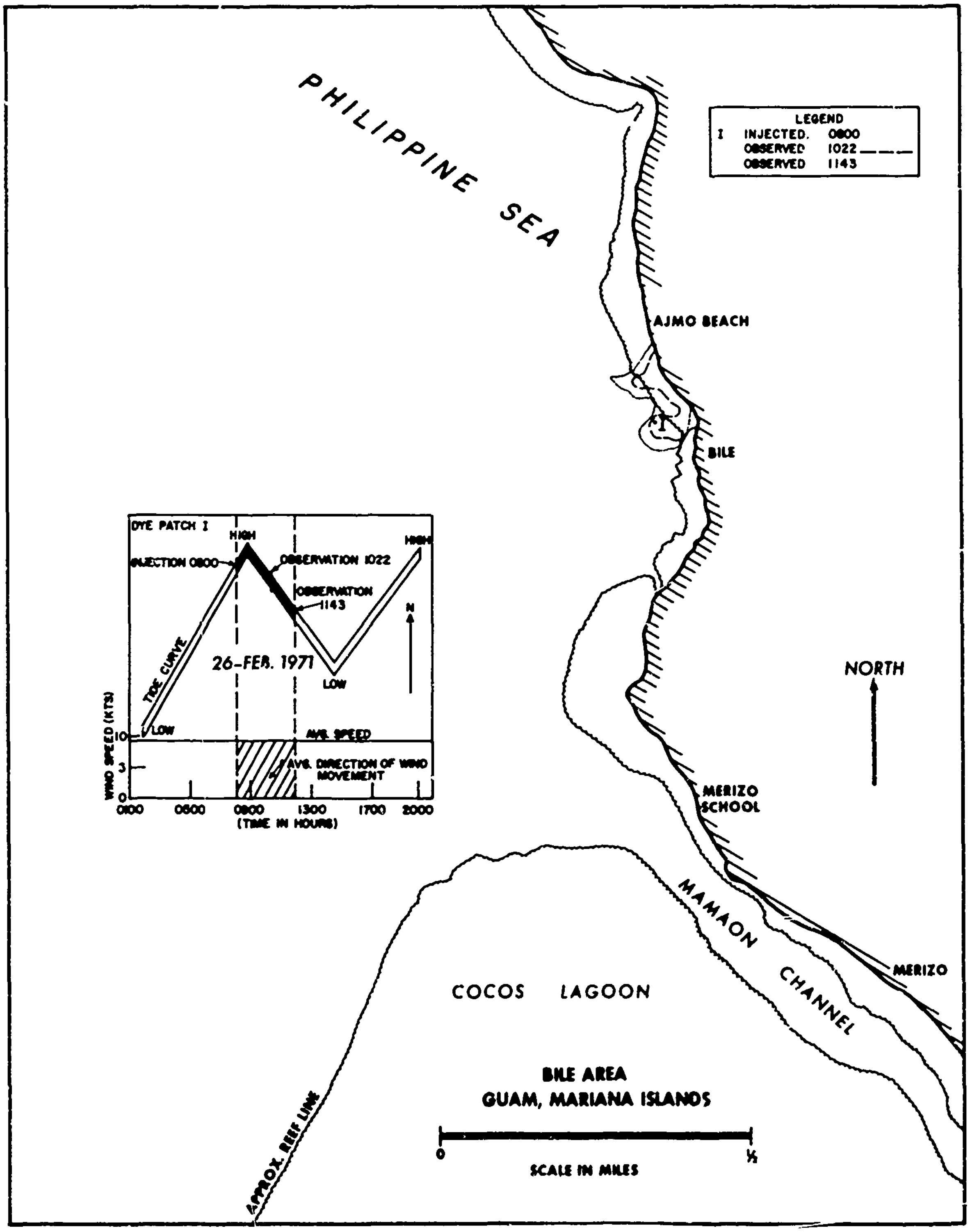


Figure 12. Dye movement at Bile Bay on 26 February 1971, A.M.

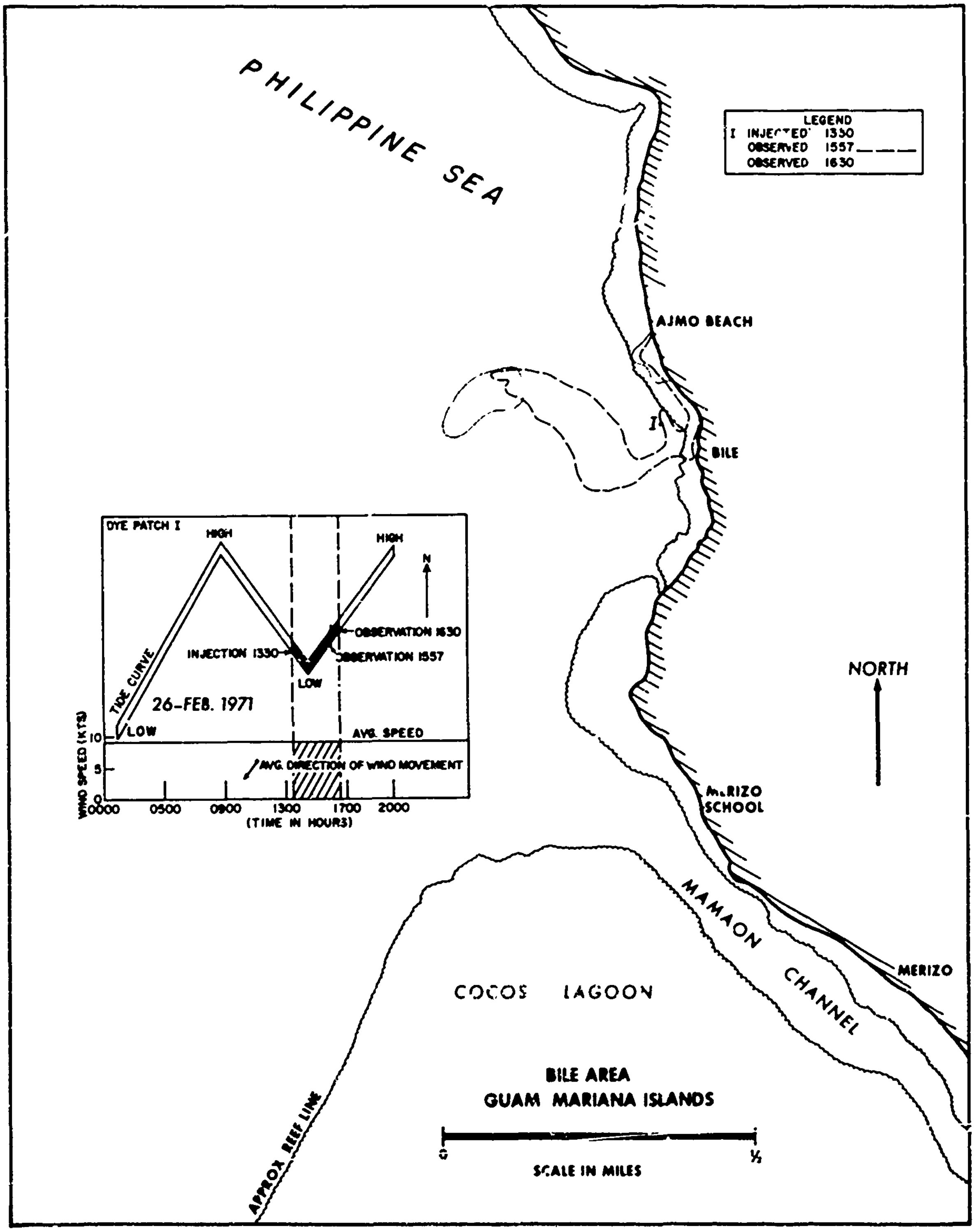


Figure 13. Dye movement at Bile Bay on 26 February 1971, P.M.

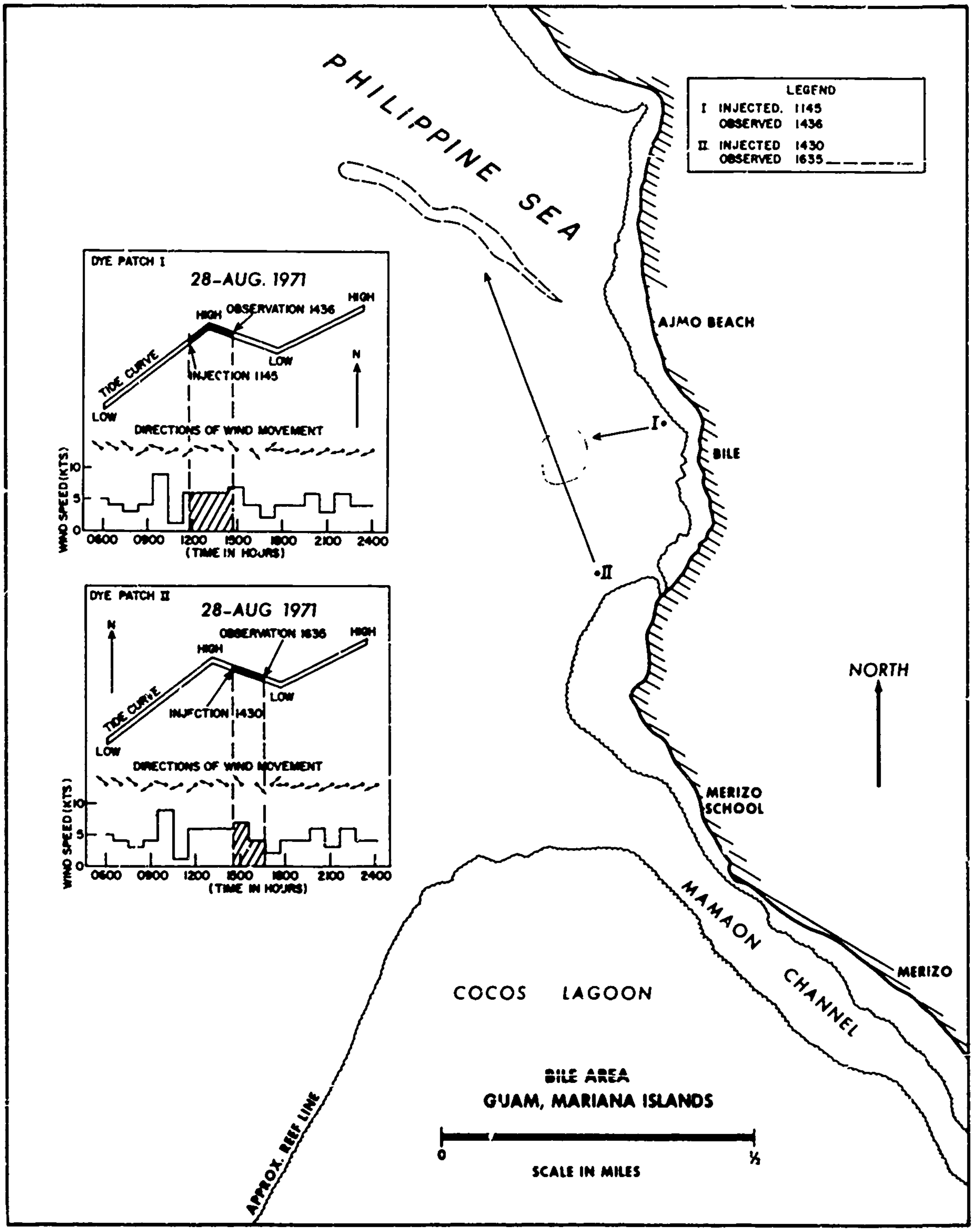


Figure 14. Dye movement at Bile Bay on 28 August 1971.

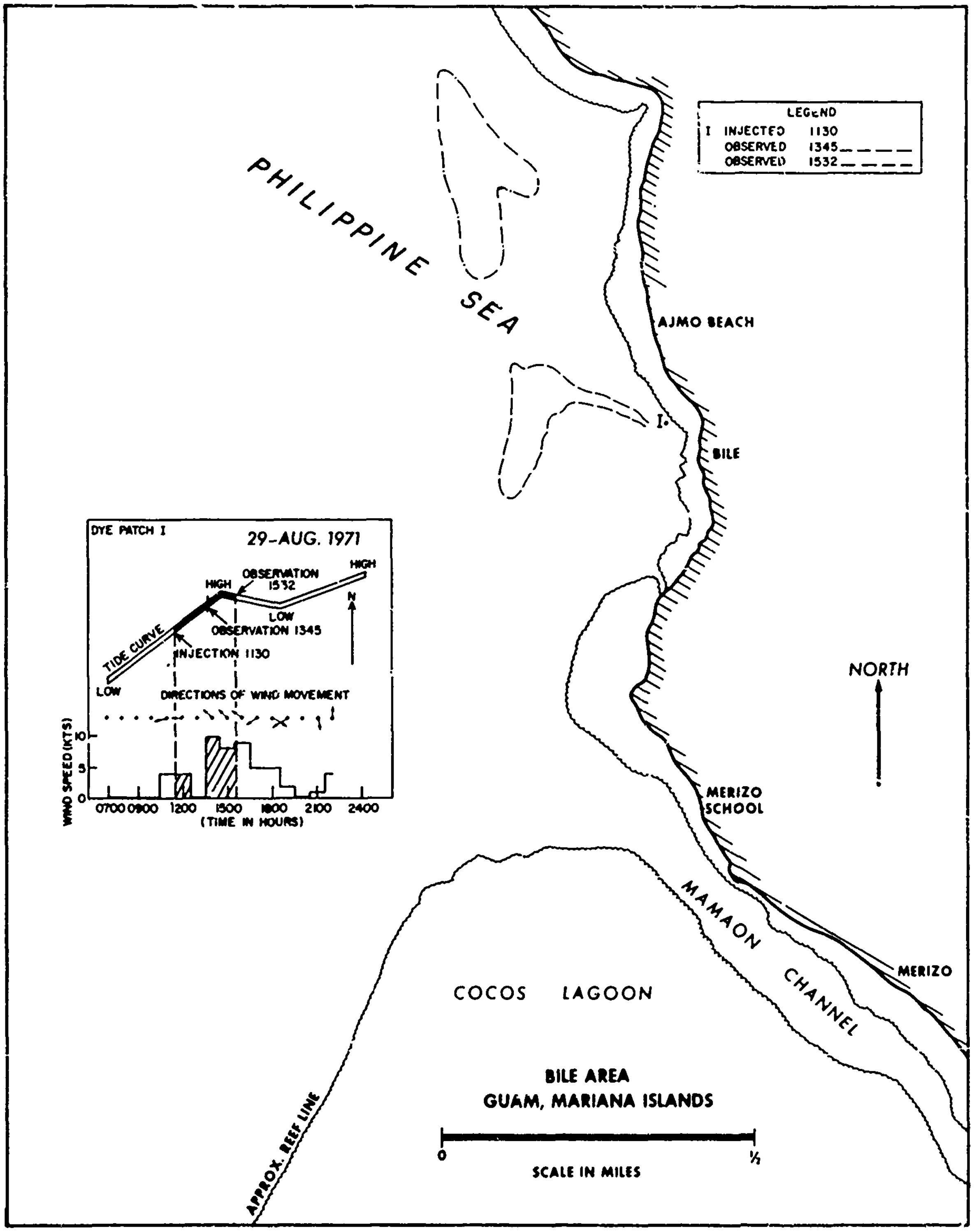


Figure 15. Dye movement at Bile Bay on 29 August 1971.

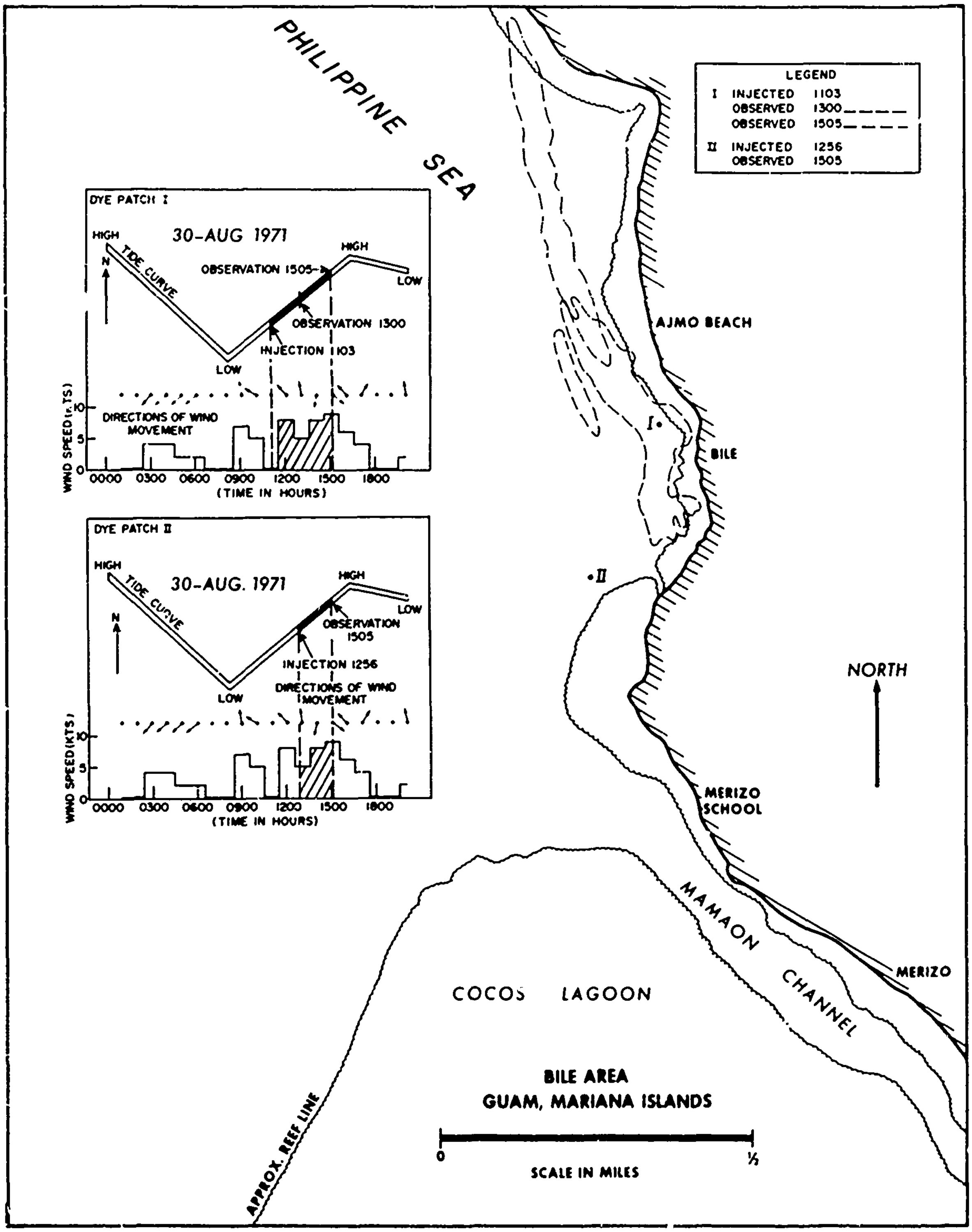


Figure 16. Dye movement at Bile Bay on 30 August 1971.

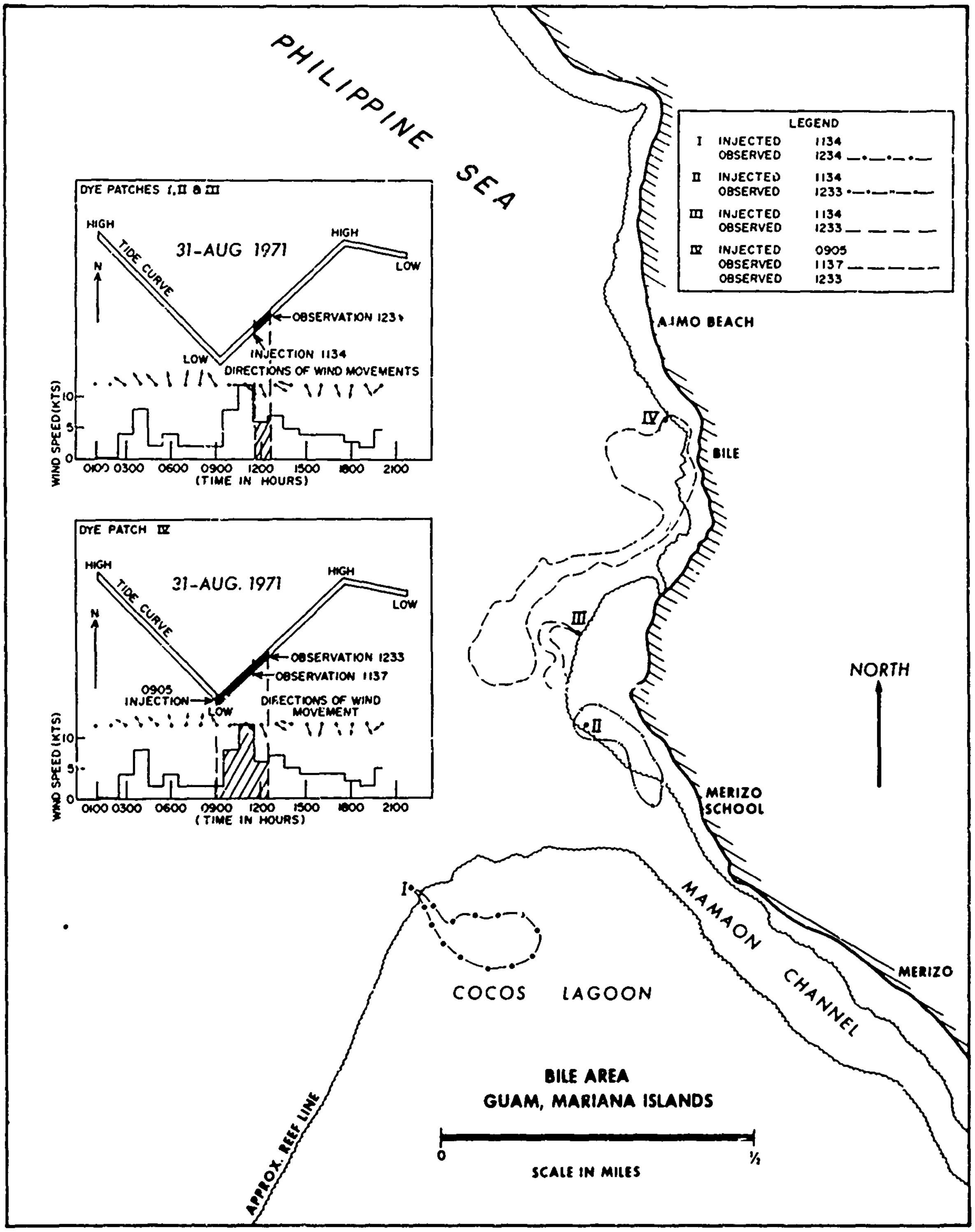


Figure 17. Dye movement at Bile Bay on 31 August 1971.

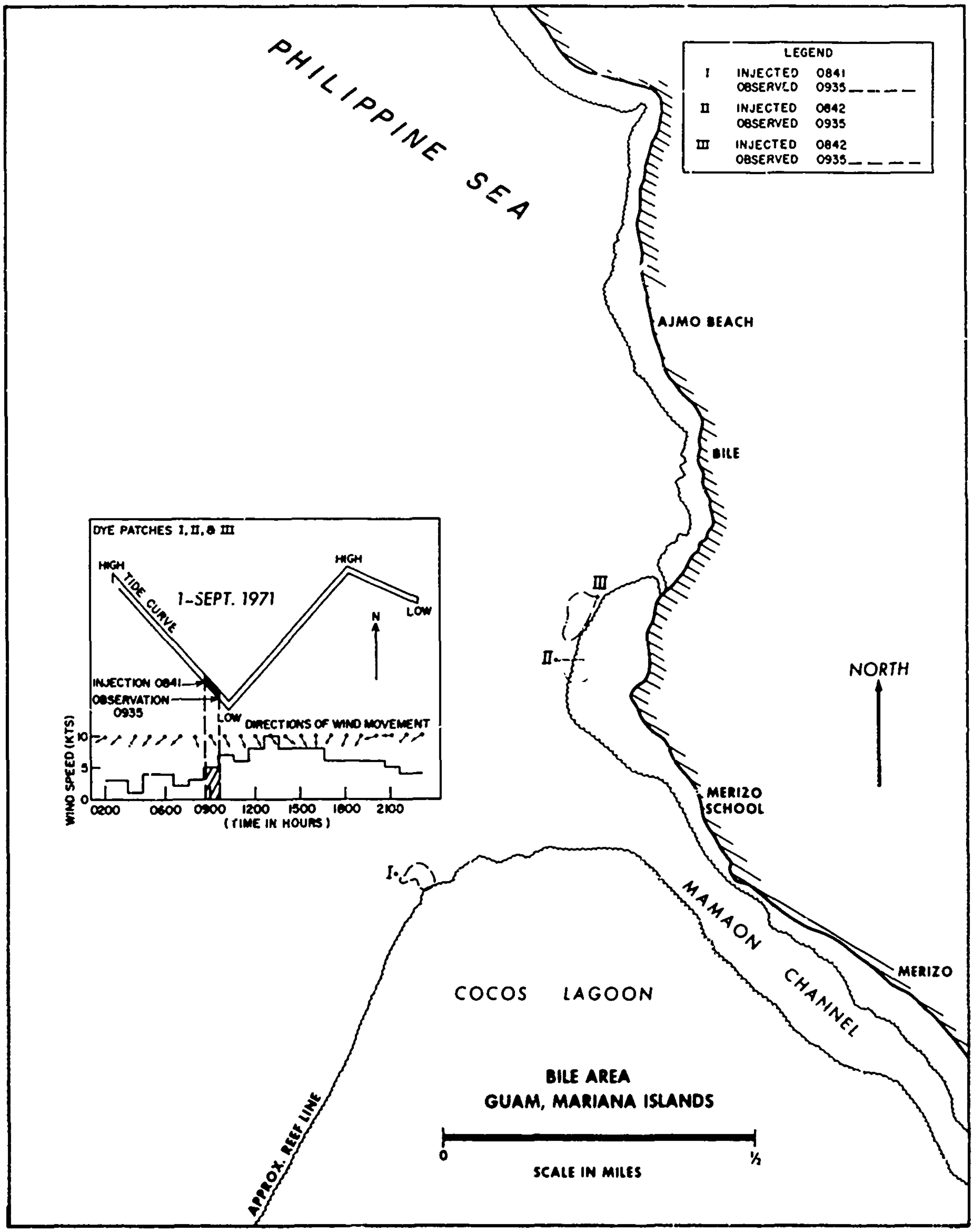


Figure 18. Dye movement at Bile Bay on 1 September 1971.

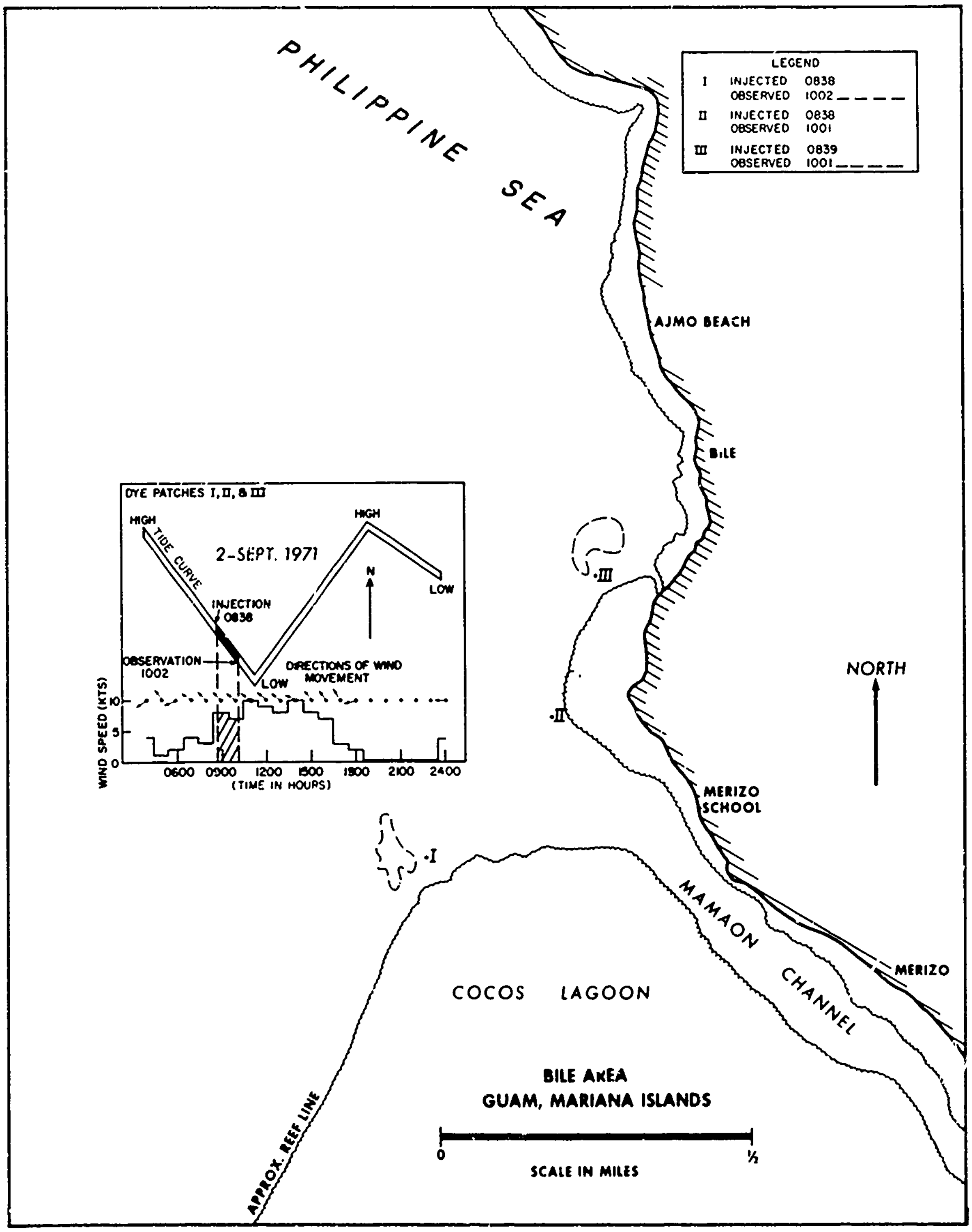


Figure 19. Dye movement at Bile Bay on 2 September 1971.

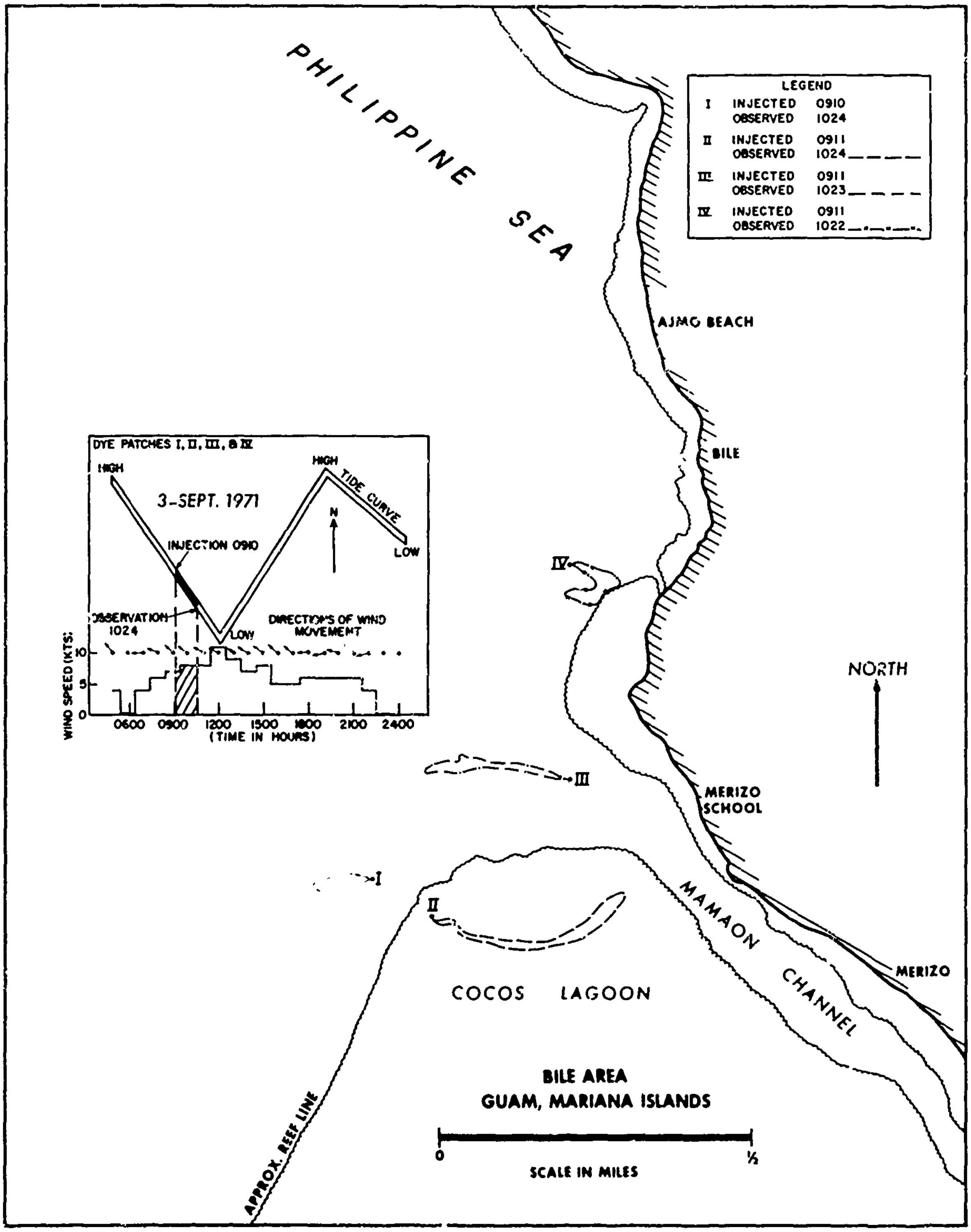


Figure 20. Dye movement at Bile Bay on 3 September 1971.

shown in the progressive vector diagrams (figs. 21 and 22). During the period 21 through 27 August currents through Mamaon Channel varied between inflow and outflow but were strongest during inflow. Figure 21 is representative of this period. Outflow was predominant from 28 August through 9 September. Current speeds increased, becoming greatest around the major high tide of the day. Figure 22 is representative of this period.

If Cocos Lagoon were filling and emptying exclusively through Mamaon Channel, a periodic current would exist equal in both directions. The vector diagrams illustrate the presence of another current which flows primarily westward through the channel. The origin of this steady current is the filling of the lagoon by the action of waves of translation carrying water across the reef flat. This wave-induced current is greatest during high tides when larger waves can cross the reef flat, and for this reason higher currents were recorded at high tide.

Although the dominant flow was westward through Mamaon Channel, it must not be assumed that pollutants dumped near the channel would invariably be carried away from the lagoon. As shown in figure 21, before 28 August, currents carried water from the Philippine Sea through the channel and into the lagoon. This situation was probably created by a temporary change in the direction and intensity of wave attack.

Current meter #418 was installed on the bottom in 95 feet (29 meters) of water off the southwestern tip of Cocos Island. Current speeds up to 0.65 knot (.325 m/sec) were recorded; however, most speeds were very low. These low speeds were probably due to the presence of a precipitous slope rising just east of the meter location, blocking the flow of the dominant northwesterly currents. The source of the dominant northwest drift is probably the North Equatorial Current. Very little periodicity is evident from the data recorded.

Currents at Sella Bay were investigated by means of eight dye dispersal operations (figs. 23 through 30) and the installation of current meter #426 on a bottom stand at 50 feet (15.2 meters). This meter recorded very consistent currents flowing north and west. Speeds were most common in the range of 0.05 to 0.11 knot (.025 to .055 m/sec). The current direction histogram shows a complete lack of currents in the southeast quadrant. This was not due to any local topographic obstruction, because the meter was installed on a flat bottom with no significant relief. Figure 31 examines a 4-day segment of the data in more detail. This illustration portrays a series of north and west projections resulting in a net northwest movement. Currents here were strongly influenced by tides; the northward projection occurred before the major low tide of the day, and the westward projection occurred after the major low. Dye injected into inner Sella Bay moved more slowly than that injected near adjacent points.

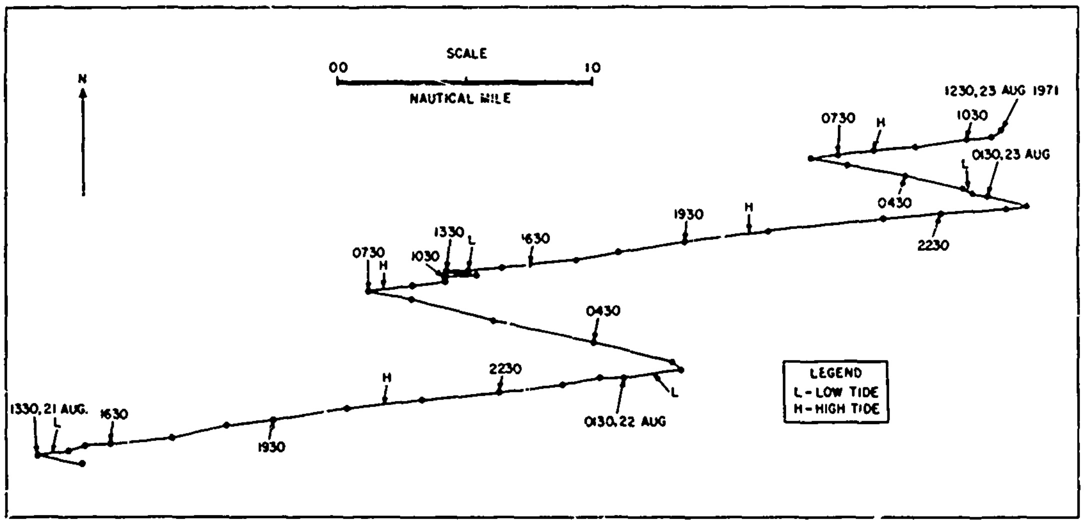


Figure 21. Progressive vector diagram of current from meter #407, 21 - 23 August 1971.

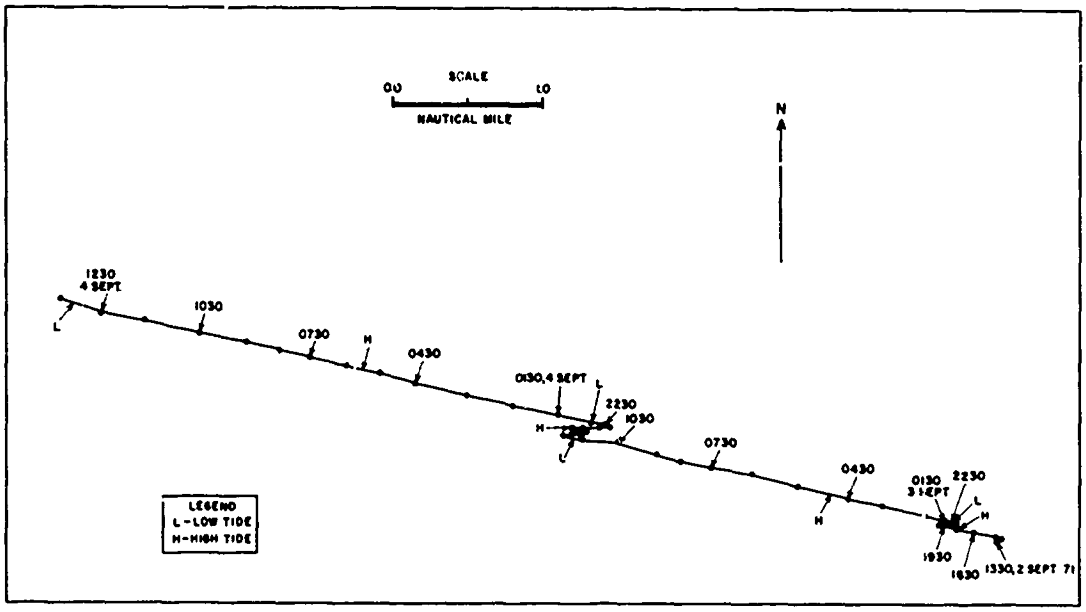


Figure 22. Progressive vector diagram of current from meter #407, 2 - 4 September 1971.

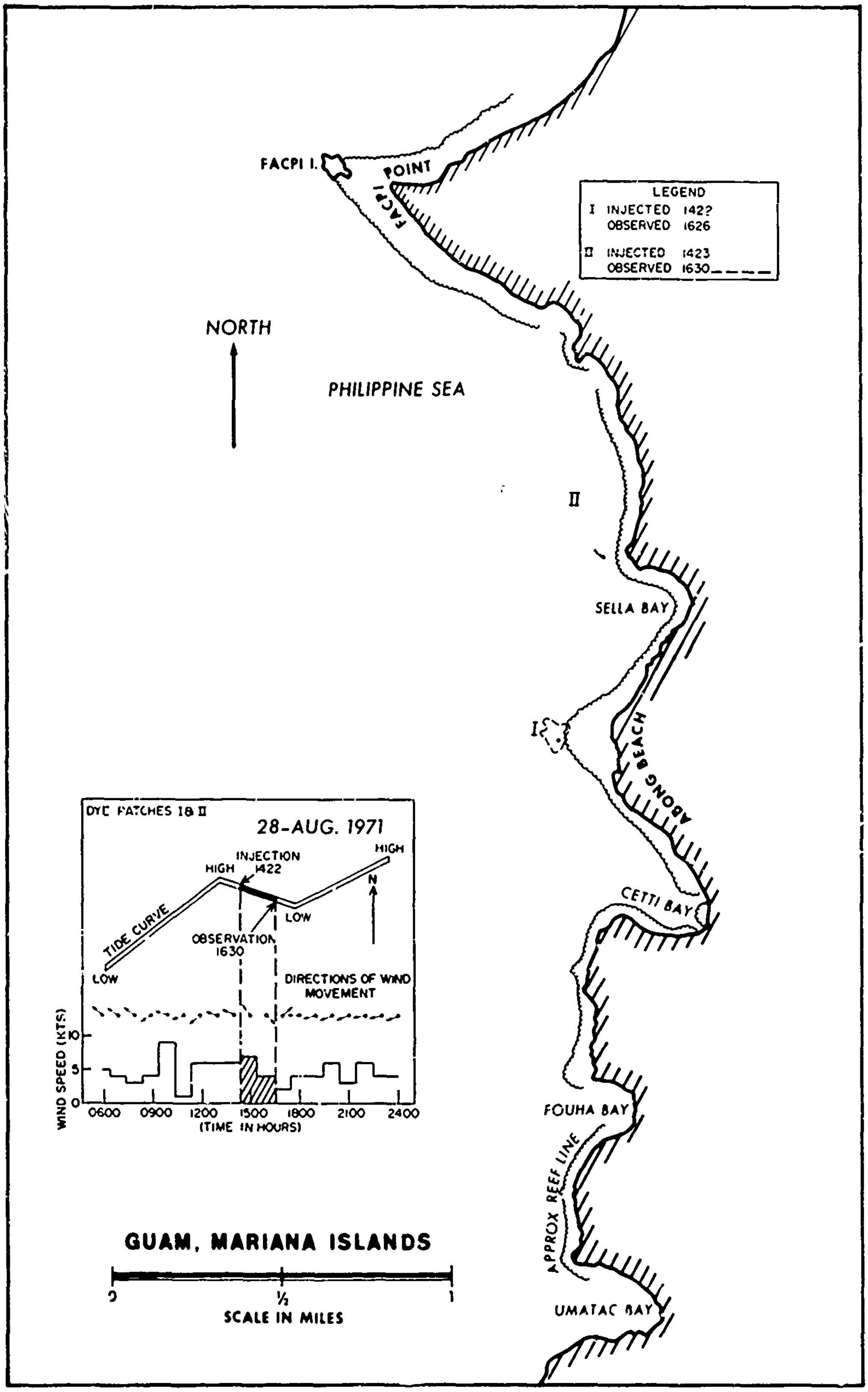


Figure 23. Dye movement at Sella Bay on 28 August 1971.

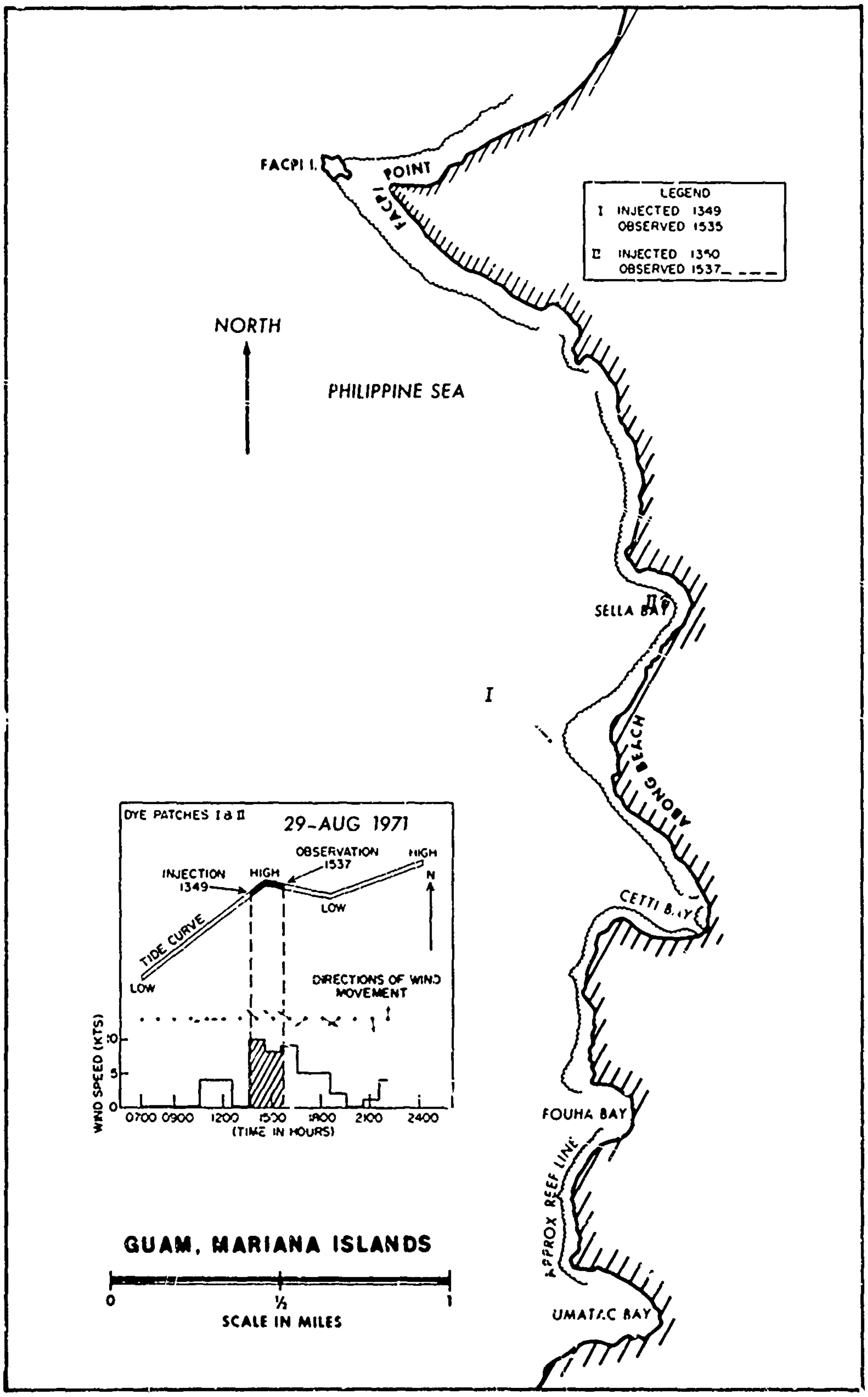


Figure 24. Dye movement at Sella Bay on 29 August 1971.

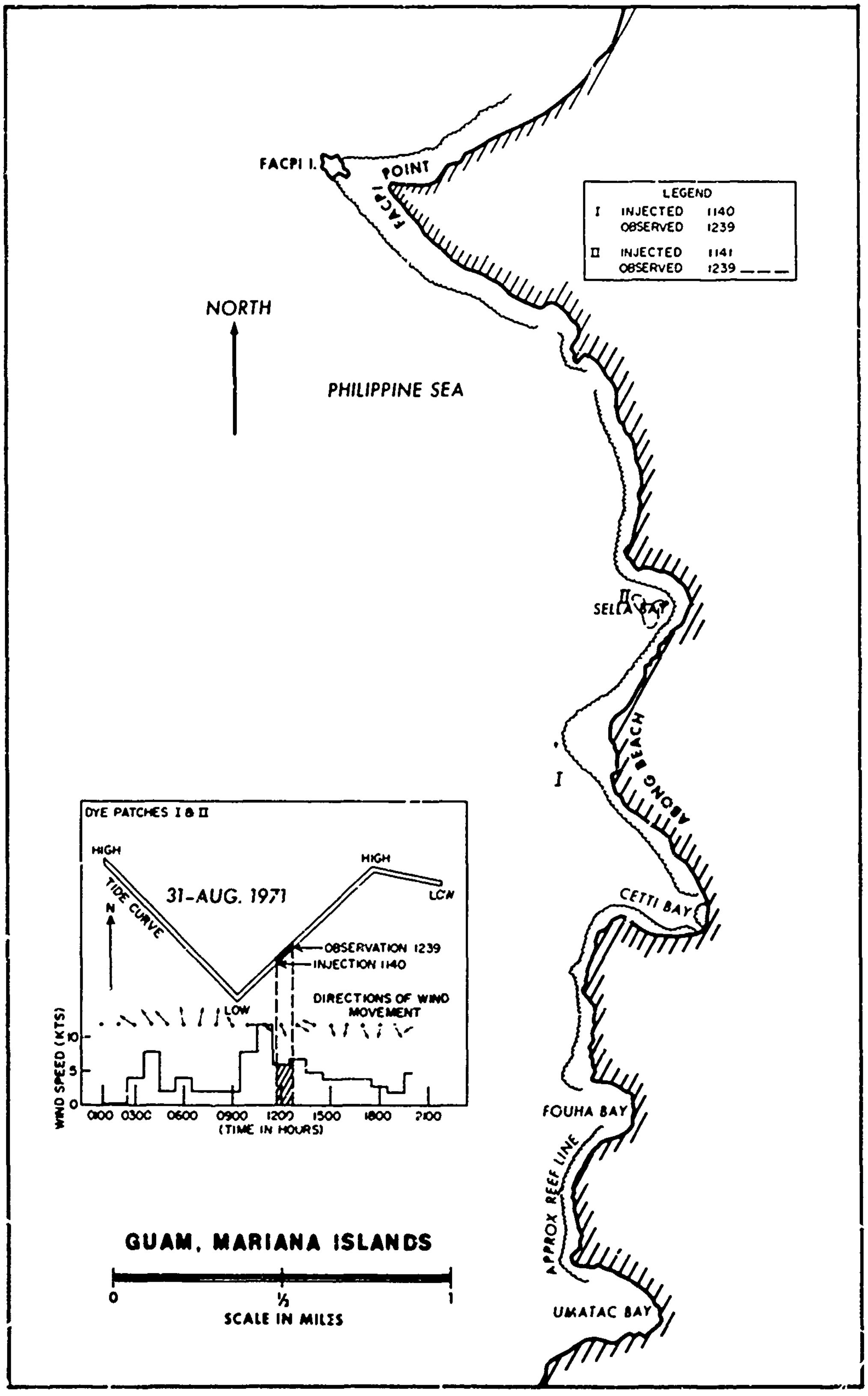


Figure 25. Dye movement at Sella Bay on 31 August 1971.

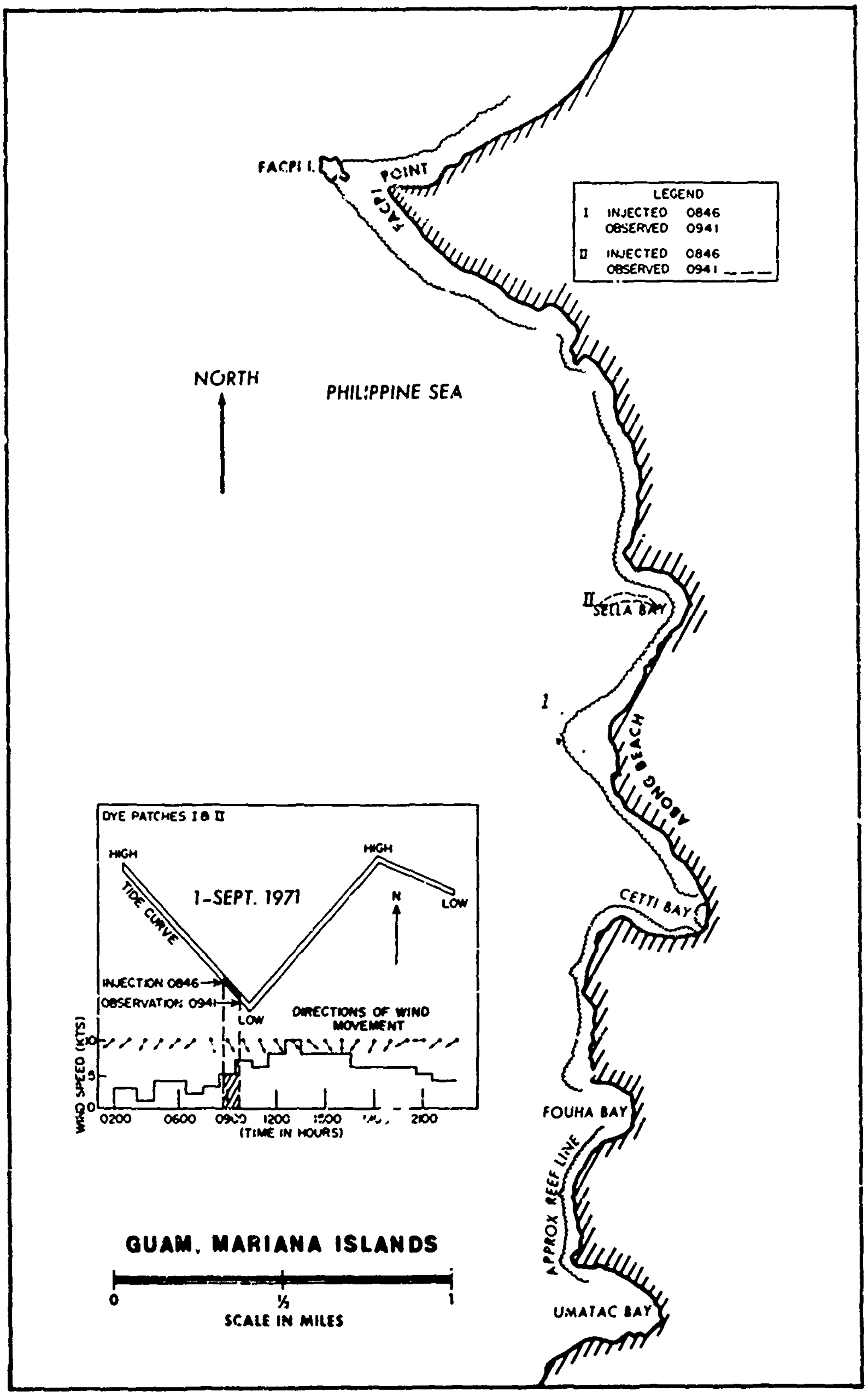


Figure 26. Dye movement at Sella Bay on 1 September 1971.

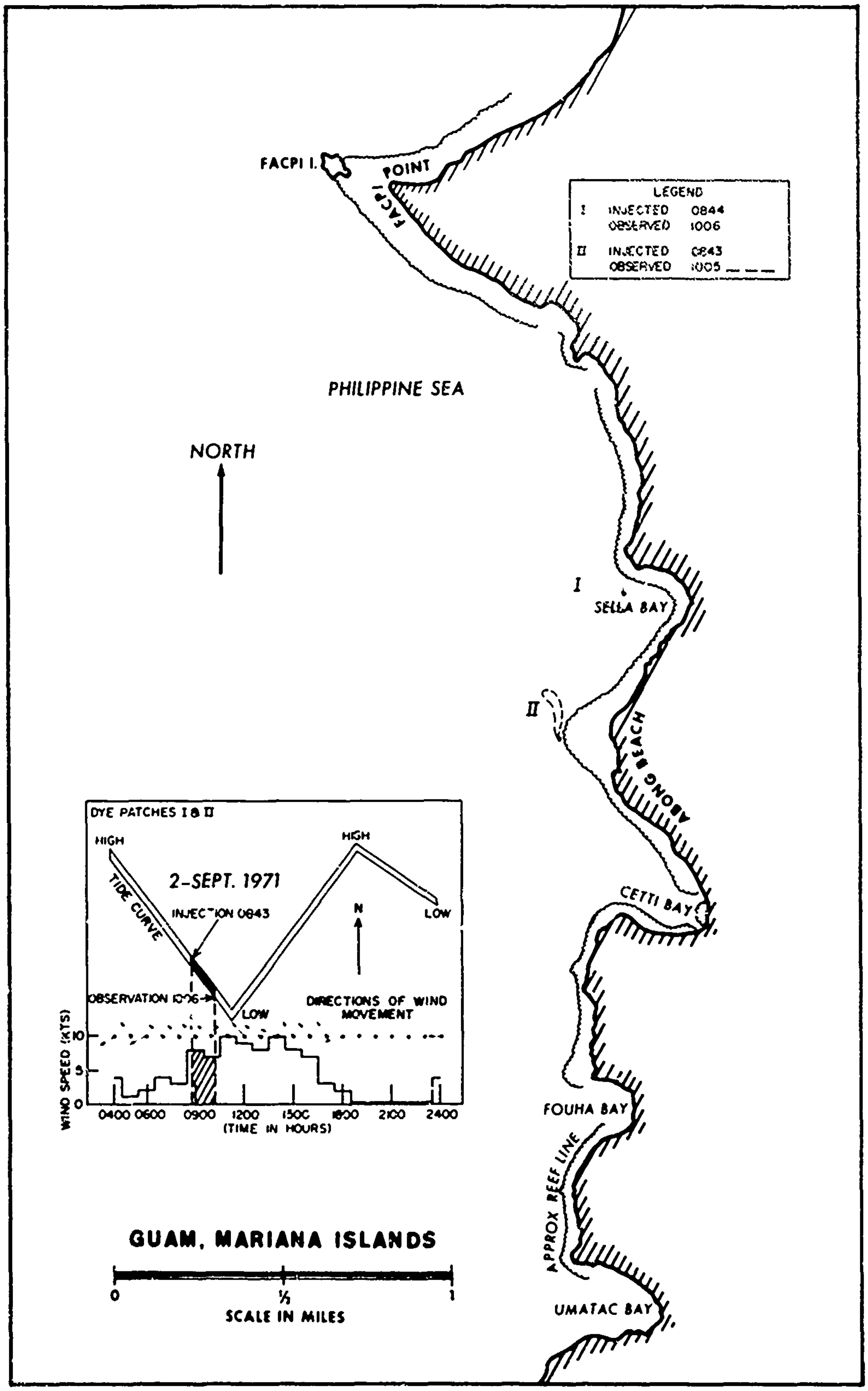


Figure 27. Dye movement at Sella Bay on 2 September 1971.

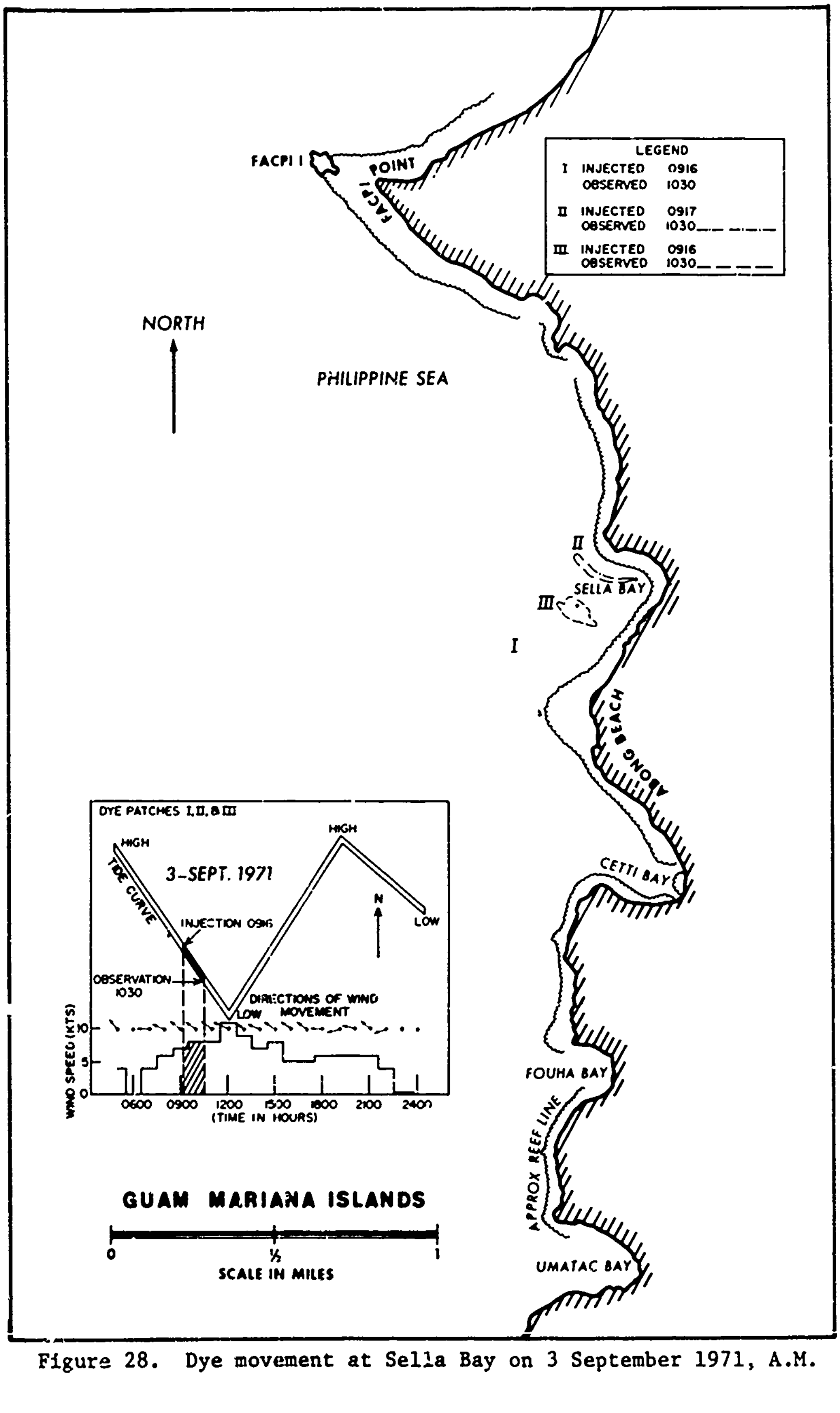


Figure 28. Dye movement at Sella Bay on 3 September 1971, A.M.

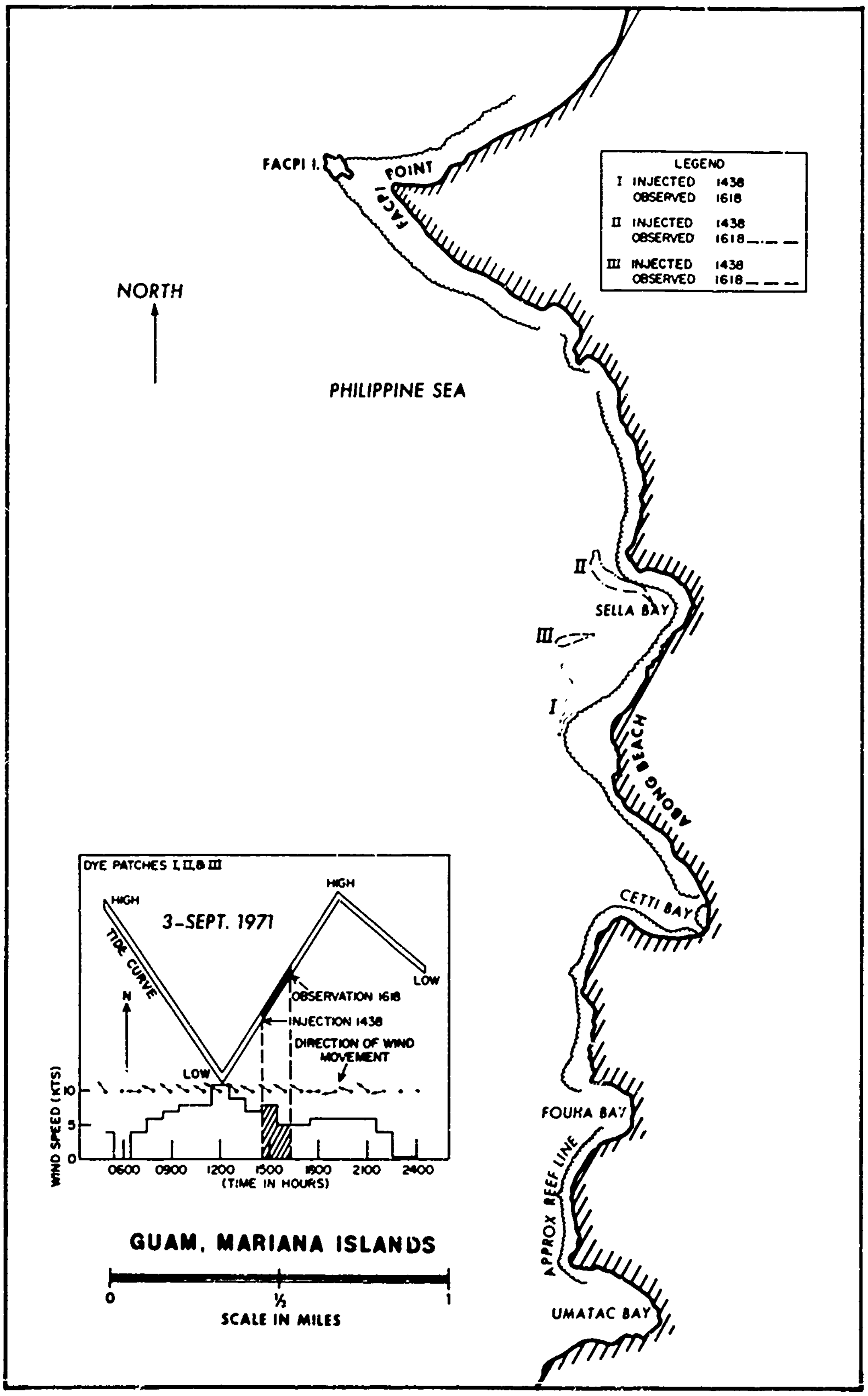


Figure 29. Dye movement at Sella Bay on 3 September 1971, P.M.

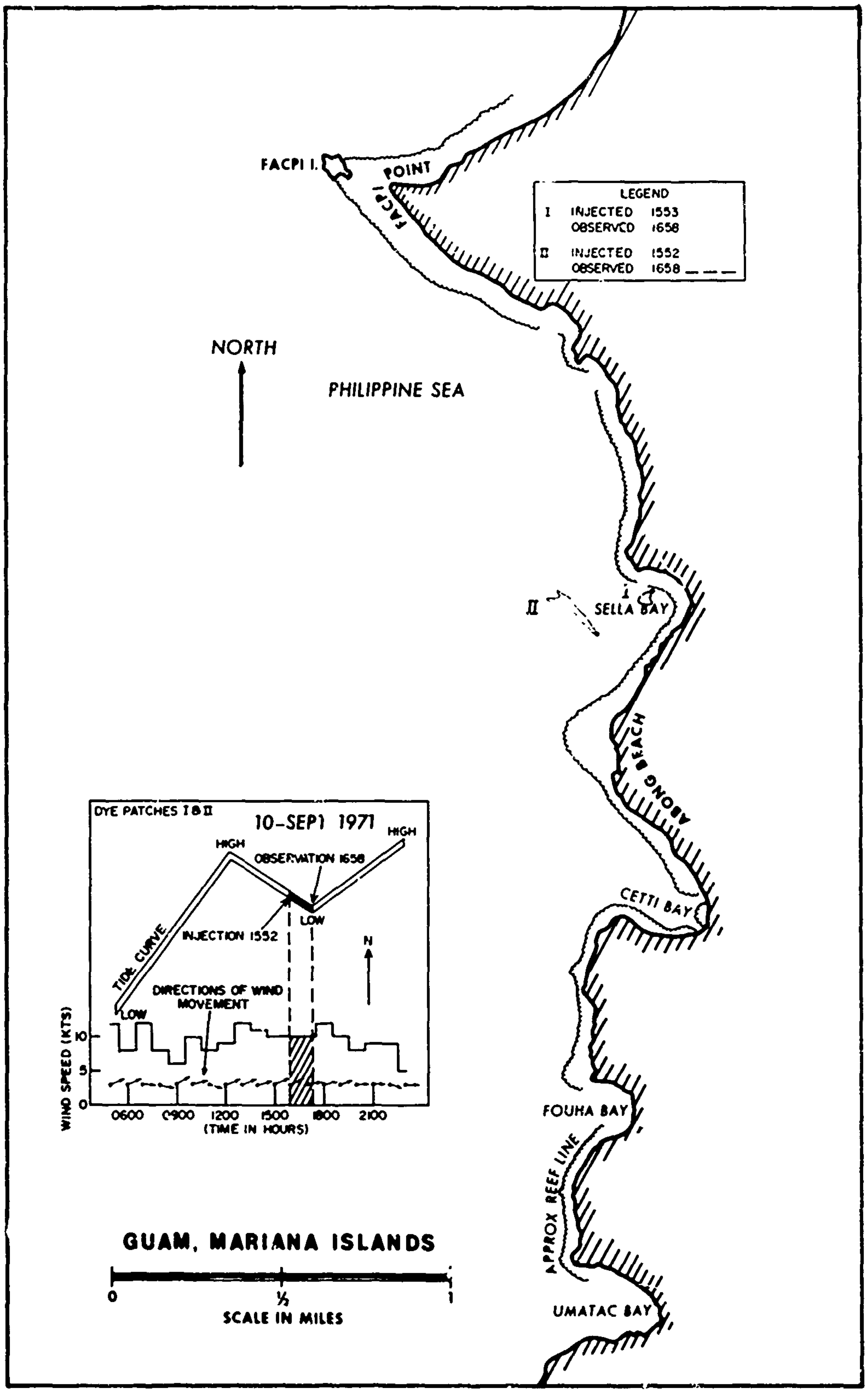


Figure 30. Dye movement at Sella Bay on 10 September 1971.

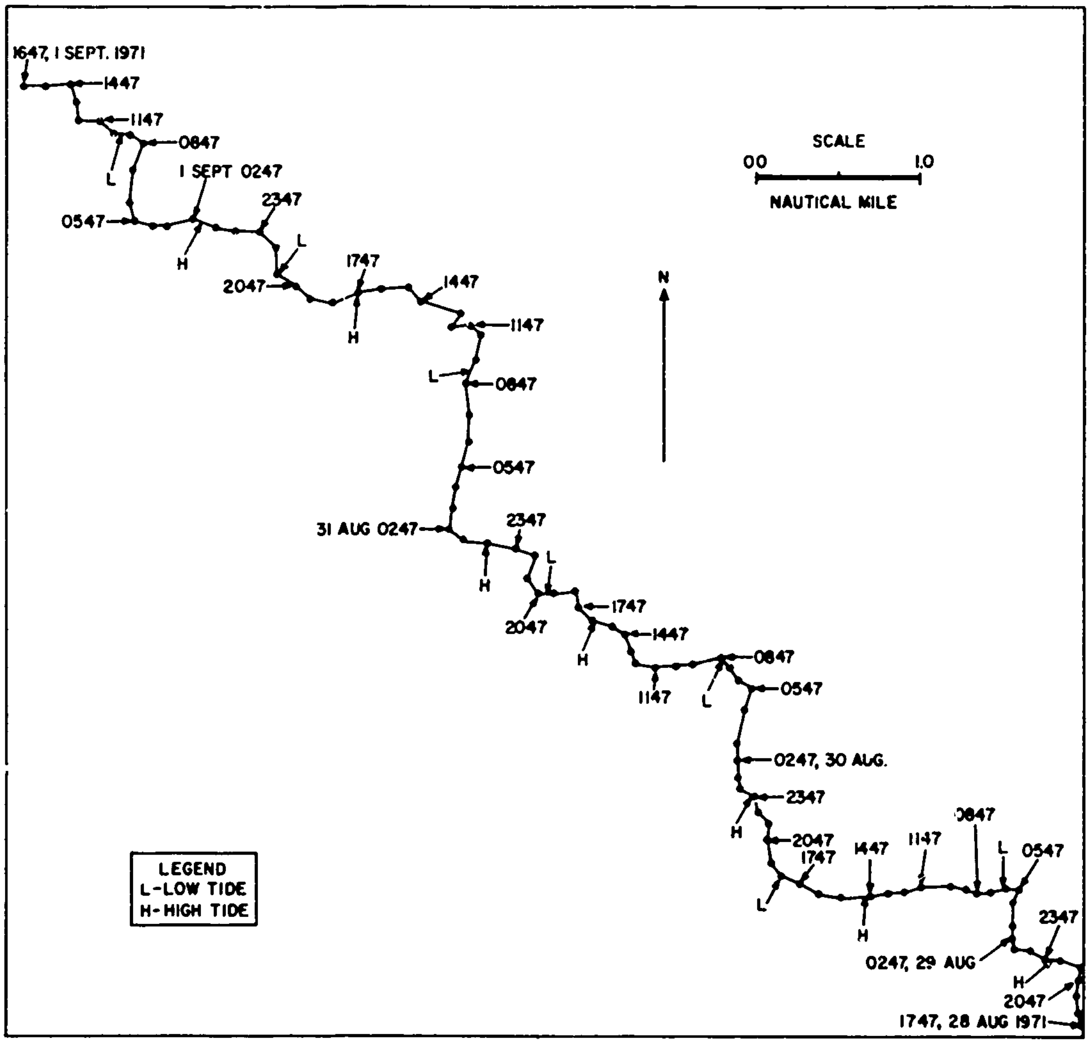


Figure 31. Progressive vector diagram of current from meter #426, 1747, 28 August to 1647, 1 September 1971.

Current meter #405 was installed on the bottom off Facpi Point in 50 feet (15.2 meters) of water. Current speeds recorded by this meter were the highest in this section. The direction histogram shows the greatest number of observations to be north and south. Currents were strongly related to tidal changes; flowing northward during ebb tide and southward during flood (fig. 32). The northward flow during ebb is similar to that at Sella Bay, but at greater speed.

Four drogues were planted and tracked in this section during the summer field survey (fig. 33). Three of the drogues moved to the southeast for the first 1-1/2 hours, then they turned northeast for 2 hours and would have beached had they not been retrieved. The southernmost drogue moved consistently northeast before shoaling.

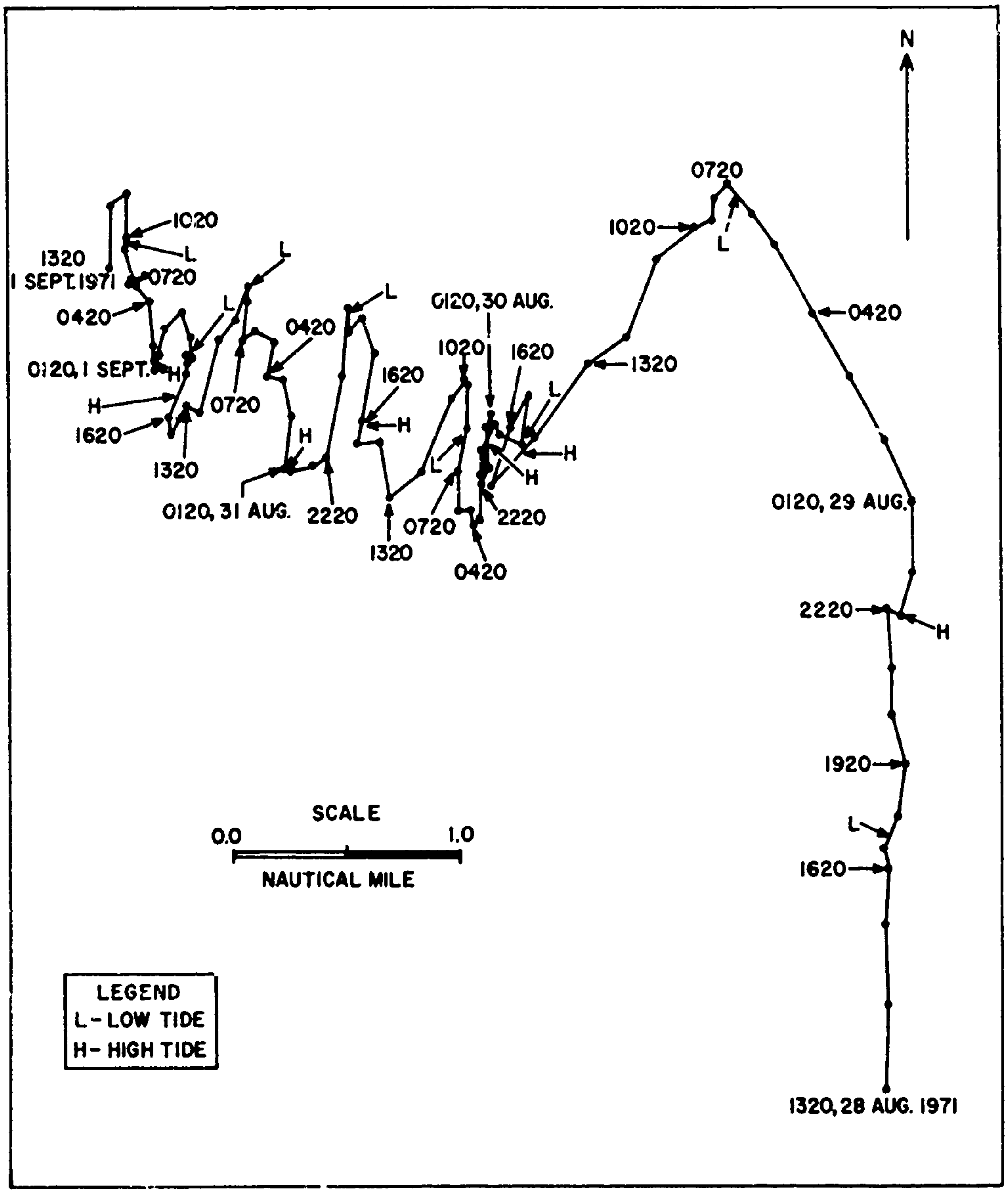


Figure 32. Progressive vector diagram of current from meter #405, 1320, 28 August to 1320, 1 September 1971.

Based on the current data collected during this study, Bile Bay appears to be a relatively poor location for a sewer outfall. Sewage discharged into the bay will be caught by slowly eddying currents and will remain in coastal waters for long periods of time. Slower exchange

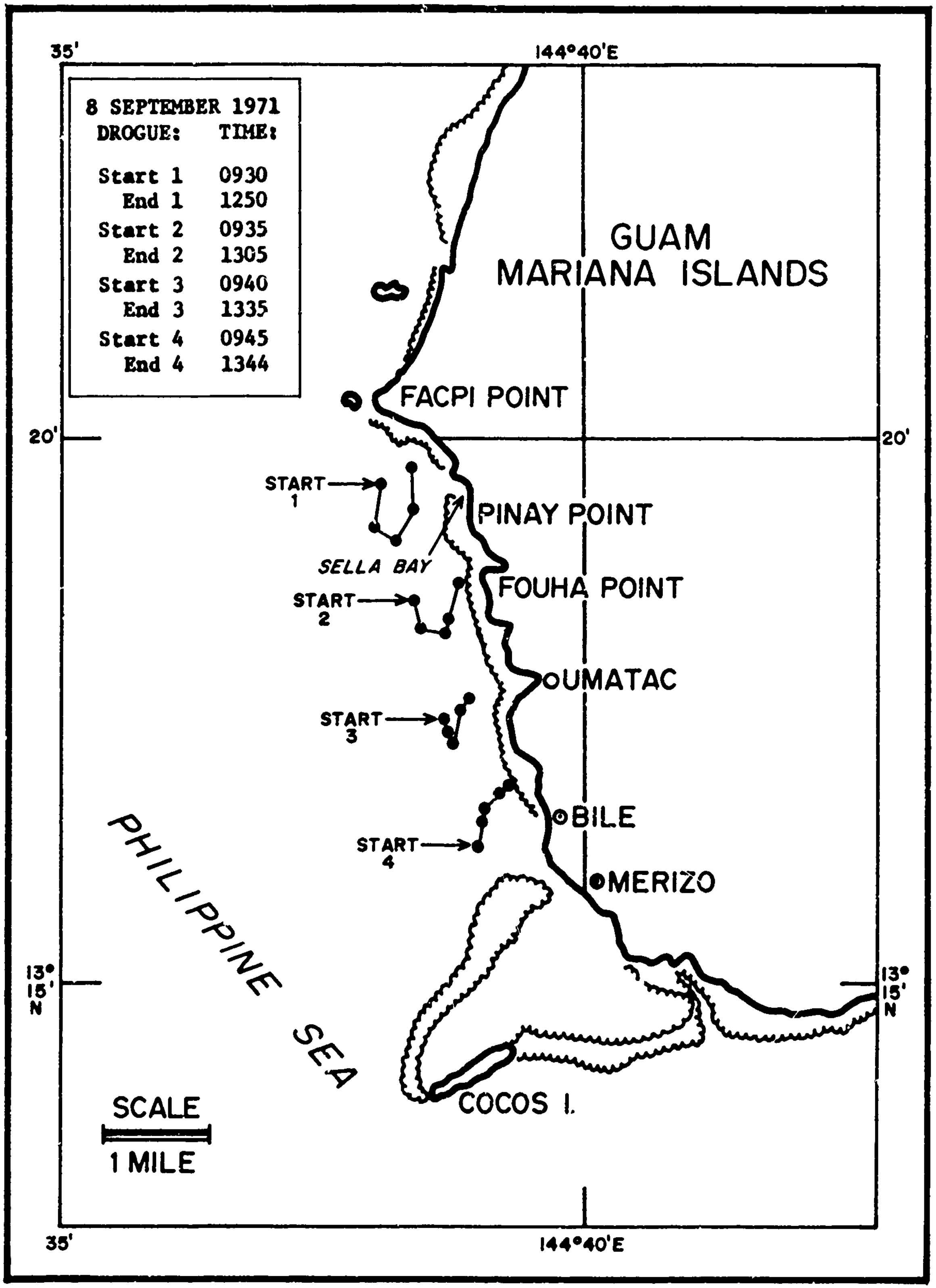


Figure 33. Drogue observations in Bile Section, 8 September 1971.

of waters can be expected in bays and other semienclosed bodies of water, and therefore less rapid dispersal of pollutants than off more exposed coastlines such as headlands or prominent points. The most favorable locations within this section would appear to be at Facpi Point and off the extreme southwestern end of Cocos Island. Mamatgun Point or Fouha Point may also have more favorable currents than does Bile Bay; however, a study of those locations would be necessary to confirm this.

2. Agat Section

This section comprises the western coast of Guam from Facpi Point to Apra Harbor. Currents in this section were investigated by means of current meters at Agat, Tantapalo Point, Apra Harbor, and an array of three meters off the western end of Glass Breakwater (figs. 34 and 36). Dye dispersal studies were conducted at Agat and Tantapalo Point. Drogues were released and tracked on five separate occasions.

Current meter #175 was installed during the winter field survey on a bottom stand in 35 feet (10.7 meters) of water approximately 300 yards (274 meters) directly offshore from the Agat sewer outfall. This meter was located very close to the reef margin and in relatively shallow water. The histograms (fig. 34) show very slight currents setting mostly parallel to the shoreline, but the effect of wave action is evident by the frequency of currents setting normal to the shoreline. Figure 35 examines a short segment of the data in more detail. The net drift during the time of observation was to the west. Currents set generally southwest on the ebbing tide and north during flood.

Current meter #427 was installed during the summer field survey in slightly deeper water (49 feet (14.9 meters)) and several hundred yards further offshore than meter #175. The direction histogram for meter #427 shows a more exaggerated northeast-southwest alignment (fig. 36) than the shallower installation. In addition, the winter data from meter #175 shows southwest currents to be dominant, whereas, the summer data from meter #427 shows a dominance of northeast currents. Faster currents were also recorded in the summer.

Two dye injections were made near the Agat outfall during the winter field survey (figs. 37 and 38), and nine injections were made during the summer survey (figs. 39 through 45). Dye injected and tracked near Alutom Island and Nimitz Beach indicated a slow southerly drift along the reef margin. The general pattern that emerges from the dye studies at the Agat outfall is that of sluggish eddying currents. On two occasions (figs. 39 and 42) dye deposited near the mouth of the outfall moved over the reef flat and spread out along the shoreline.

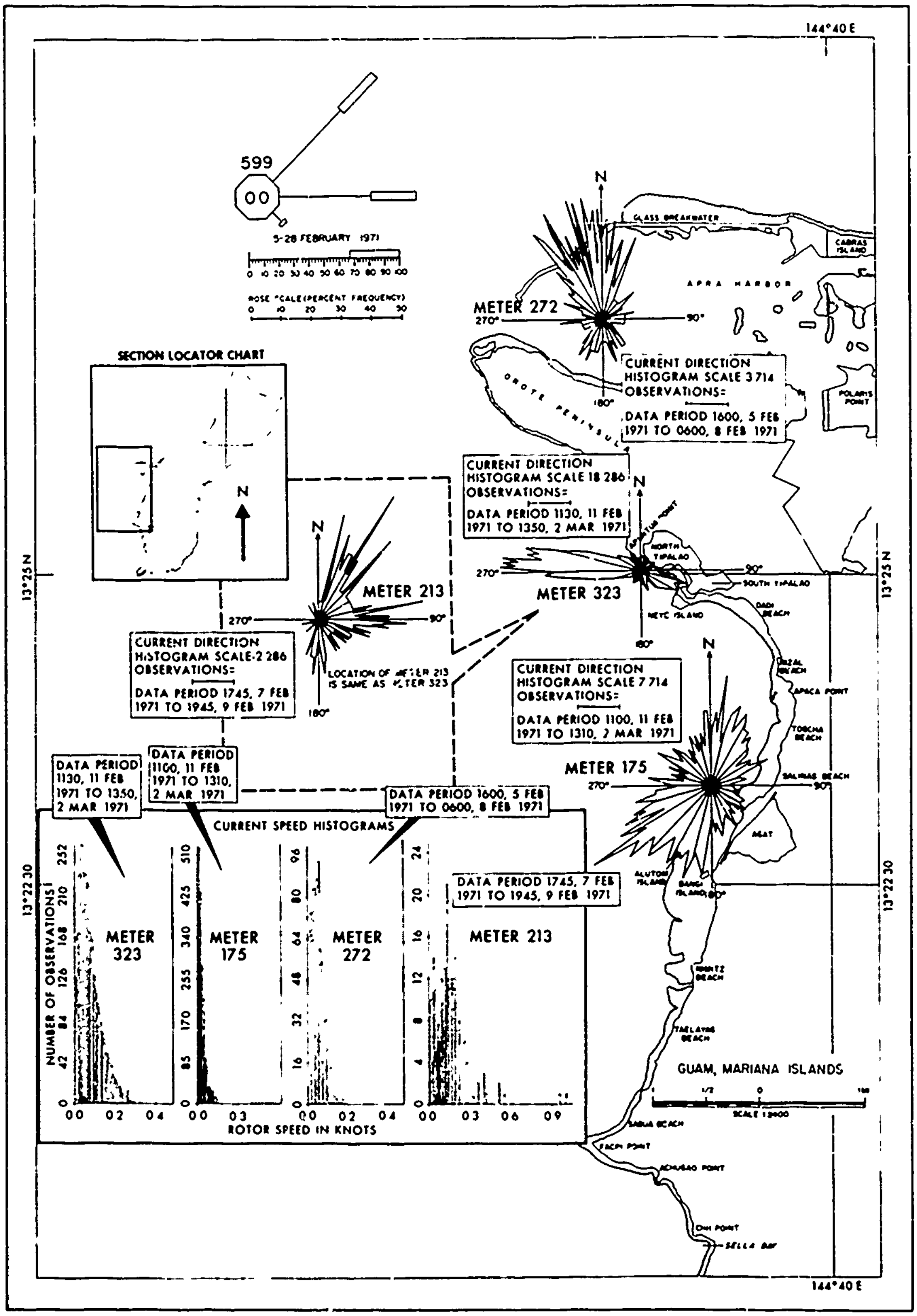


Figure 34. Current speed histograms and current direction histograms for the Agat Section in winter including meters #323, #175, #272, and #213 and a wind rose for the data period.

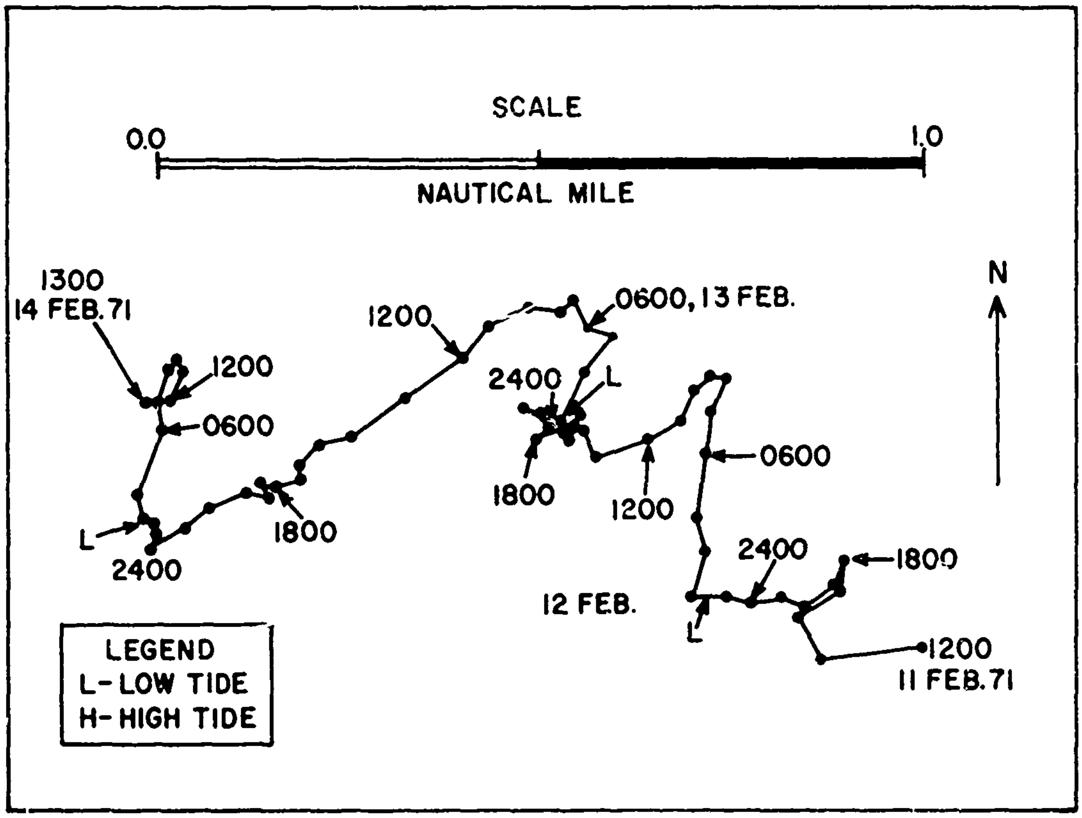


Figure 35. Progressive vector diagram of current from meter #175, 1200, 11 February to 1300, 14 February 1971.

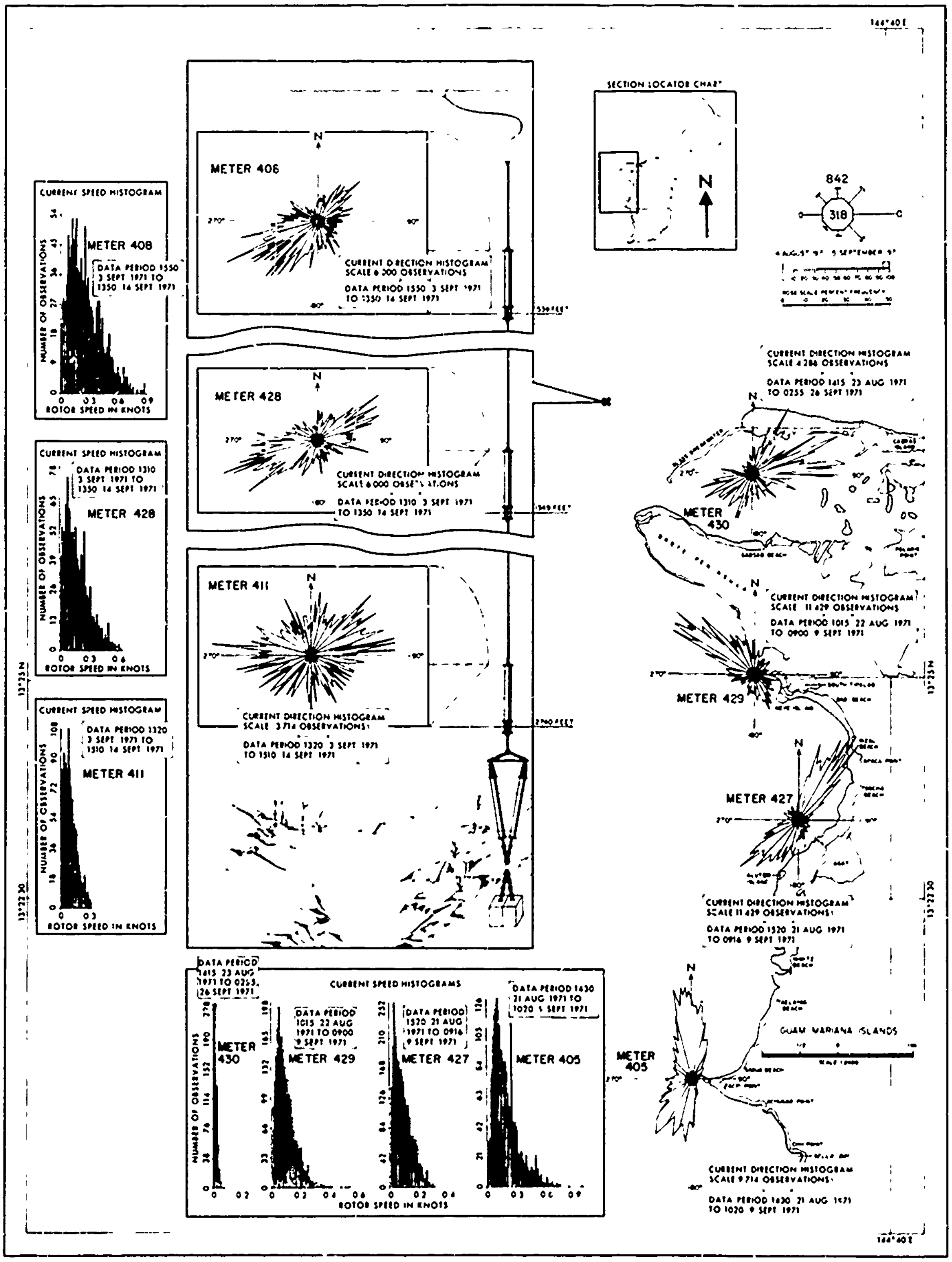


Figure 36. Current speed histograms and current direction histograms for the Agat Section in summer including meters #408, #428, #411, #405, #427, #429, and #430 and a wind rose for the data period.

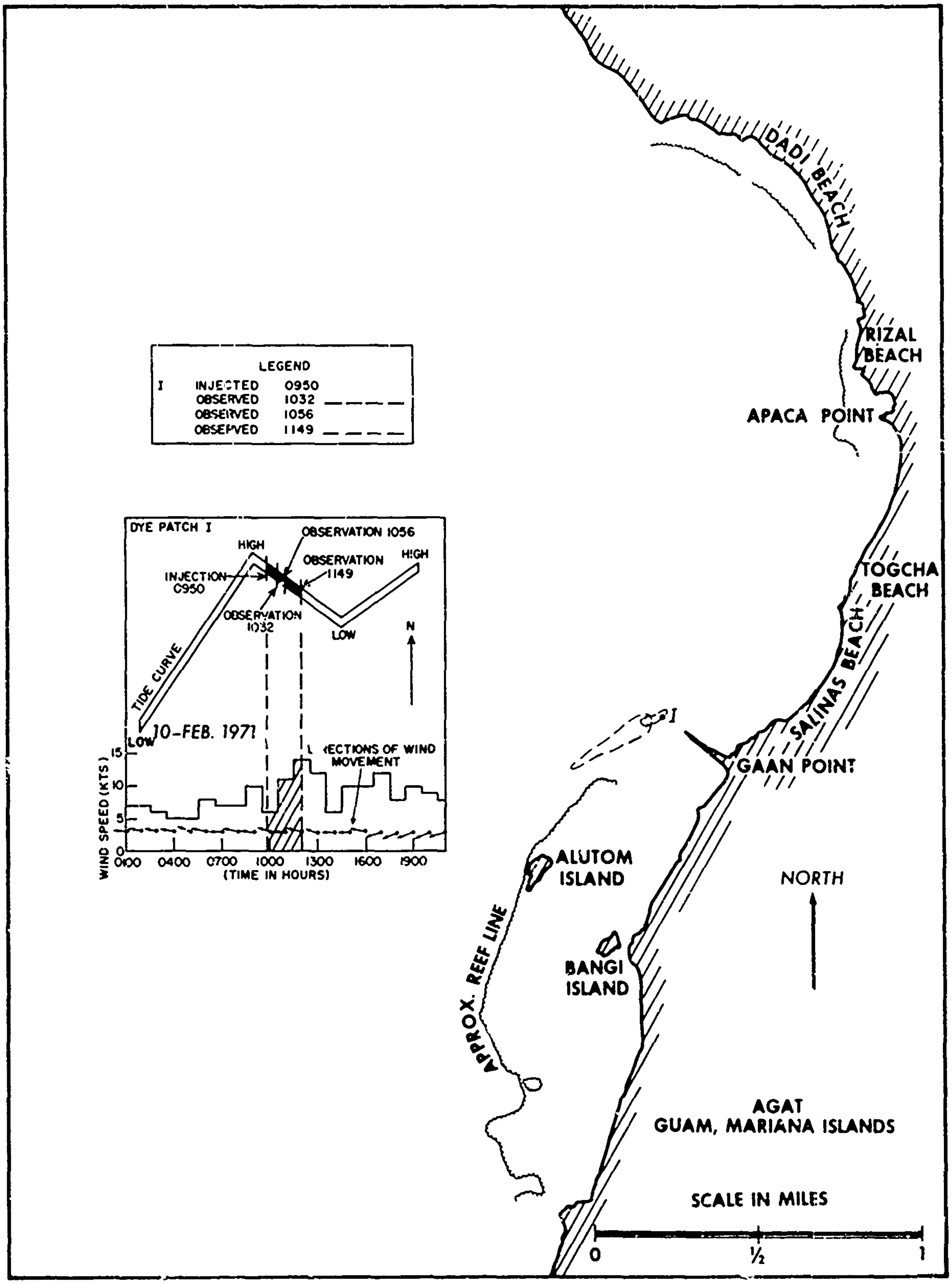


Figure 37. Dye movement at Agat Bay on 10 February 1971, A.M.

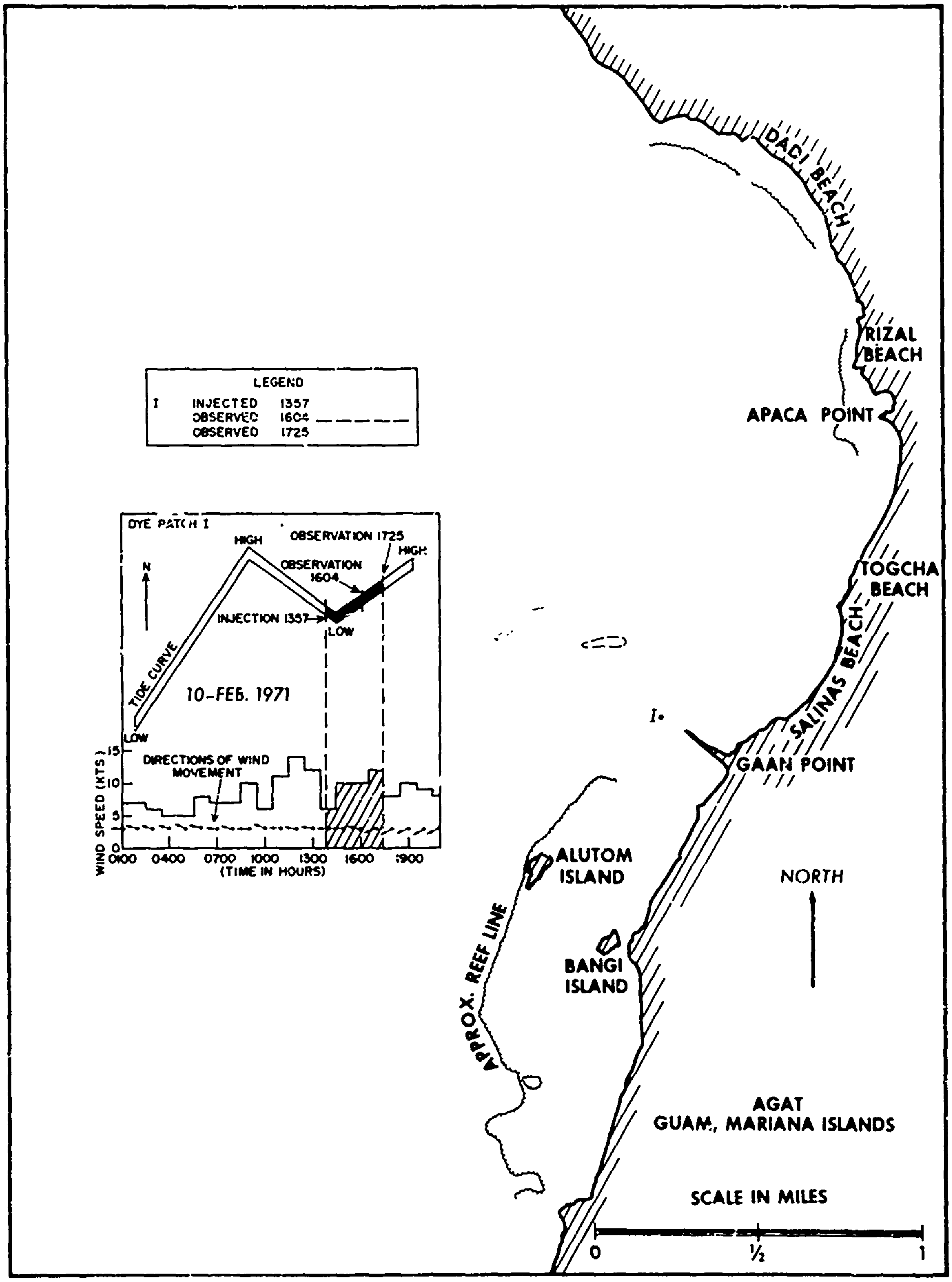


Figure 38. Dye movement at Agat Bay on 10 February 1971, P.M.

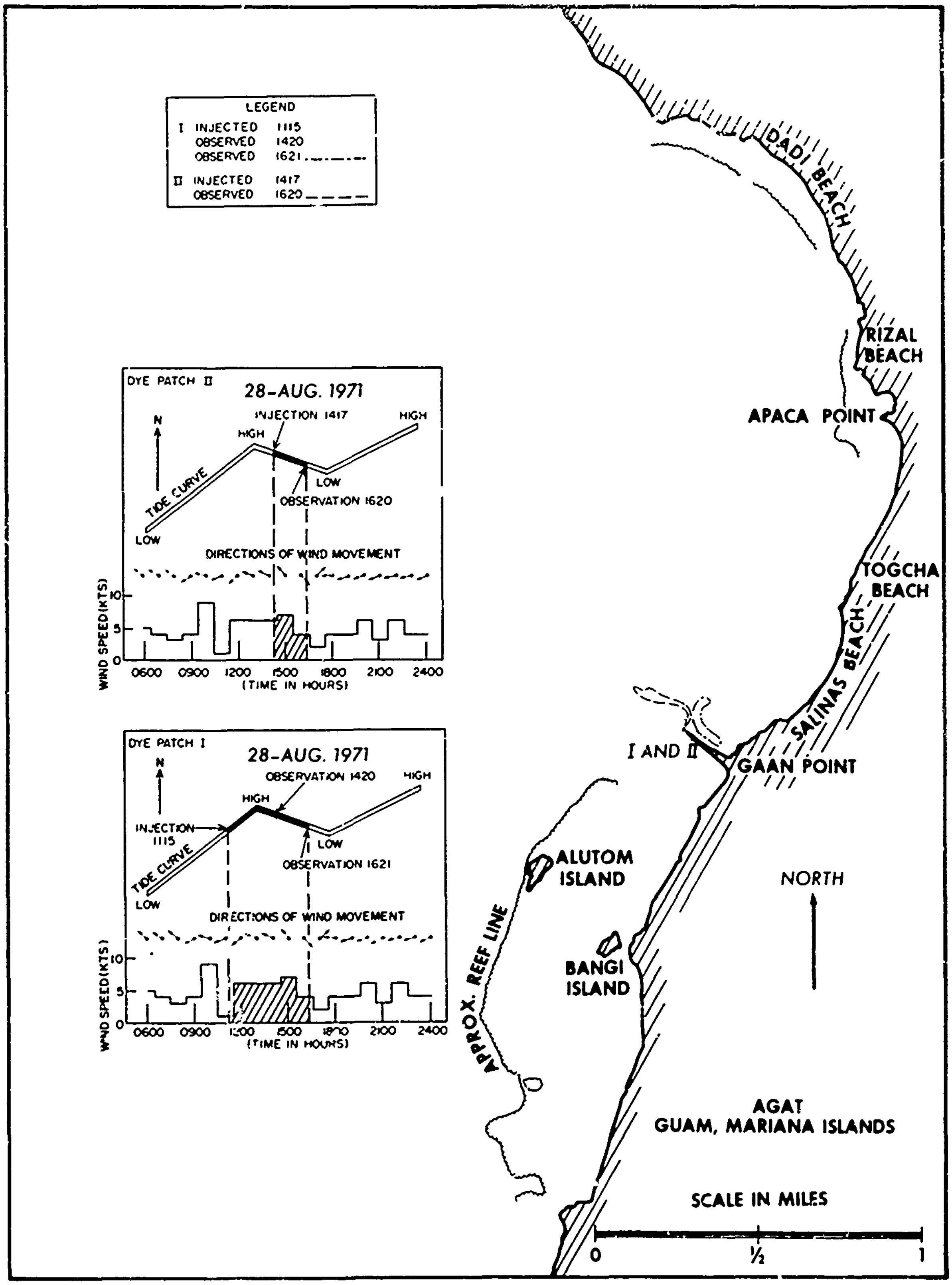


Figure 39. Dye movement at Agat Bay on 28 August 1971.

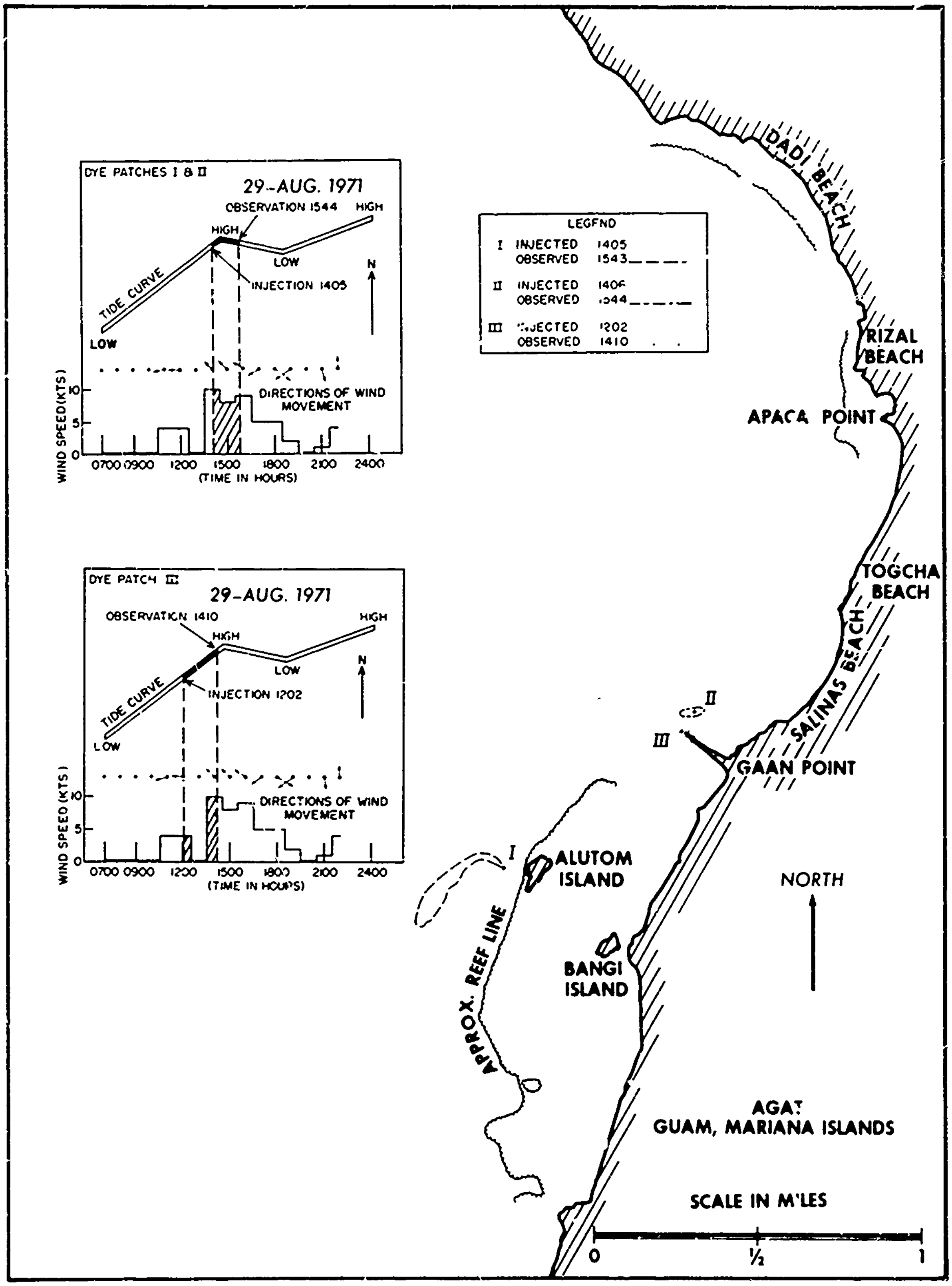


Figure 40. Dye movement at Agat Bay on 29 August 1971.

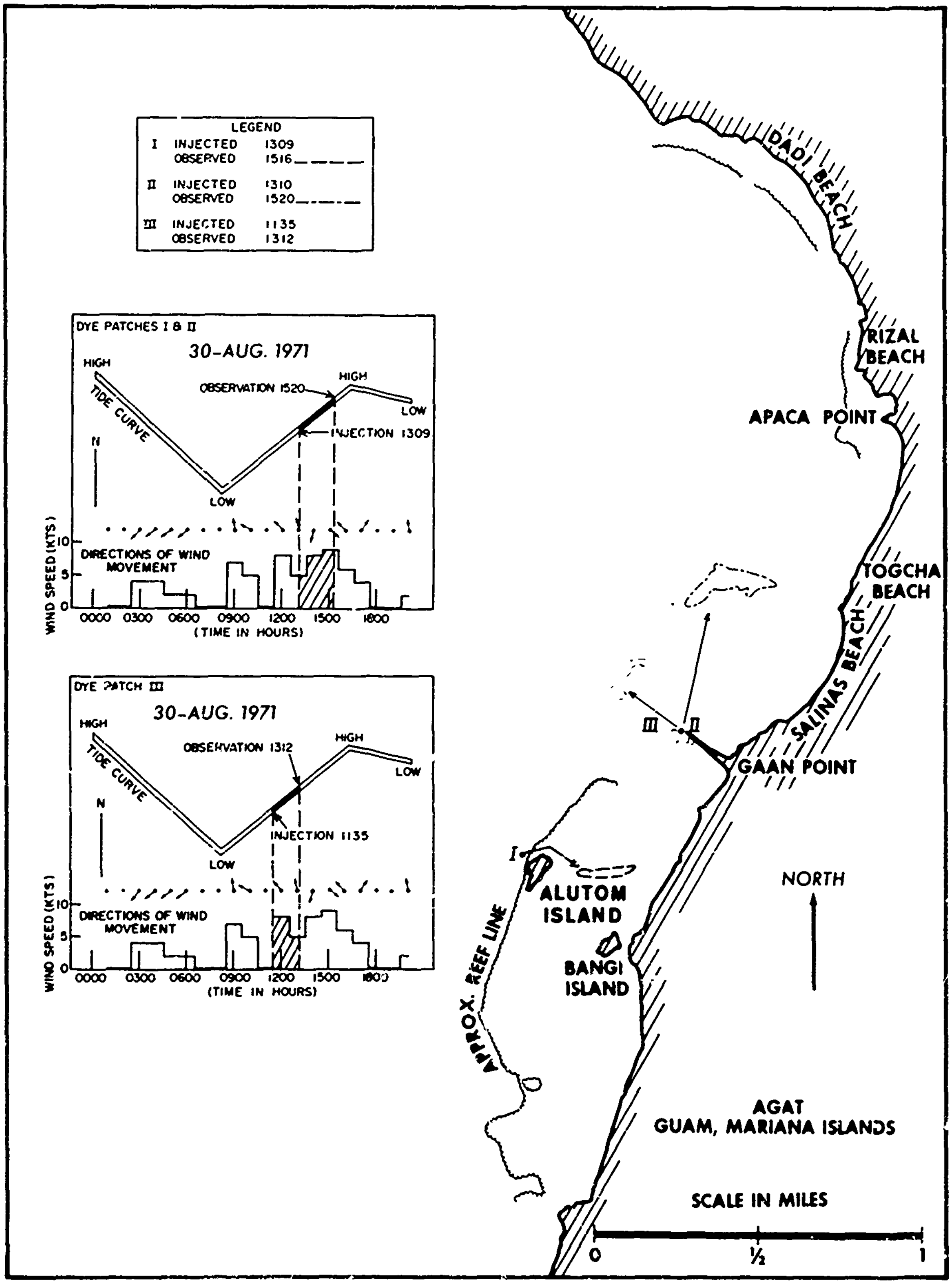


Figure 41. Dye movement at Agat Bay on 30 August 1971.

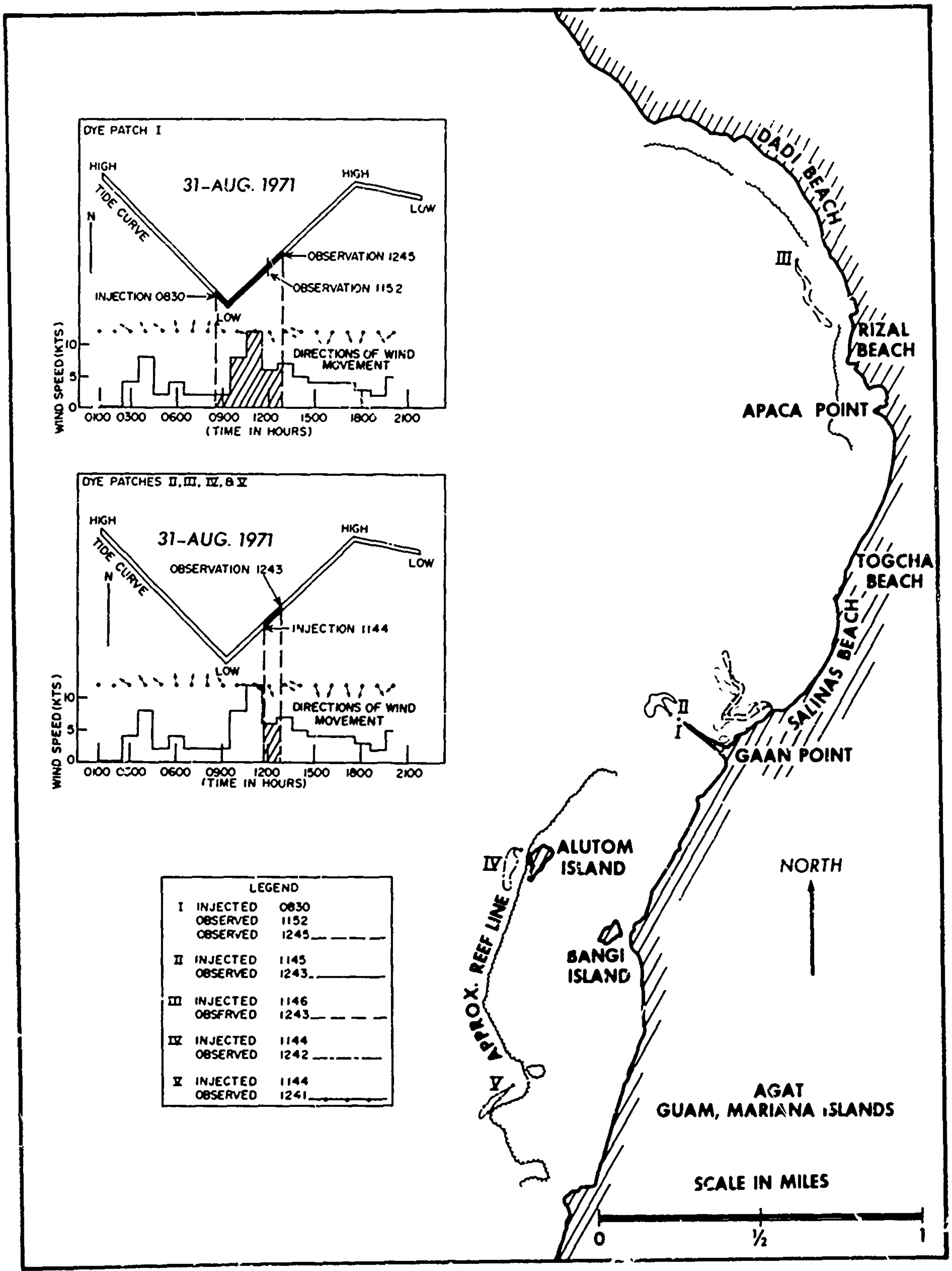


Figure 42. Dye movement at Agat Bay on 31 August 1971.

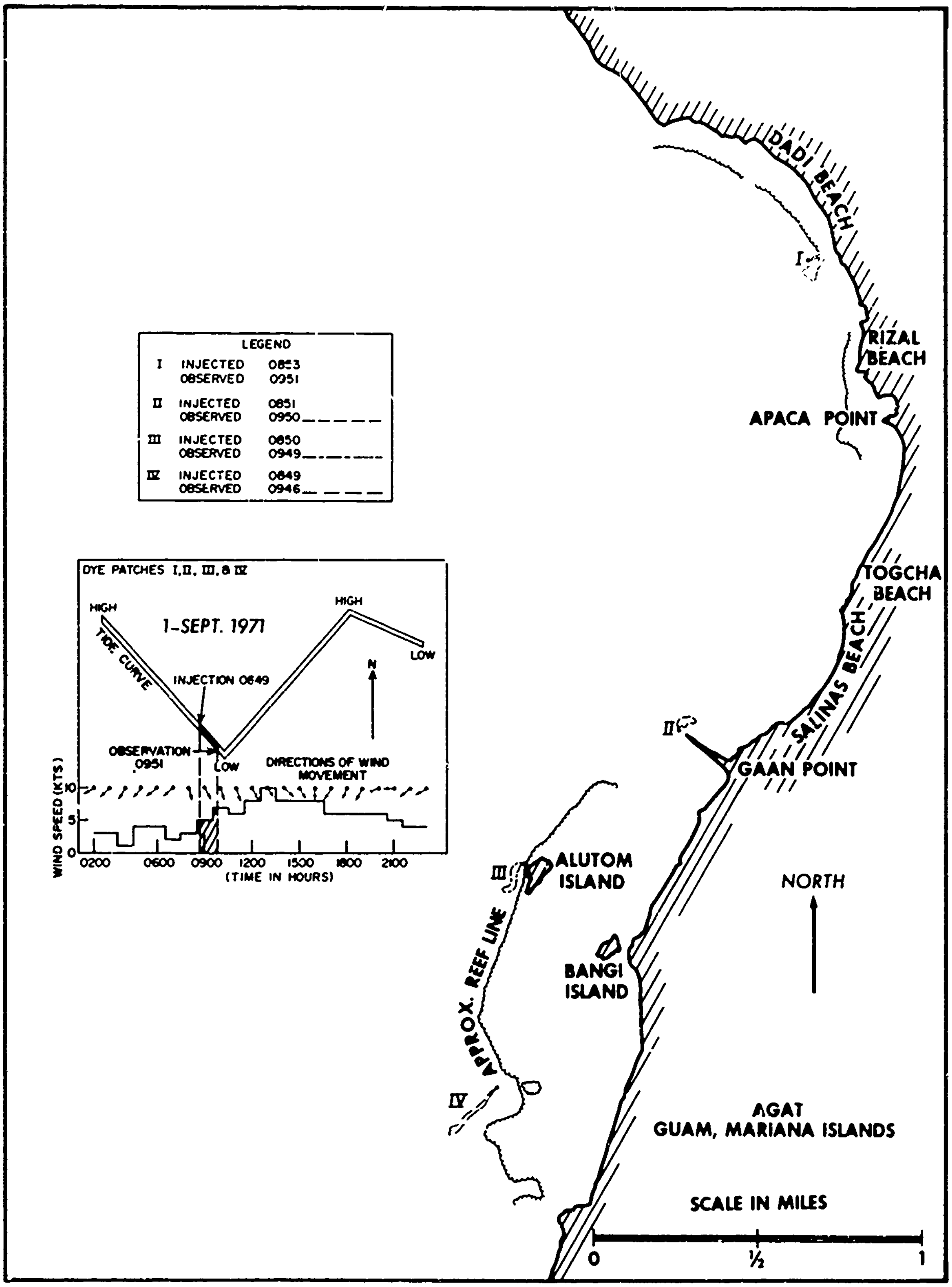


Figure 43. Dye movement at Agat Bay on 1 September 1971.

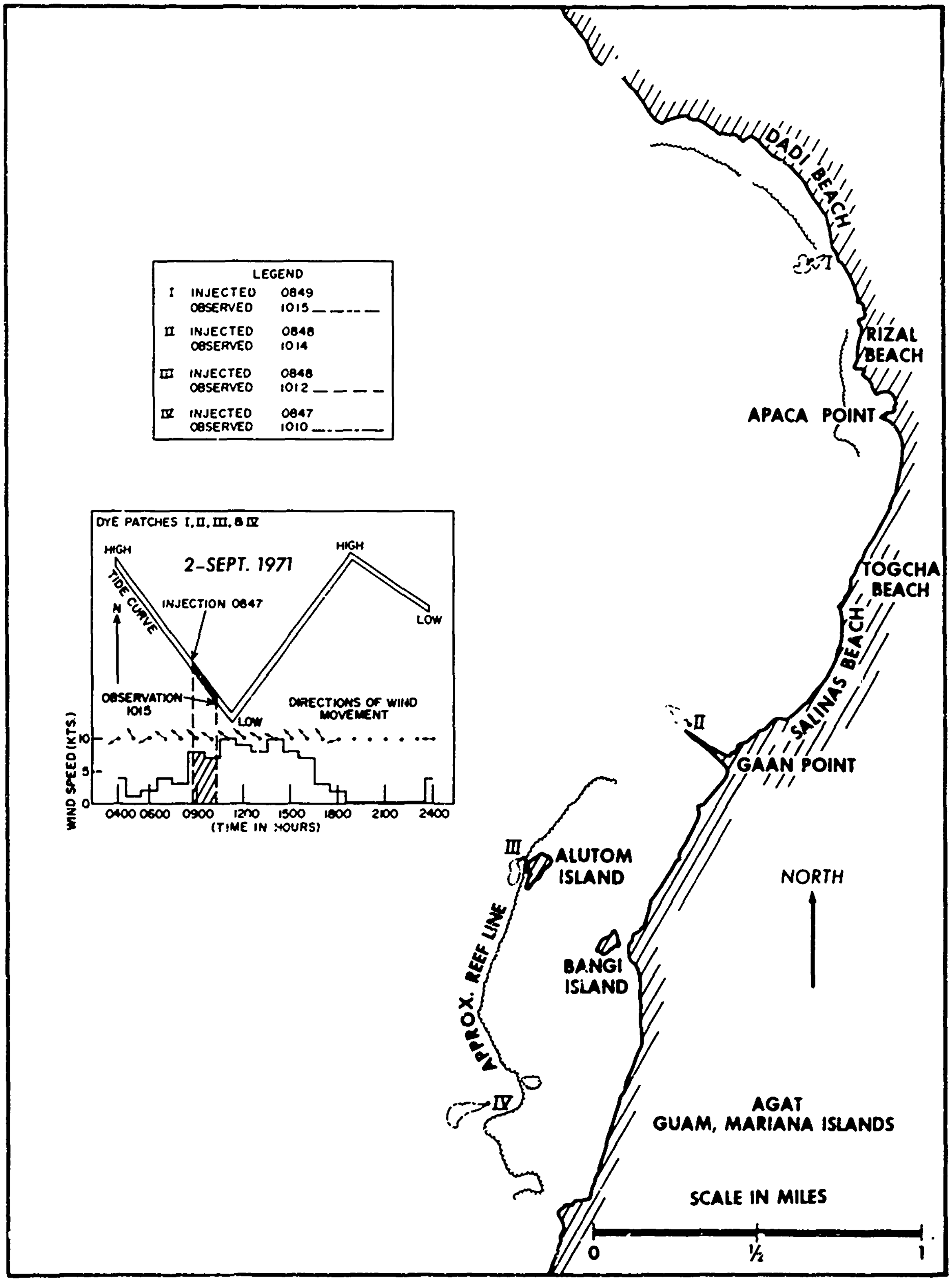


Figure 44. Dye movement at Agat Bay on 2 September 1971.

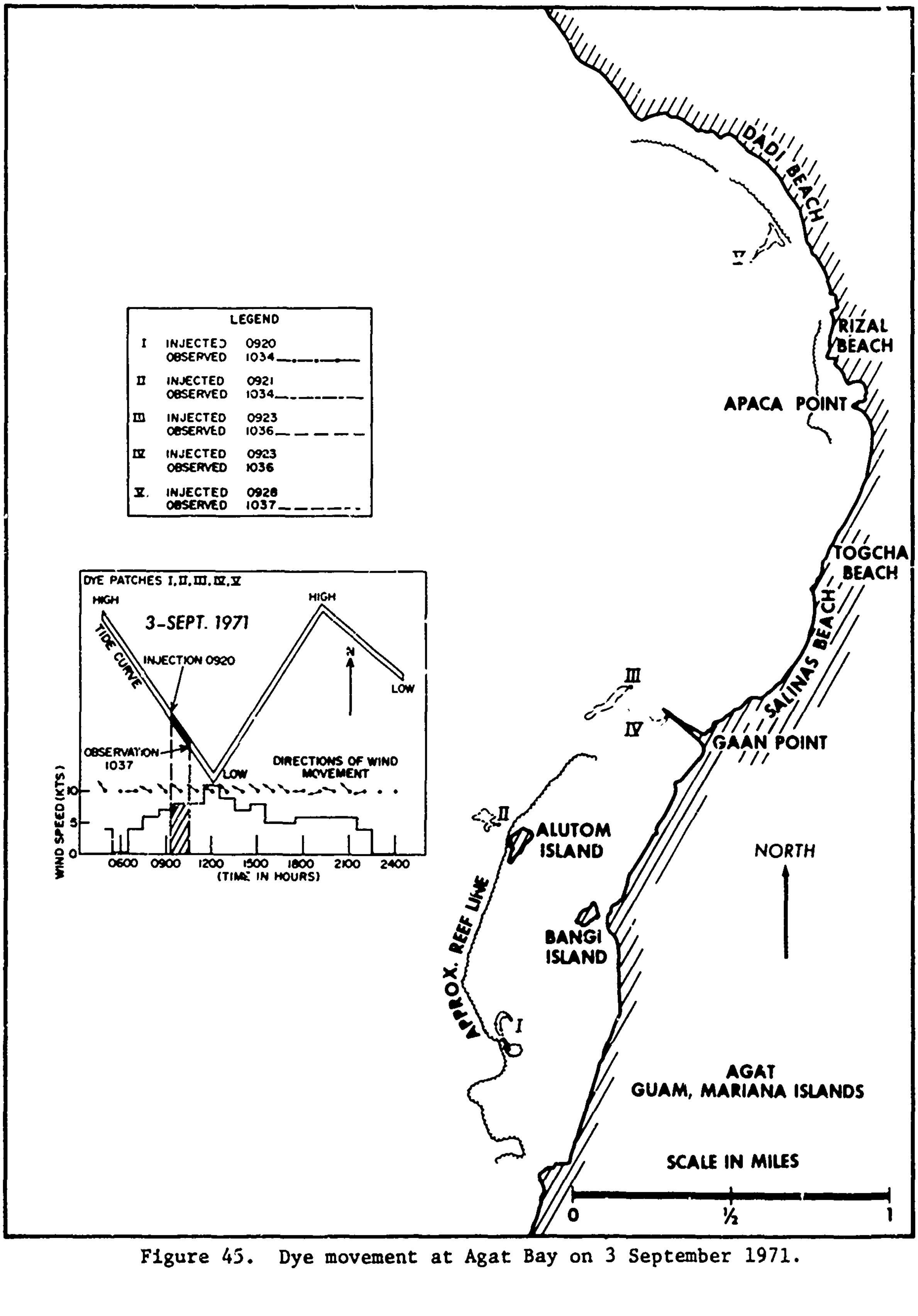


Figure 45. Dye movement at Agat Bay on 3 September 1971.

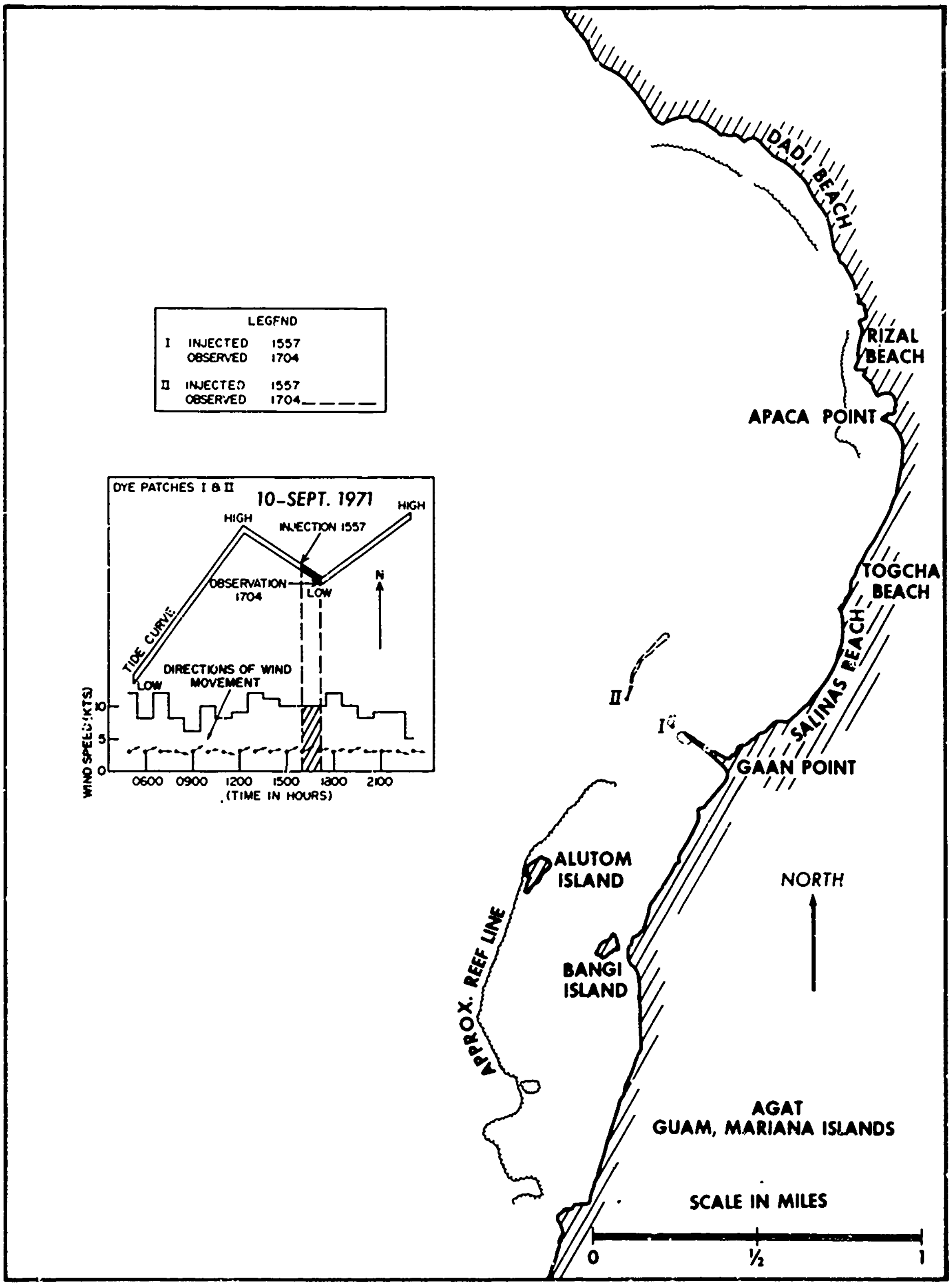


Figure 46. Dye movement at Agat Bay on 10 September 1971.

Current meters were installed at Tantapalo Point during both winter and summer field surveys. They were placed on a bottom stand in 65 feet (19.8 meters) of water 200 feet (61 meters) from an outfall which dumps sewage over a cliff into the water. Data from meter #323, installed during the winter field survey, are presented in figures 34, 47, and 48. Most of the currents observed flowed toward the west; however, the direction histogram shows a secondary peak toward the southeast. Current speeds were strongly influenced by tides. The highest current speeds occurred 1 to 2 hours after each low tide. Currents were westerly during the peak flows changing to southeasterly after each high tide when speeds were least.

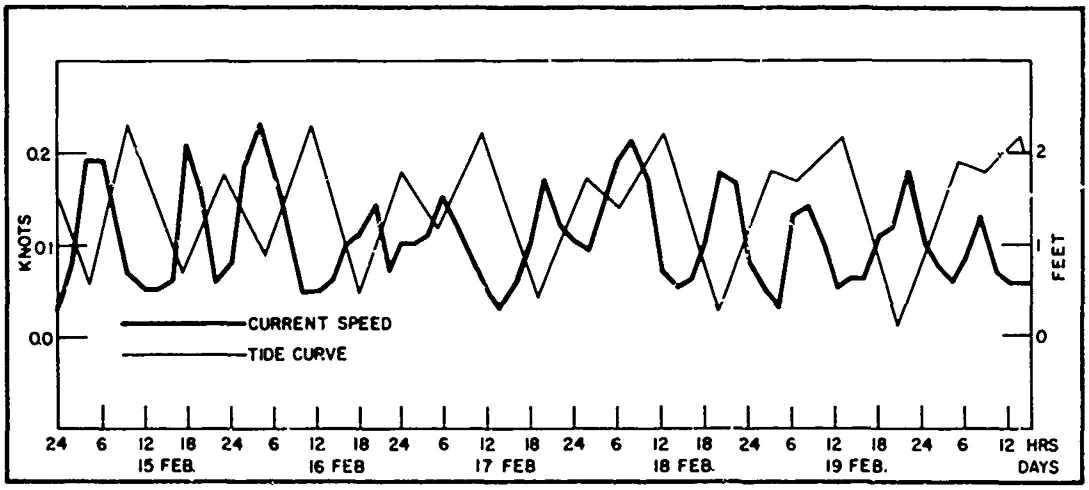


Figure 47. Current speeds versus tides from meter #323, 0000, 15 February to 1400, 20 February 1971.

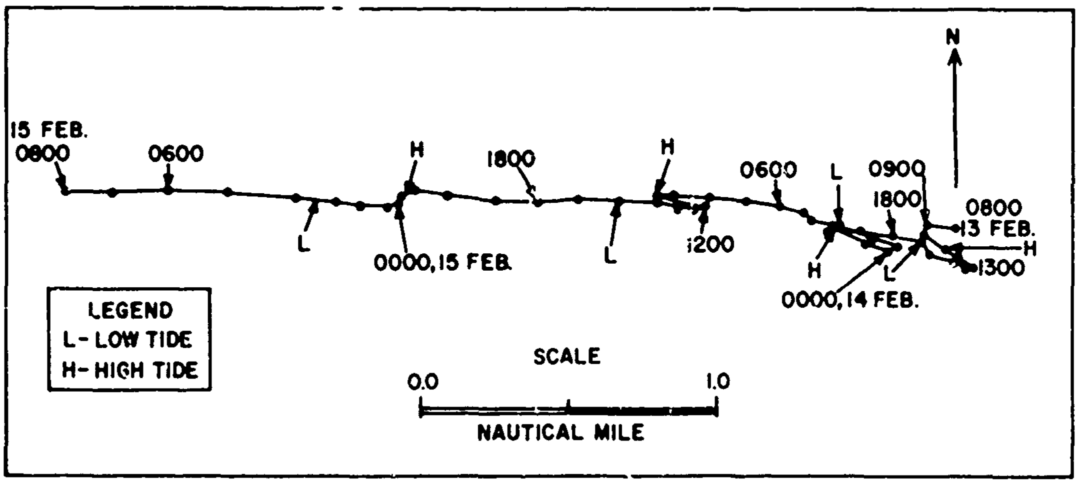


Figure 48. Progressive vector diagram of current from meter #323, 0800, 13 February to 0800, 15 February 1971.

A similar situation existed during the summer field survey as shown in the data from meter #429 (figs. 36 and 49). Peak speeds occurred during rising tide and lower speeds were recorded during ebb. Speeds were generally higher during the summer, reaching a maximum of 0.55 knot (.275 m/sec). Currents flowed northwest during flood and were variably southeast and northwest during ebb.

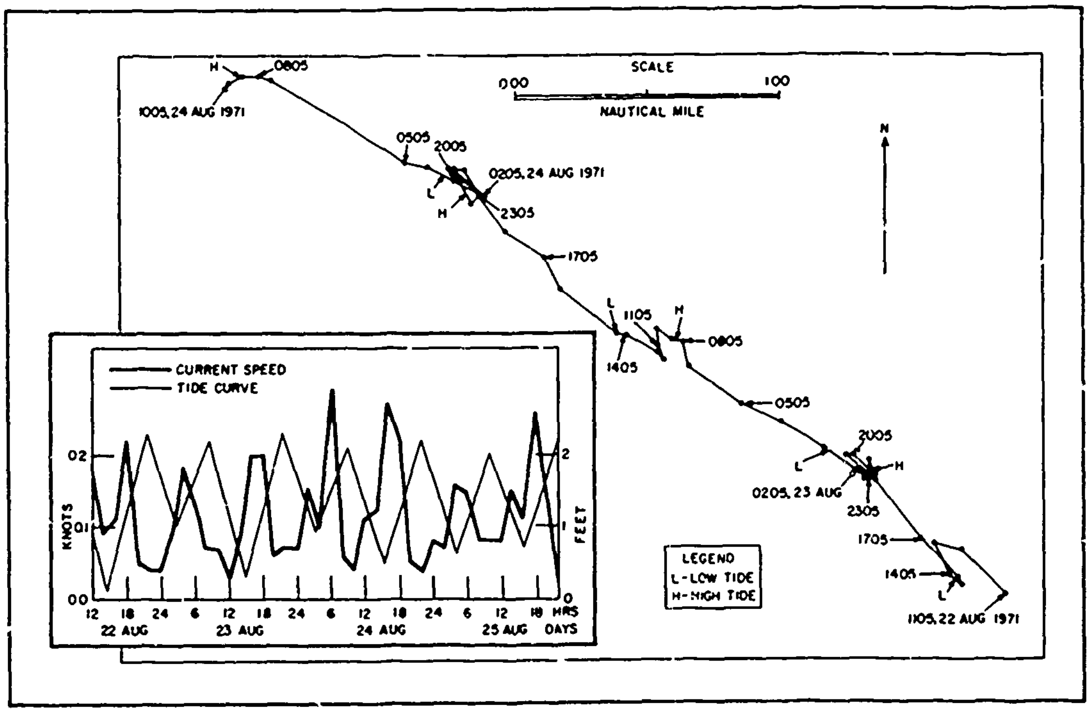


Figure 49. Progressive vector diagram of current from meter #429, 1105, 22 August to 1005, 24 August 1971, and current speeds versus tides from 1200, 22 August to 2000, 25 August 1971.

Two dye patches were tracked off Tantapalo Point on 10 February (figs. 50 and 51) and an aerial photograph was taken of the sewage effluent on 26 February (fig. 52). Dye and sewage movements confirmed the general pattern shown by the current meter data. Four dye injections were made off Dadi Beach during August and September (figs. 42 through 45). Three of these were observed during the falling tide and showed sluggish eddying currents. One dye patch, observed during flood, was subject to a relatively strong current setting to the south (fig. 42). This southerly flow during flood was exactly opposite to the general pattern at Tantapalo Point and illustrates the eddying nature of the currents in Agat Bay.

An array of three current meters was installed off Orote Peninsula during the summer survey. Currents decreased in speed with depth,

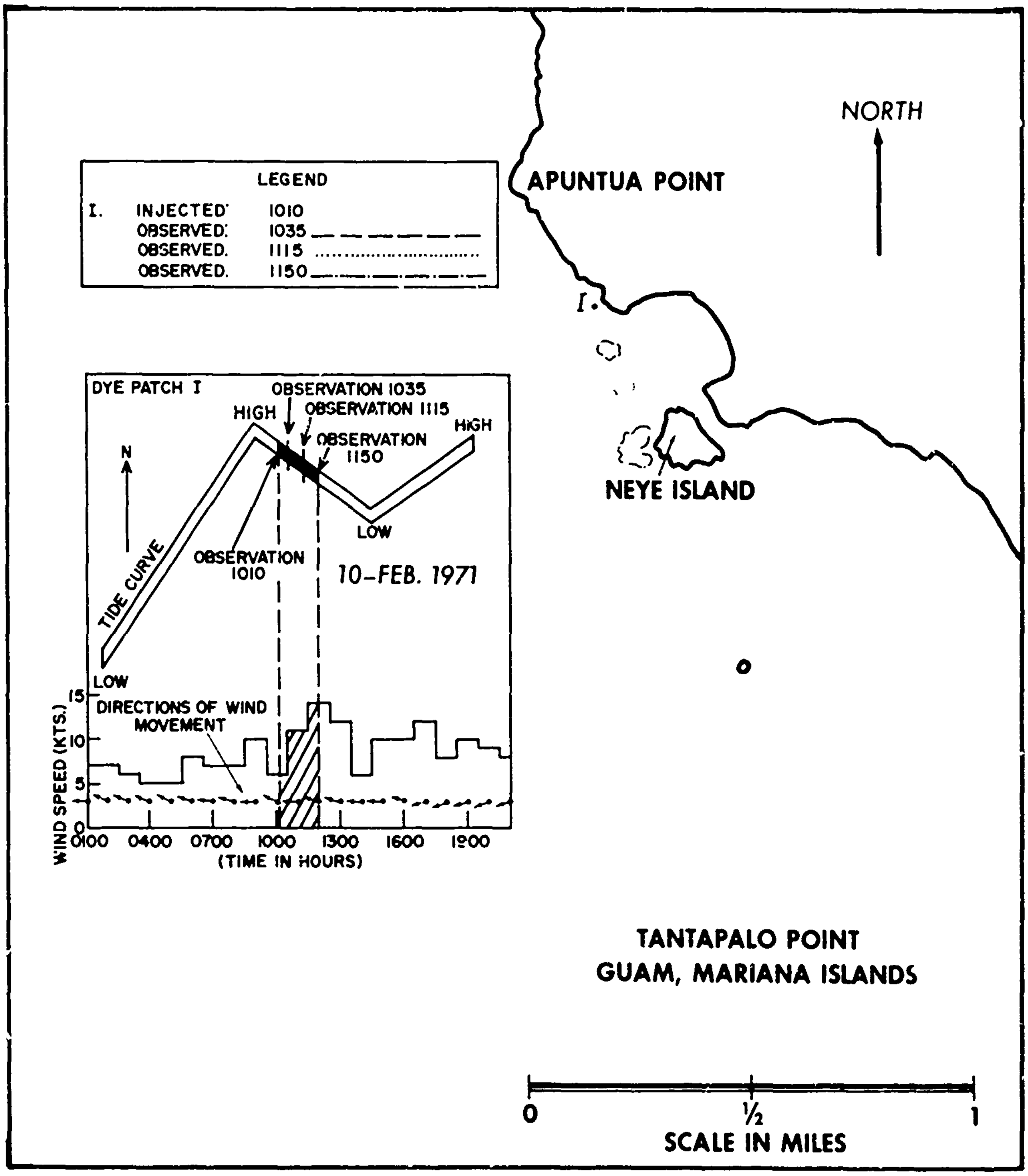


Figure 50. Dye movement at Tantapalo Point on 10 February 1971, A.M.

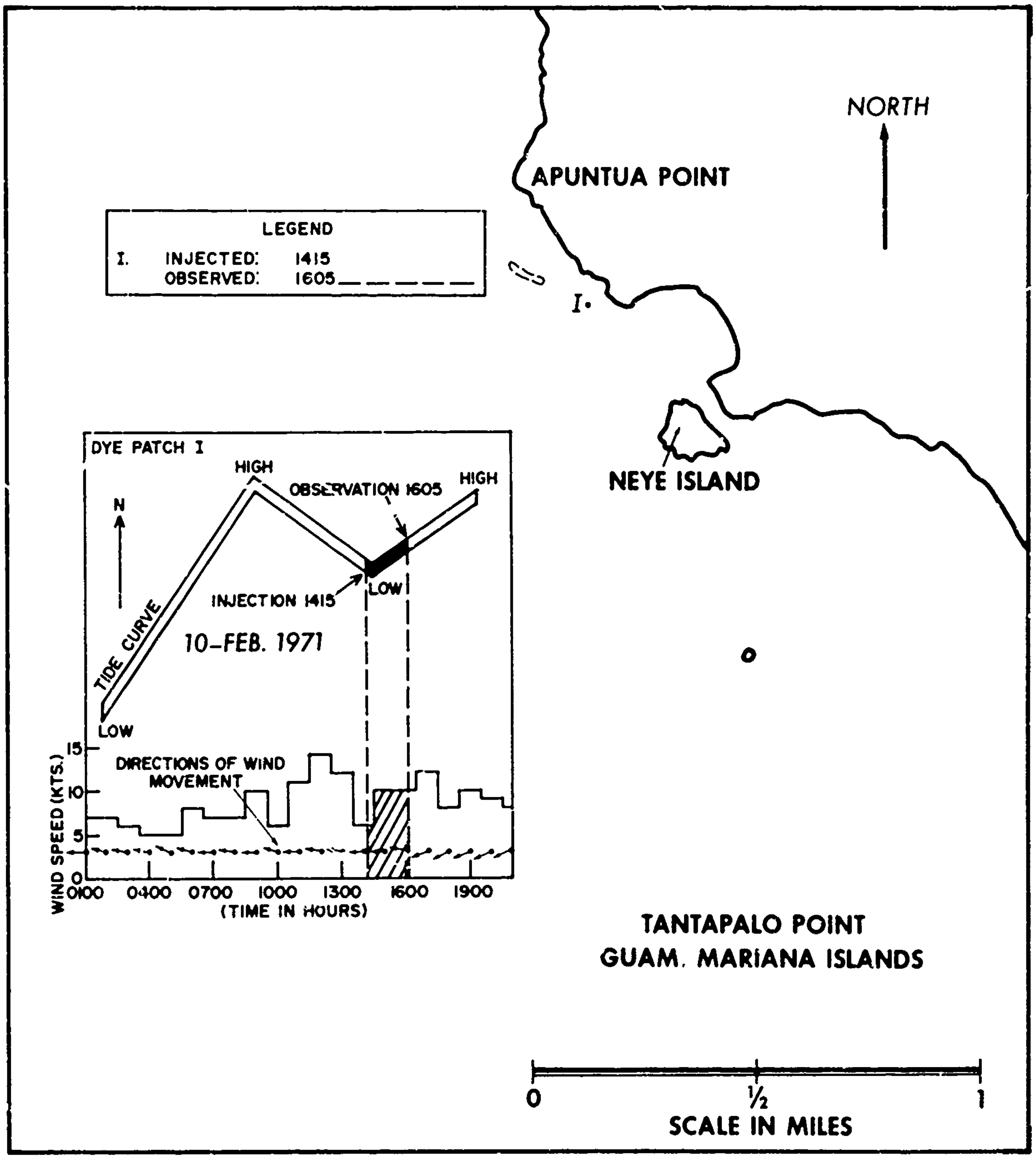


Figure 51. Dye movement at Tantapalo Point on 10 February 1971, P.M.

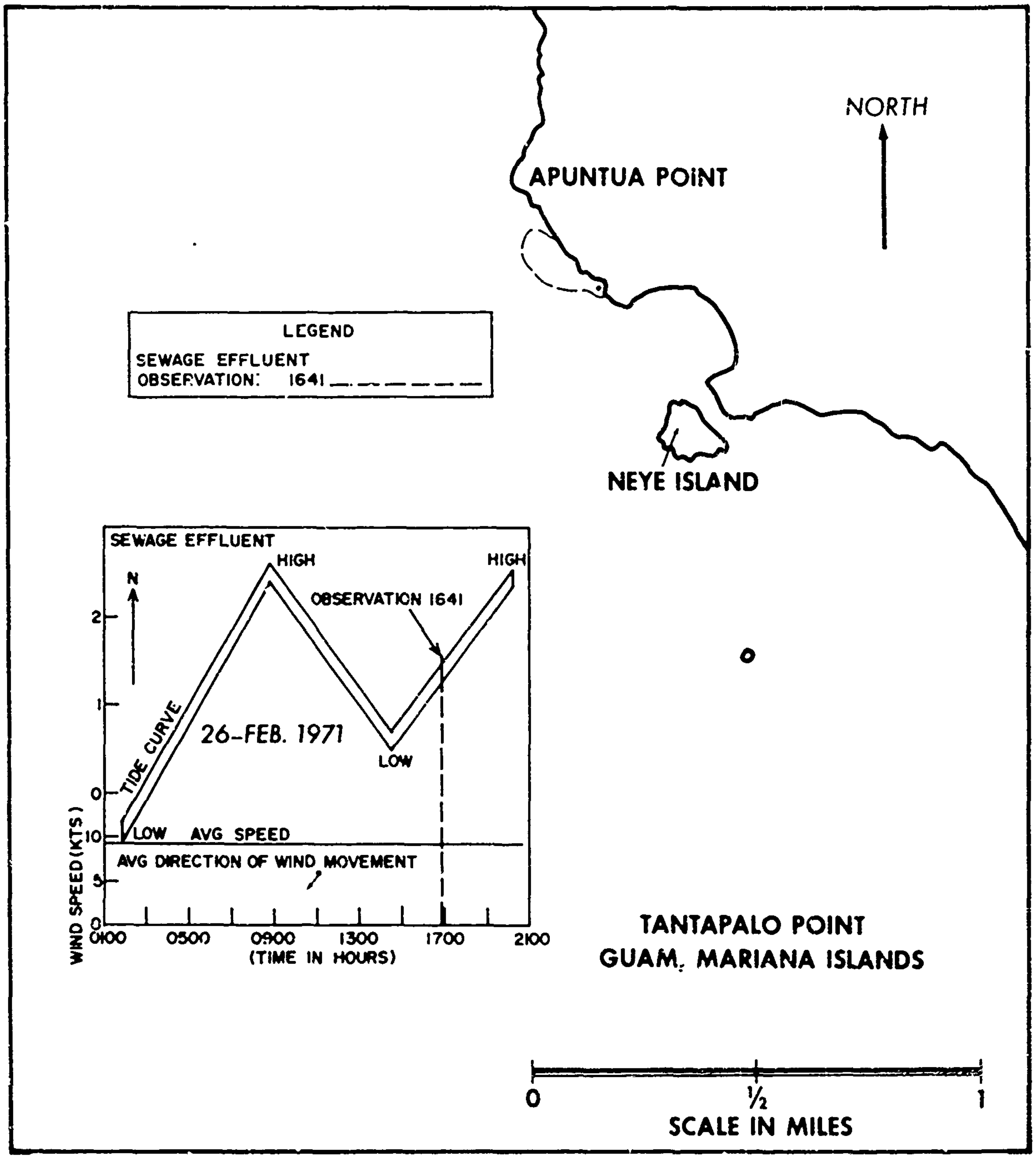


Figure 52. Sewage effluent at Tantapalo Point on 26 February 1971.

attaining a maximum speed of 0.89 knot (.445 m/sec) at the shallowest meter and a maximum speed of 0.33 knot (.165 m/sec) at the deepest meter. The current direction histograms show a northeast-southwest orientation for the top and middle meters, but an almost circular pattern for the bottom meter.

In figures 53 and 54 the relationship of the data to tides and times can be examined more closely. At middepth currents flowed southwest for 2 to 3 hours before and after each low tide and reached a maximum speed approximately at the time of low tide. Similarly, currents flowed northeast for approximately 6 hours around high tide and reached another maximum speed at about the time of high tide.

The surface meter showed a similar but opposite pattern during the late evening and early morning hours; the flow being southwest at high tide and northeast at low tide. Between approximately 0600 hours and 2300 hours on 6 September a consistent southwest current was recorded. A maximum speed was reached during the times of high tides and a minimum speed was reached at the time of low tides. This periodicity resulted from a steady southwest current being reinforced by the tidal current during high tide. The source of the steady current was probably the local winds that reached highest velocities at midday and died down during late evening.

The bottom meter recorded very sluggish currents that varied in speed and direction without revealing any definite pattern. This meter was only 35 feet (10.7 meters) above the bottom and might have been affected by bottom topography.

Two current meters were installed near the bottom in Apra Harbor during the winter survey and one during the summer survey. They all recorded slight to non-existent currents that appear to be caused by the tidal emptying and filling of the harbor.

Five drogue-tracking operations were conducted in Agat Bay and off Orote Peninsula (figs. 55 through 59). Most of the drogues moved northward; and, in some cases, with considerable eddying. On 23 February the drogues drifted initially toward the east-southeast, but they turned to parallel the coastline upon approaching the island.

The current data collected in this section is another example of the general unsuitability of bays and other semienclosed waters for sewage disposal. The slow eddying of surface waters within Agat Bay is in marked contrast to the stronger, more consistent flow off Facpi Point, Orote Peninsula, and Tantapalo Point. A water sampling program conducted by the Guam Department of Public Health and Social Services revealed that the sewage released at the Agat outfall pollutes a large area of Agat Bay. The outfall at Tantapalo Point appears to be in a more favorable location. The prevailing currents tend to carry the

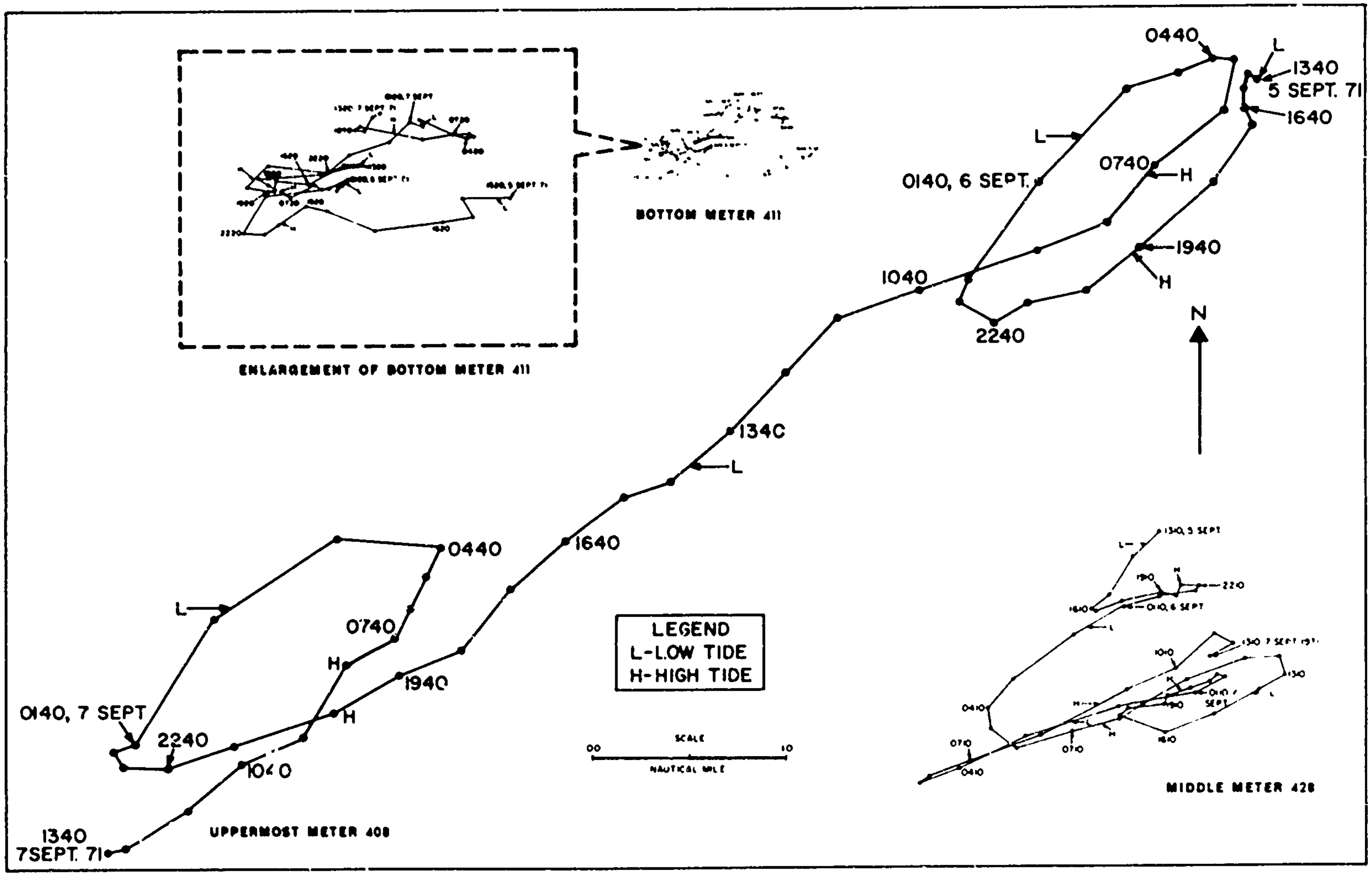


Figure 53. Progressive vector diagram of current from meters #408, #428, and #411.

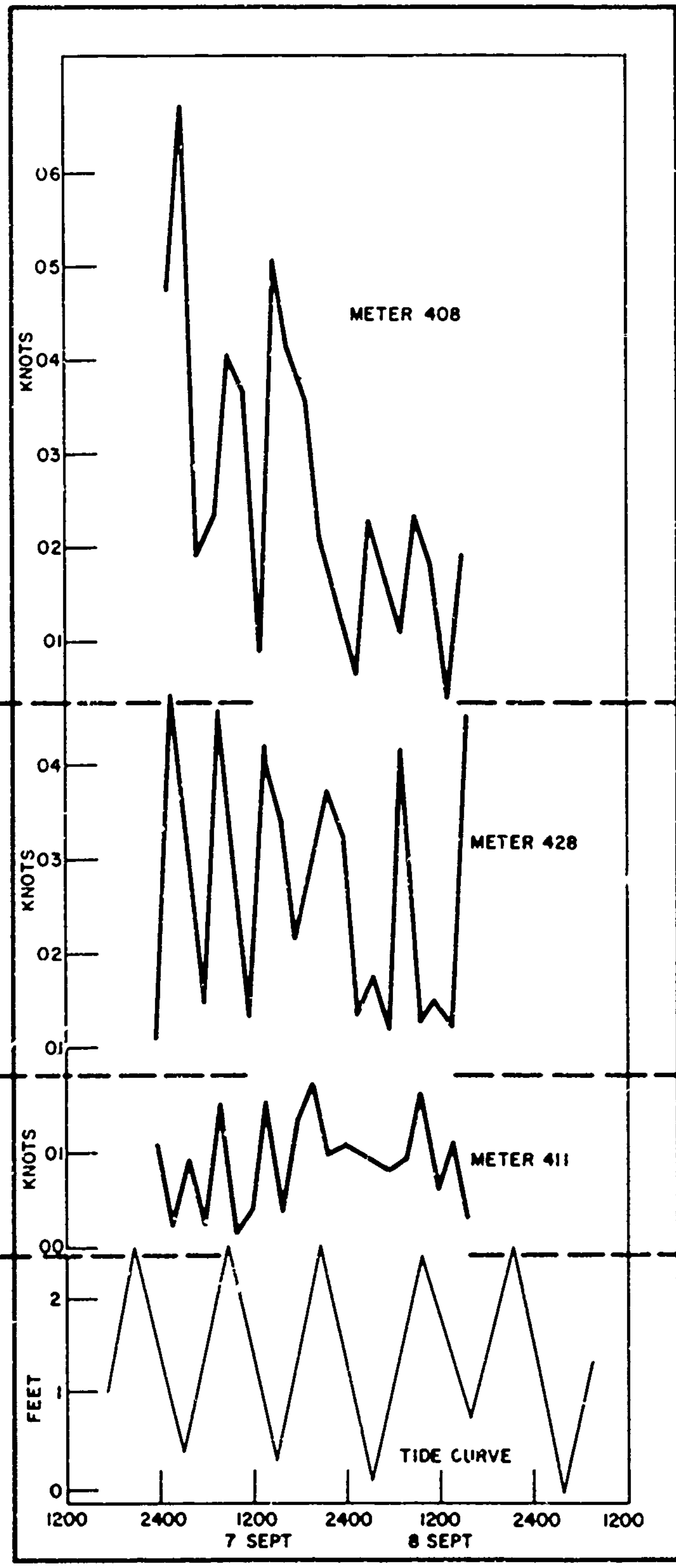


Figure 54. Current speeds versus tides from meters #408, #428, and #411.

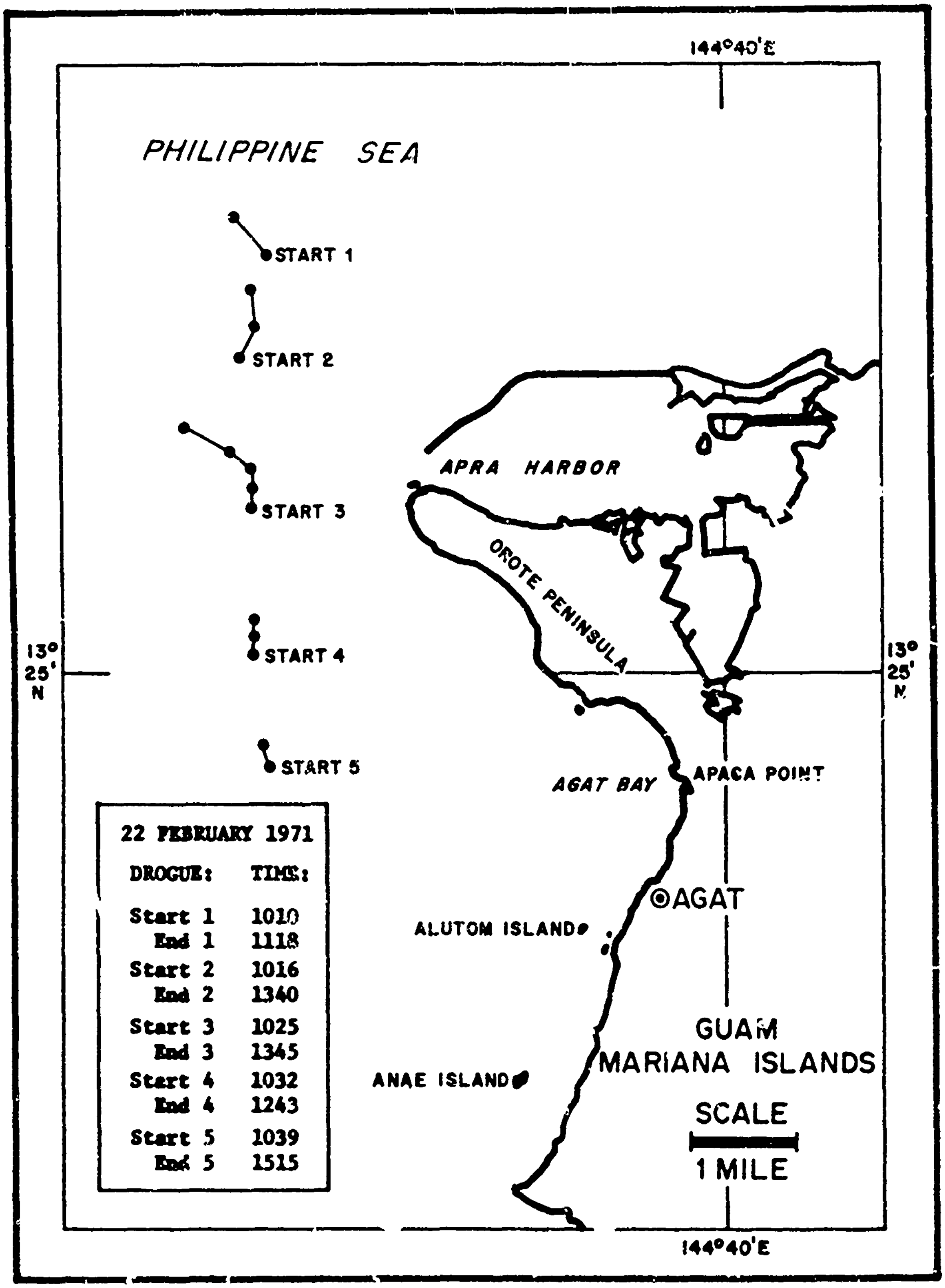


Figure 55. Drogue observations in Agat Section, 22 February 1971.

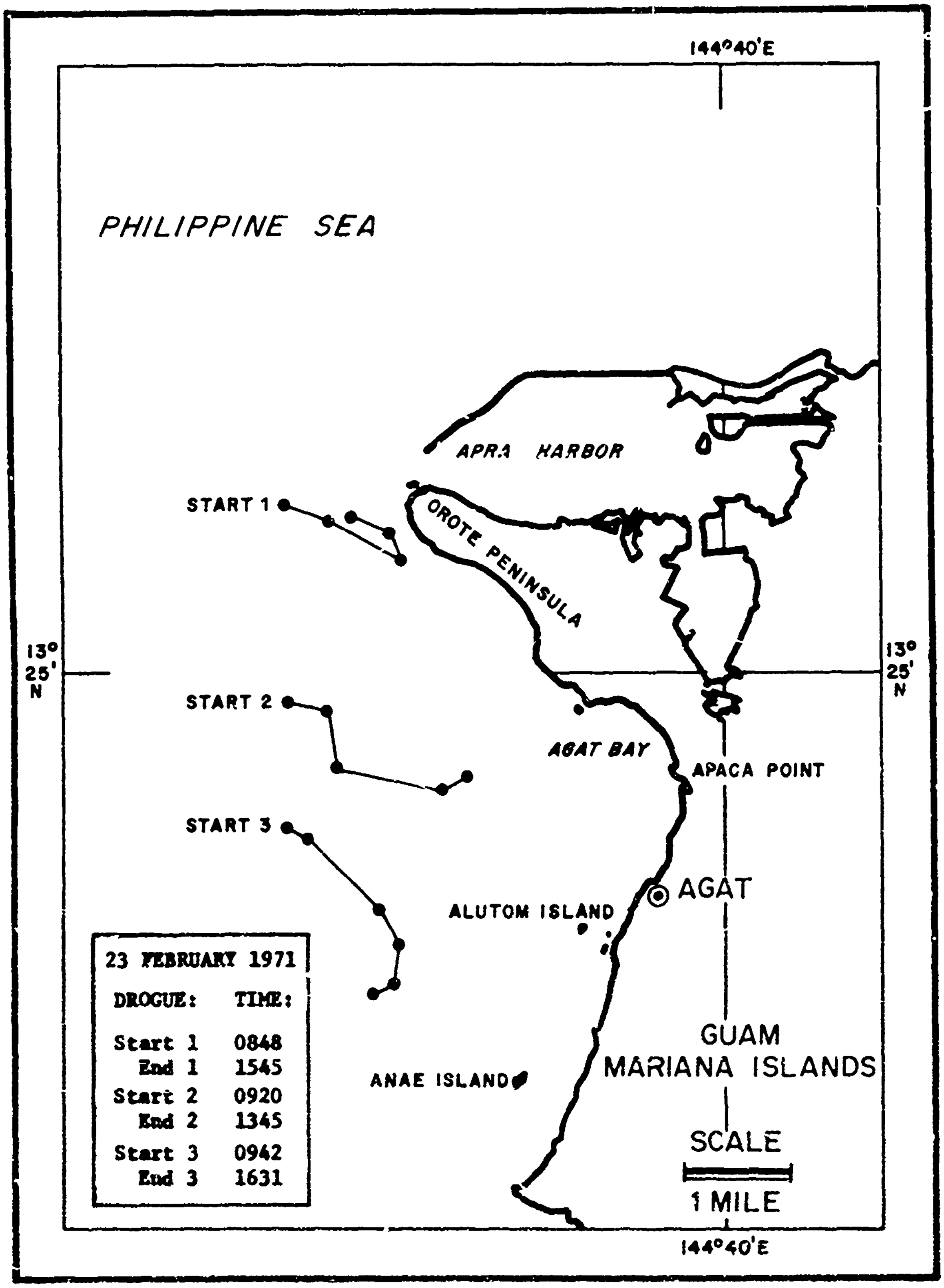


Figure 56. Drogue observat.ons in Agat S. · .on, 23 February 1971.

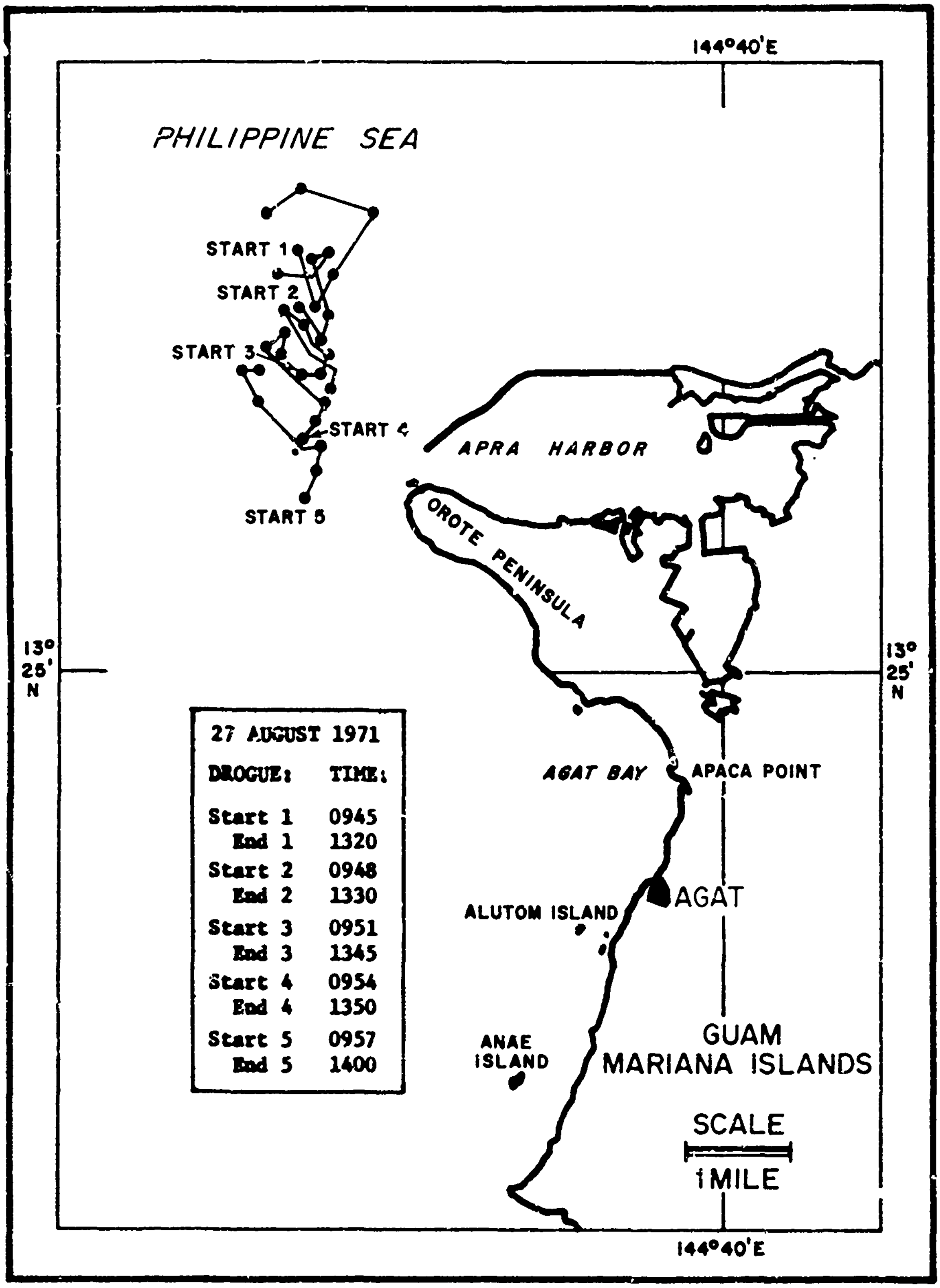


Figure 57. Drogue observations in Agat Section, 27 August 1971.

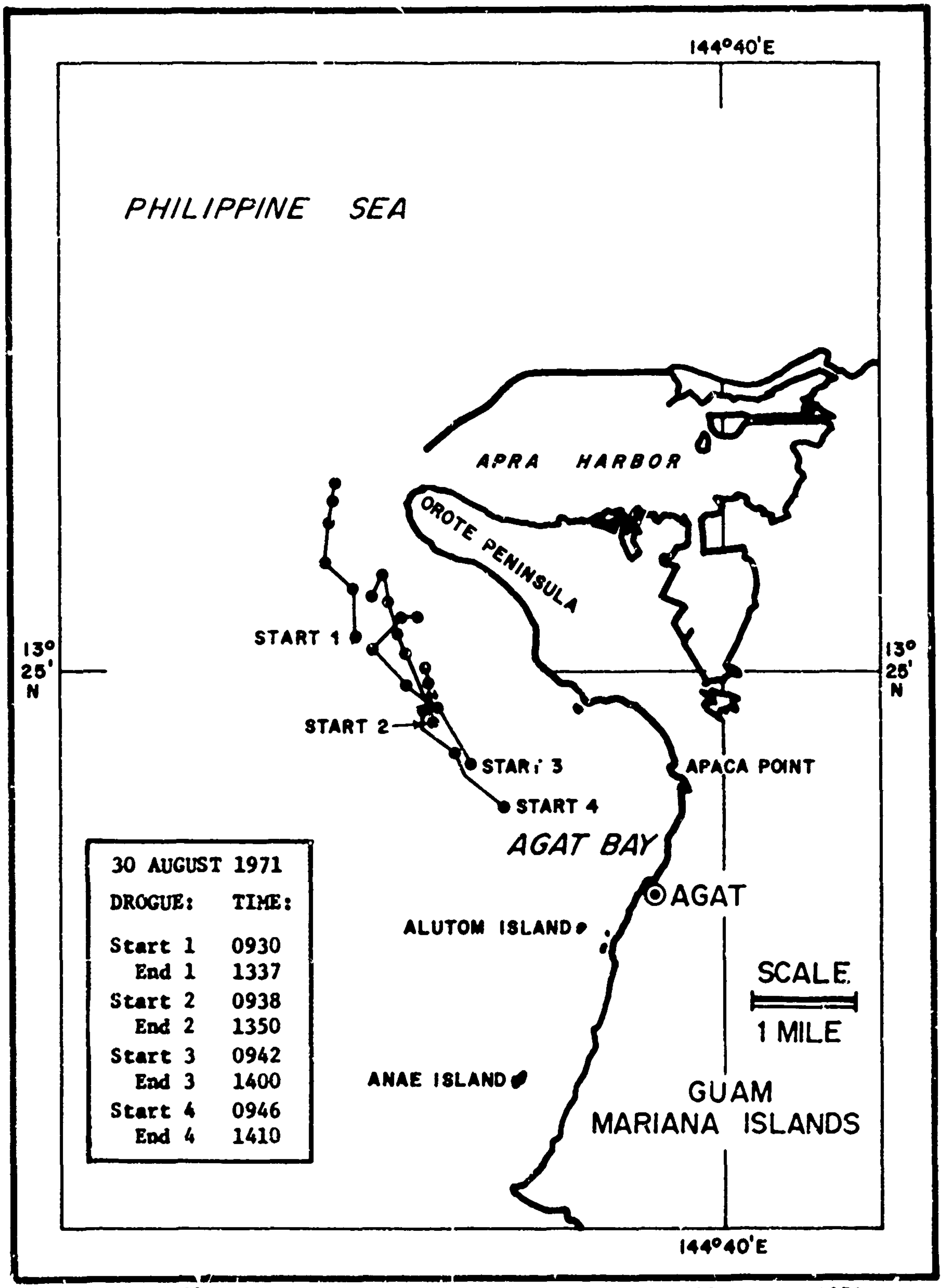


Figure 58. Drogue observations in Agat Section, 30 August 1971.

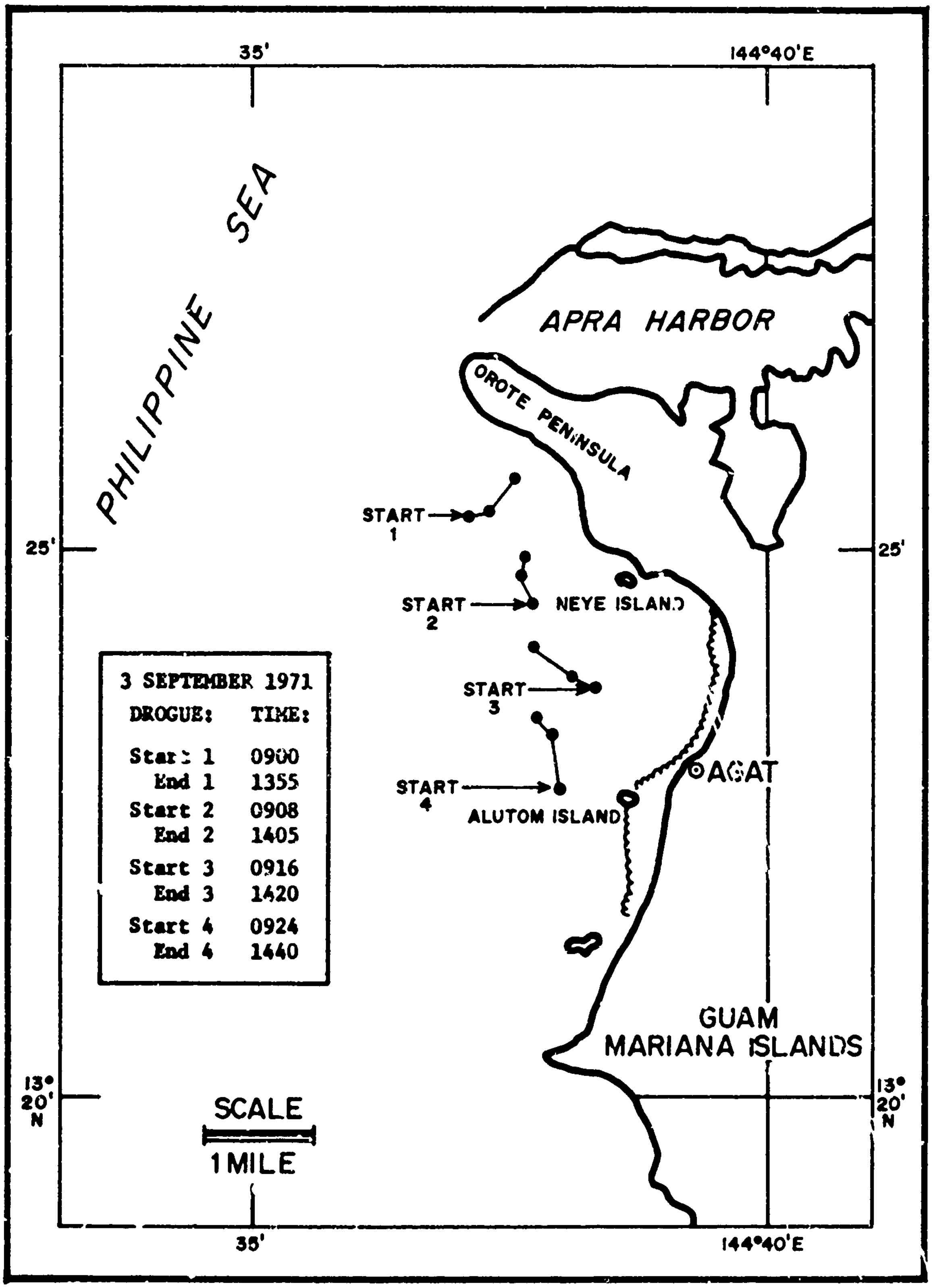


Figure 59. Drogue observations in Agat Section, 3 September 1971.

effluent west along the rugged, unpopulated coast of Orote Peninsula where it is eventually dispersed by the strong currents off the tip of the peninsula.

3. Agana Section

This section extends from Cabras Island on the west to Ypao Point on the east. The northerly facing coast is more exposed to the northeast trades than the sections discussed previously. Waves and surf along this coast were particularly high during the winter months when the majority of the winds were out of the east and northeast.

Cabras Island is the proposed site for an ocean outfall. Currents in this area were investigated by the installation of current meters during both surveys and by dye dispersal studies.

Current meter #361 was installed during the winter survey on a bottom stand in 35 feet (10.7 meters) of water approximately 200 yards (183 meters) off the northwest tip of Cabras Island. Currents during the period of installation flowed primarily to the west at speeds up to 0.59 knot (.295 m/sec) as shown in figure 60. Progressive vector plots (fig. 61) show that the westerly currents were not only more frequent but were stronger and resulted in a consistent westerly net movement. Little correlation between tidal changes and shifts in current speed or direction is apparent from this data.

Current meter #419 was installed during the summer survey in about the same location as #361 but in deeper water at 55 feet (16.8 meters). Current speeds (fig. 62) were considerably less than the speeds recorded during the winter. Current directions were almost equally divided between east and west. Two days of the record from meter #419 are plotted in figure 63 as progressive vectors and as current speed versus tide. During this period, directions shifted between northwest and northeast and resulted in a net northerly drift. Current speeds were low but reached maximums near low tides.

Four dye injections were made during the winter survey from the shore adjacent to the current meter location. This dye moved rapidly toward the west, initially spreading out along the shoreline. These data are shown in figures 64 through 67. On 26 February (fig. 66) dye entered Apra Harbor at the juncture of Glass Breakwater and Cabras Island. This dye may have penetrated the breakwater during the spring high tide, which occurred that morning, or it may have percolated through cavities in the old reef flat on which the breakwater was constructed. Dye patches were tracked on six occasions during the summer survey (figs. 68 through 73). Dye injected during the rising tide flowed rapidly toward the west in a pattern similar to that observed in the winter study. Dye injected during the falling tide flowed easterly or eddied slowly. Comparisons of dye dispersal data to the current meter

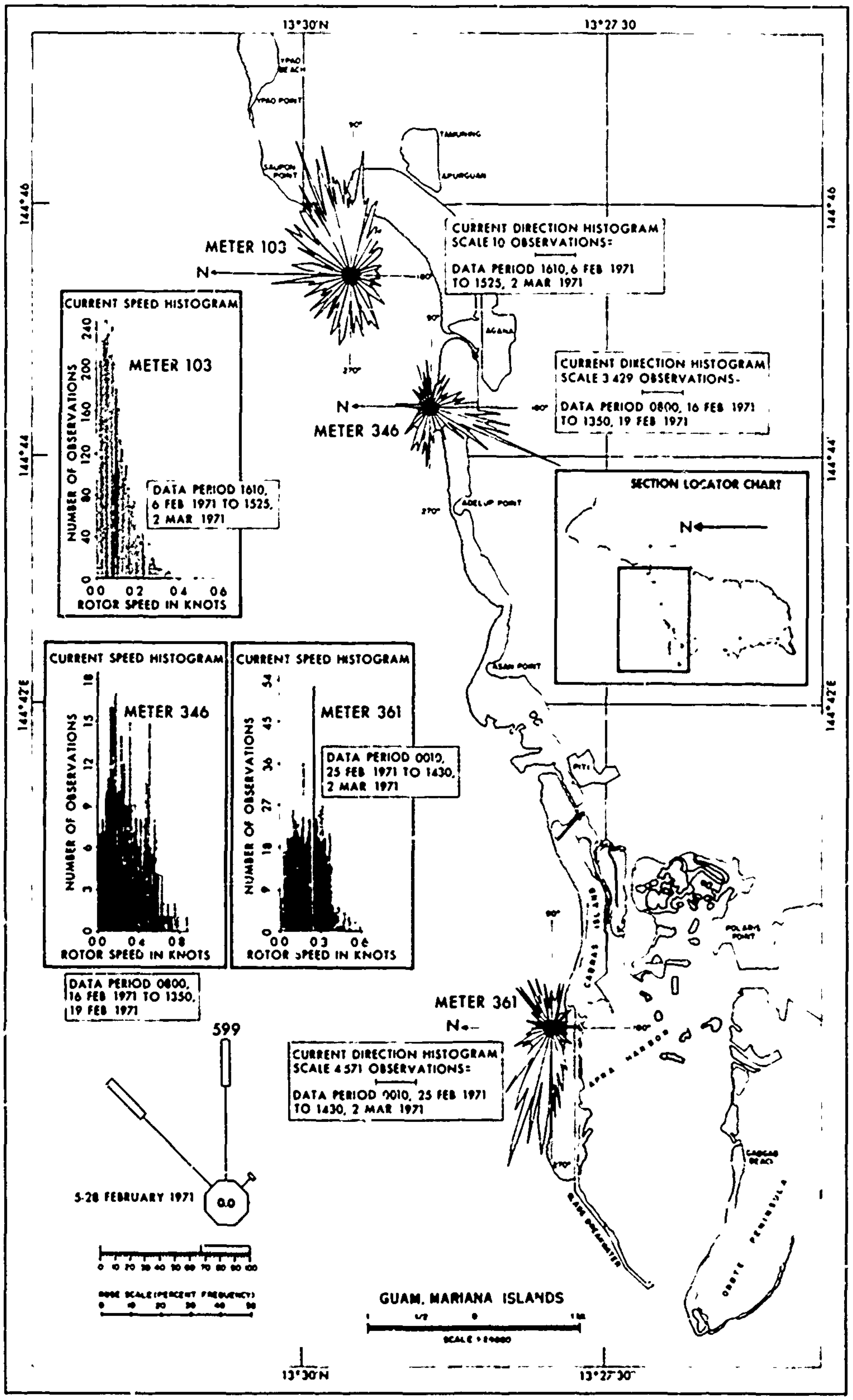


Figure 60. Current speed histograms and current direction histograms for the Agana Section in winter including meters #103, #346, and #361 and a wind rose for the data period.

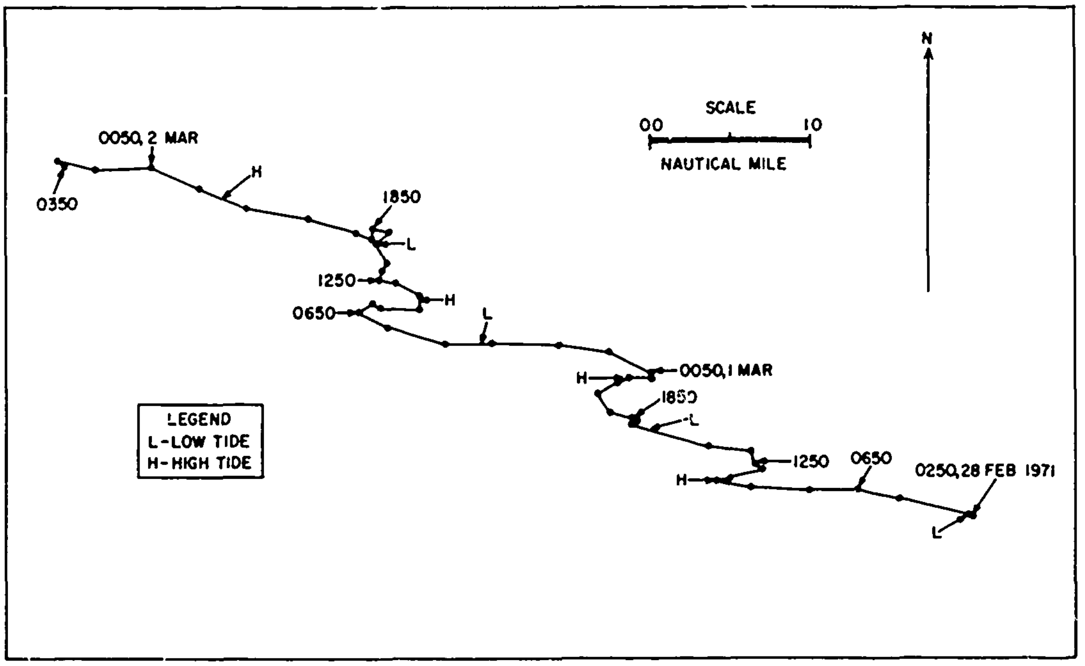


Figure 61. Progressive vector diagram of current from meter #361, 0250, 28 February to 0350, 2 March 1971.

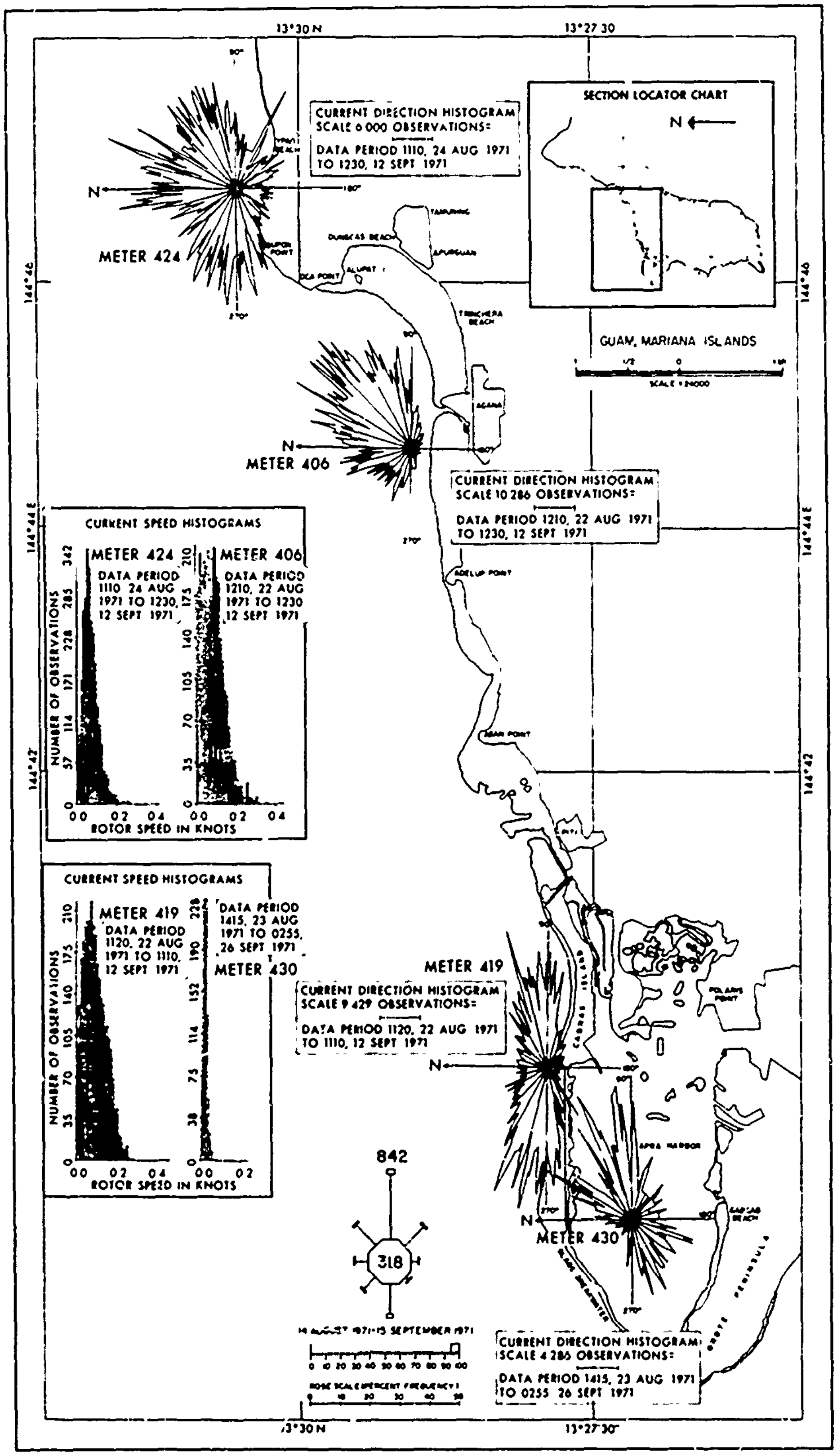


Figure 62. Current speed histograms and current direction histograms for the Agana Section in summer including meters #424, #406, #419, and #430 and a wind rose for the data period.

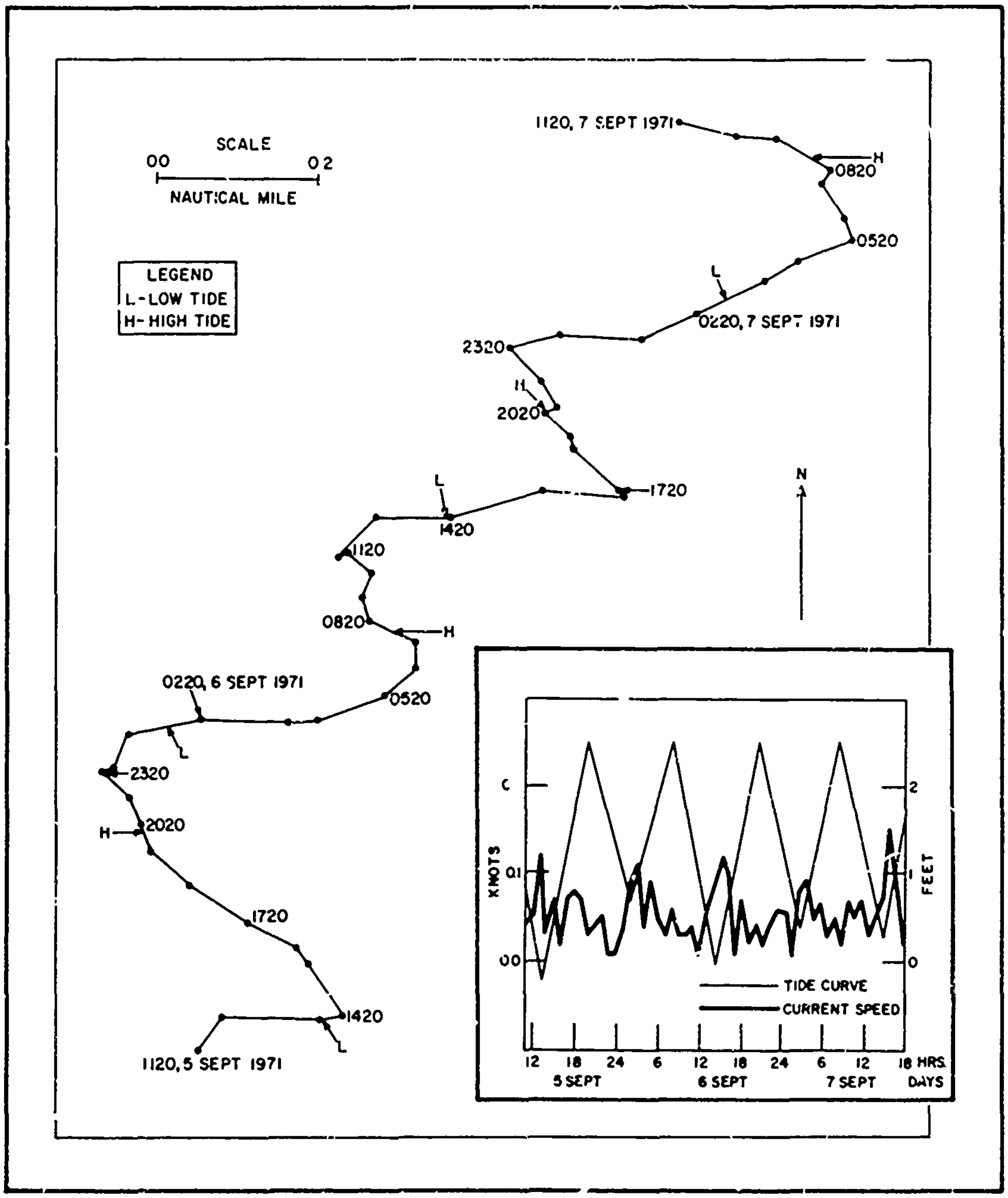


Figure 63. Progressive vector diagram of current from meter #419, 1120, 5 September to 1120, 7 September 1971, and current speeds versus tides for the same period.

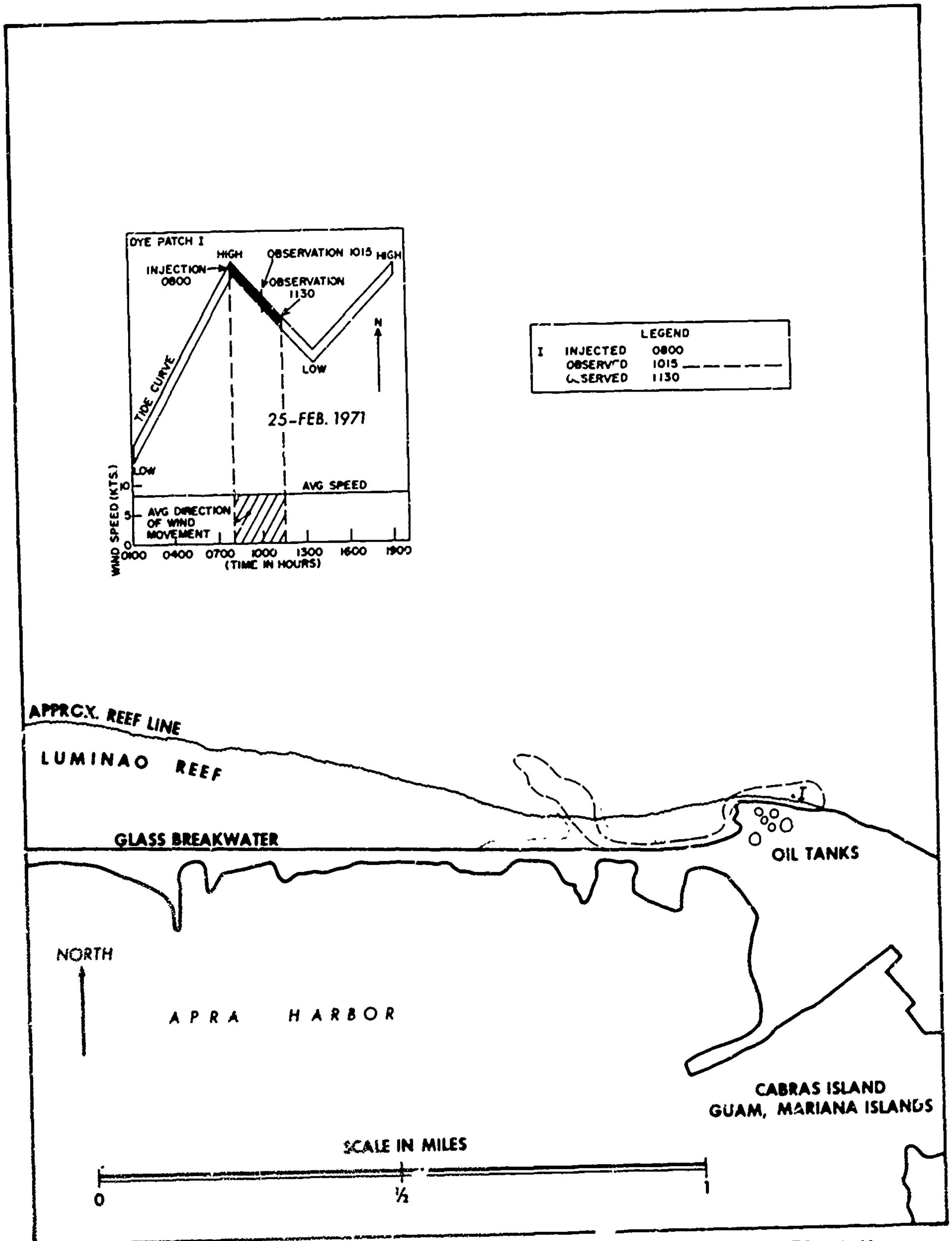


Figure 64. Dye movement at Cabras Island on 25 February 1971, A.M.

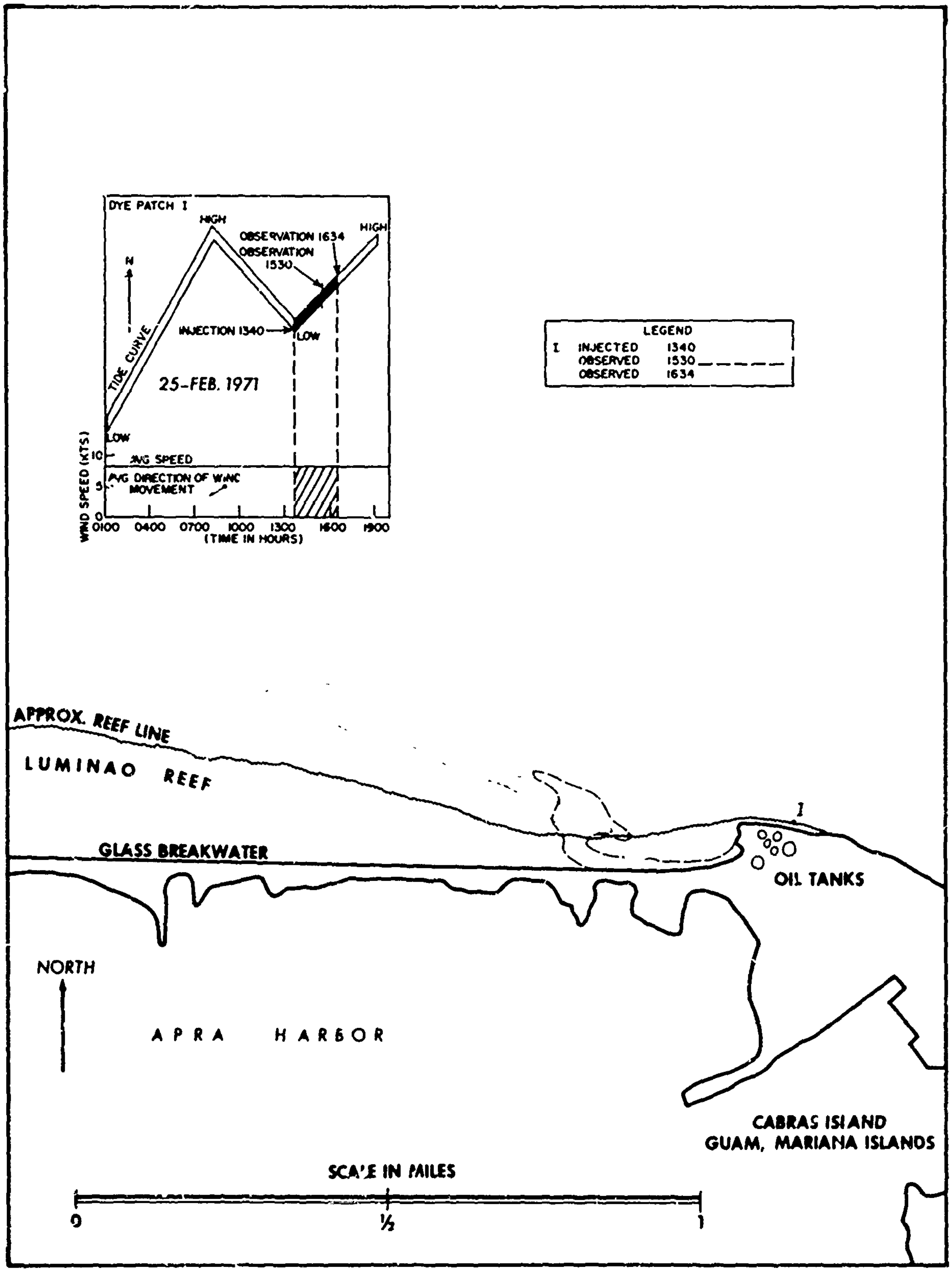


Figure 65. Dye movement at Cabras Island on 25 February 1971, P.M.

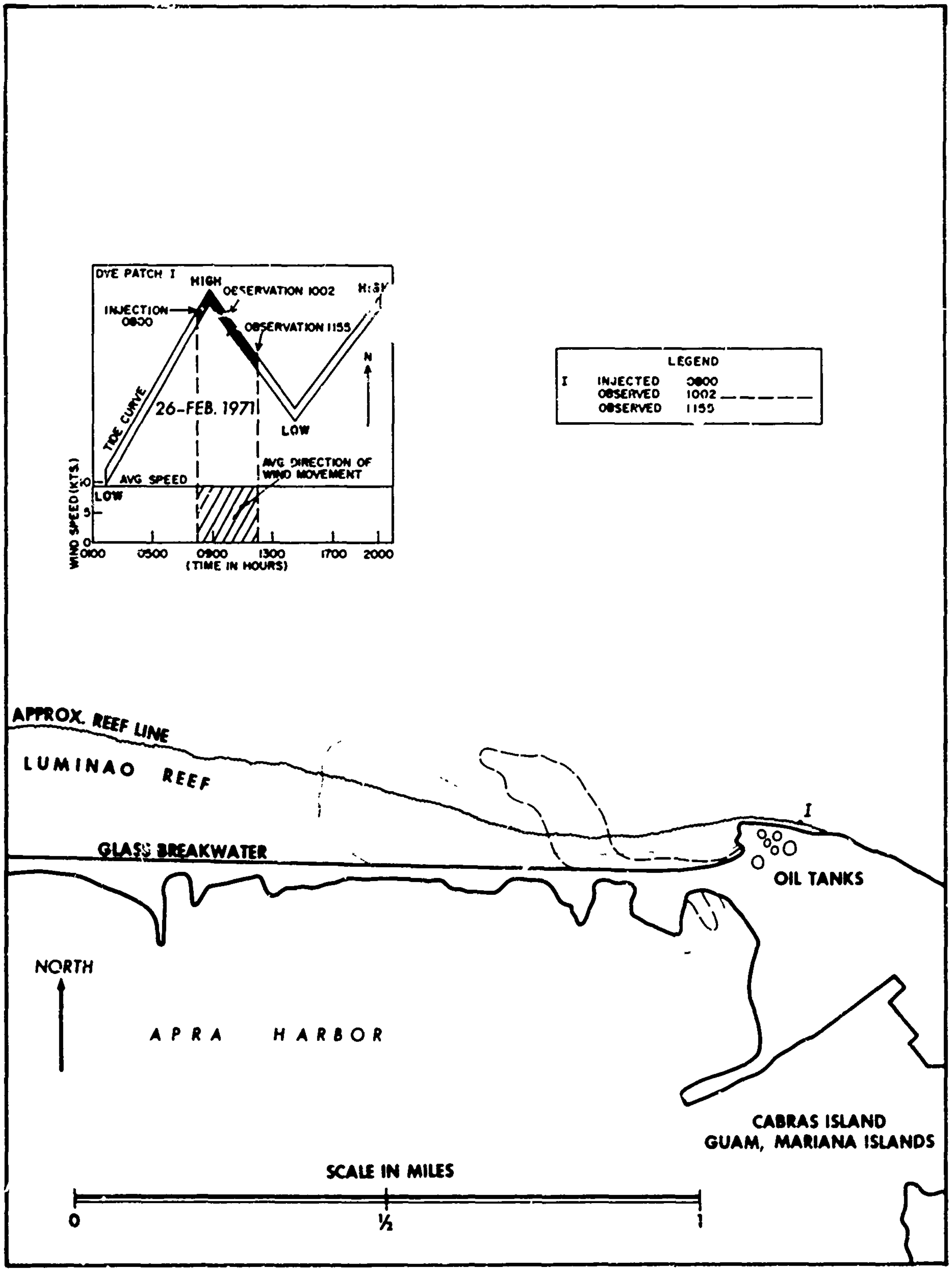


Figure 66. Dye movement at Cabras Island on 26 February 1971, A.M.

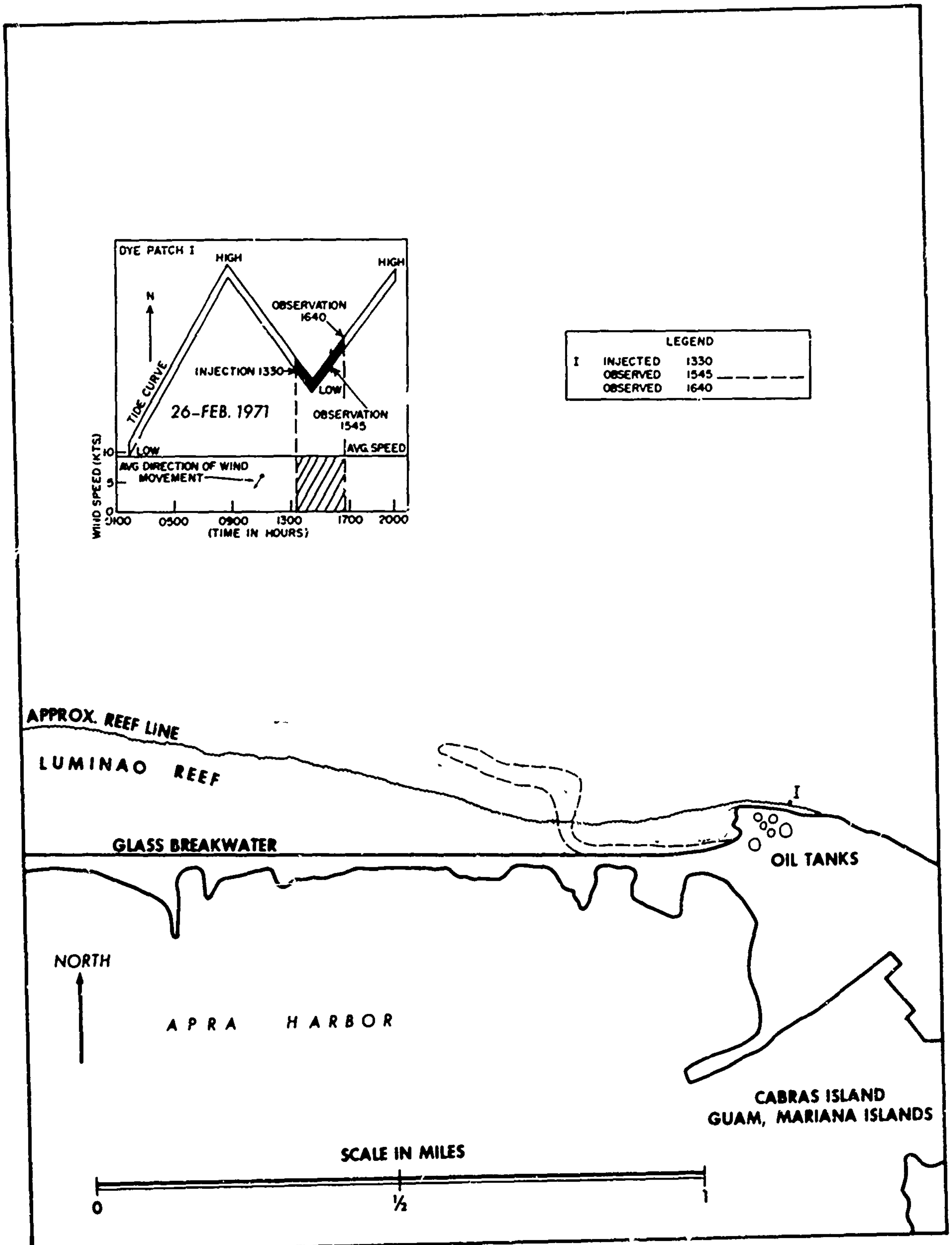


Figure 67. Dye movement at Cabras Island on 26 February 1971, P.M.

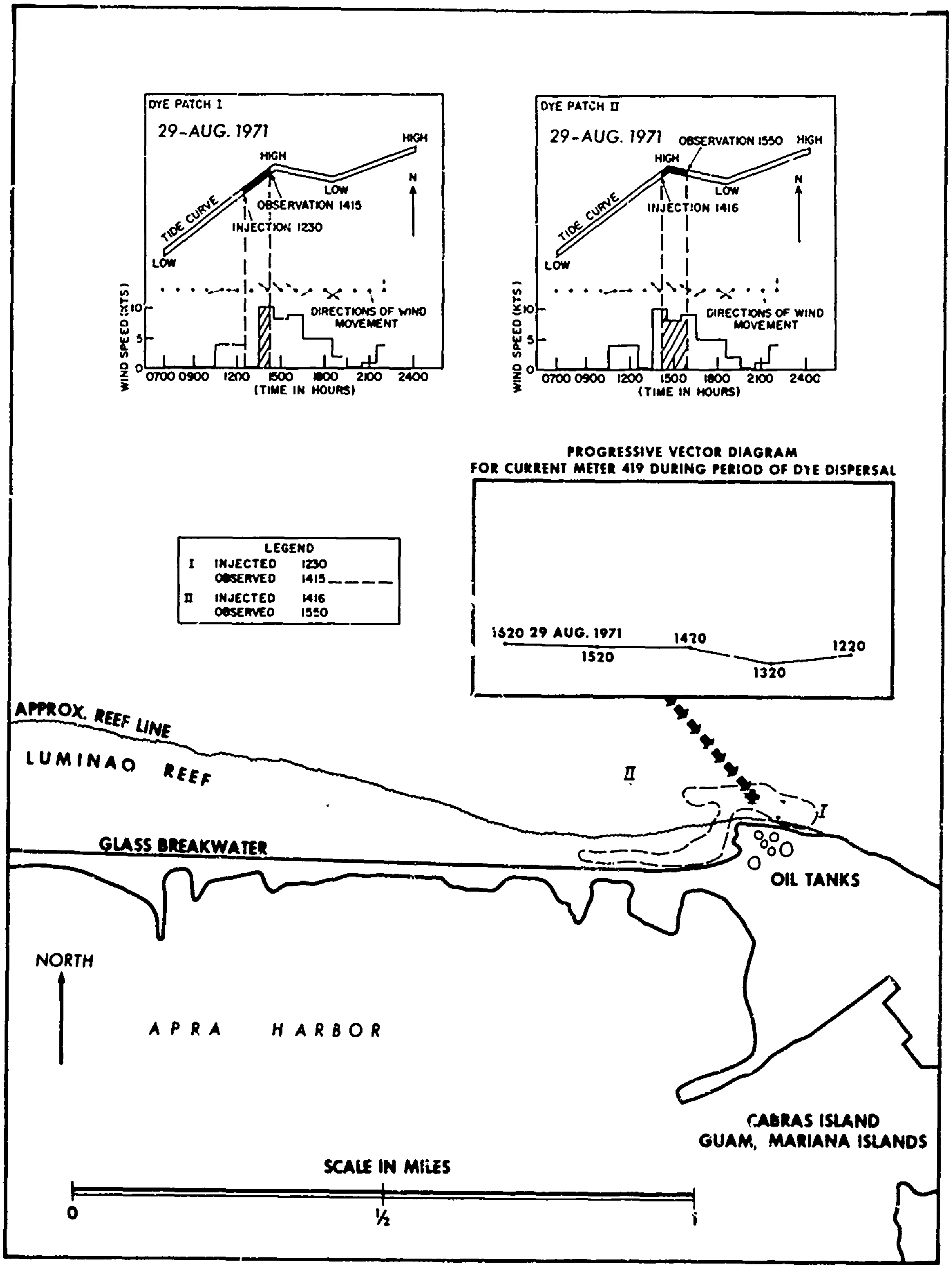


Figure 68. Dye movement at Cabras Island on 29 August 1971.

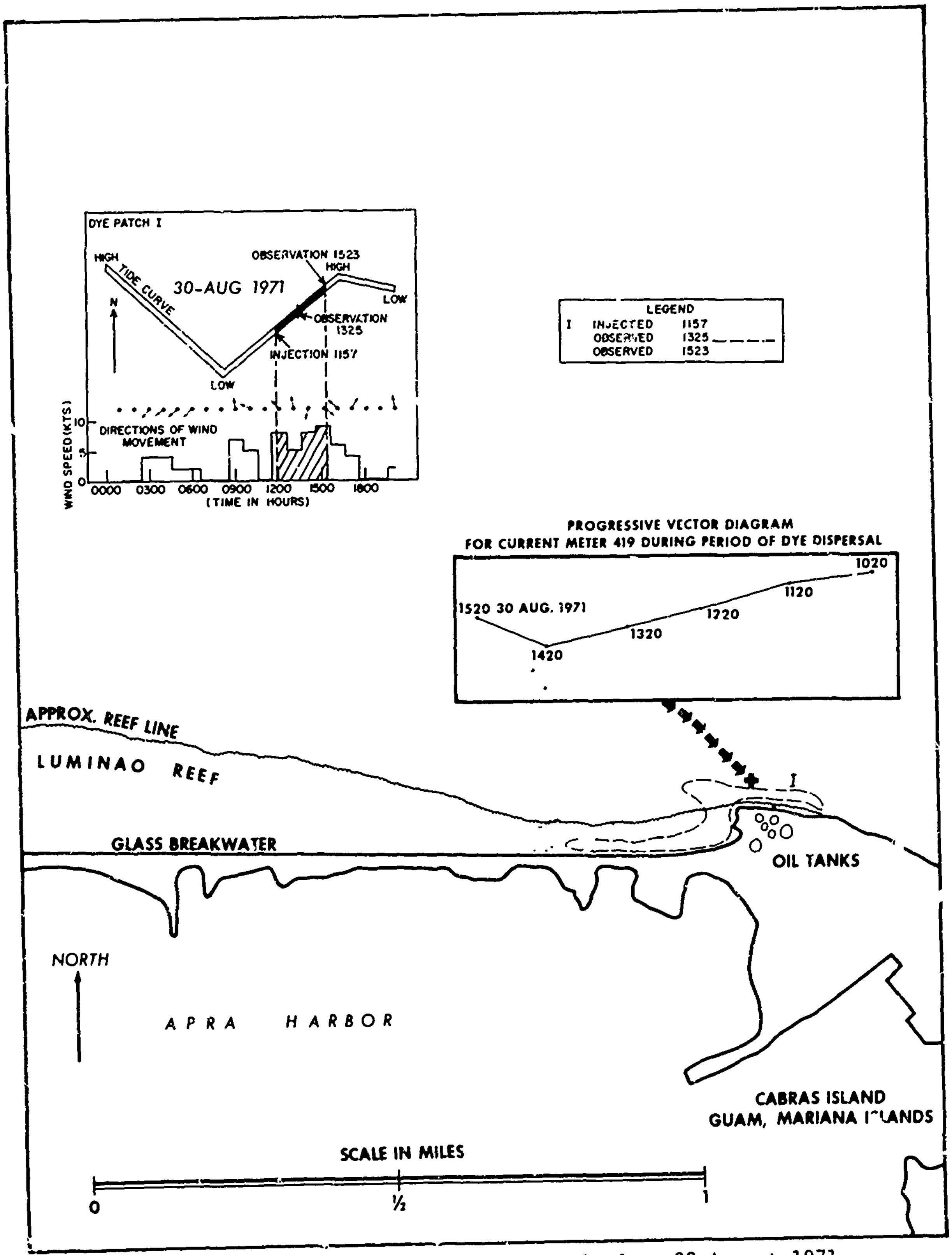


Figure 69. Dye movement at Cabras Island on 30 August 1971.

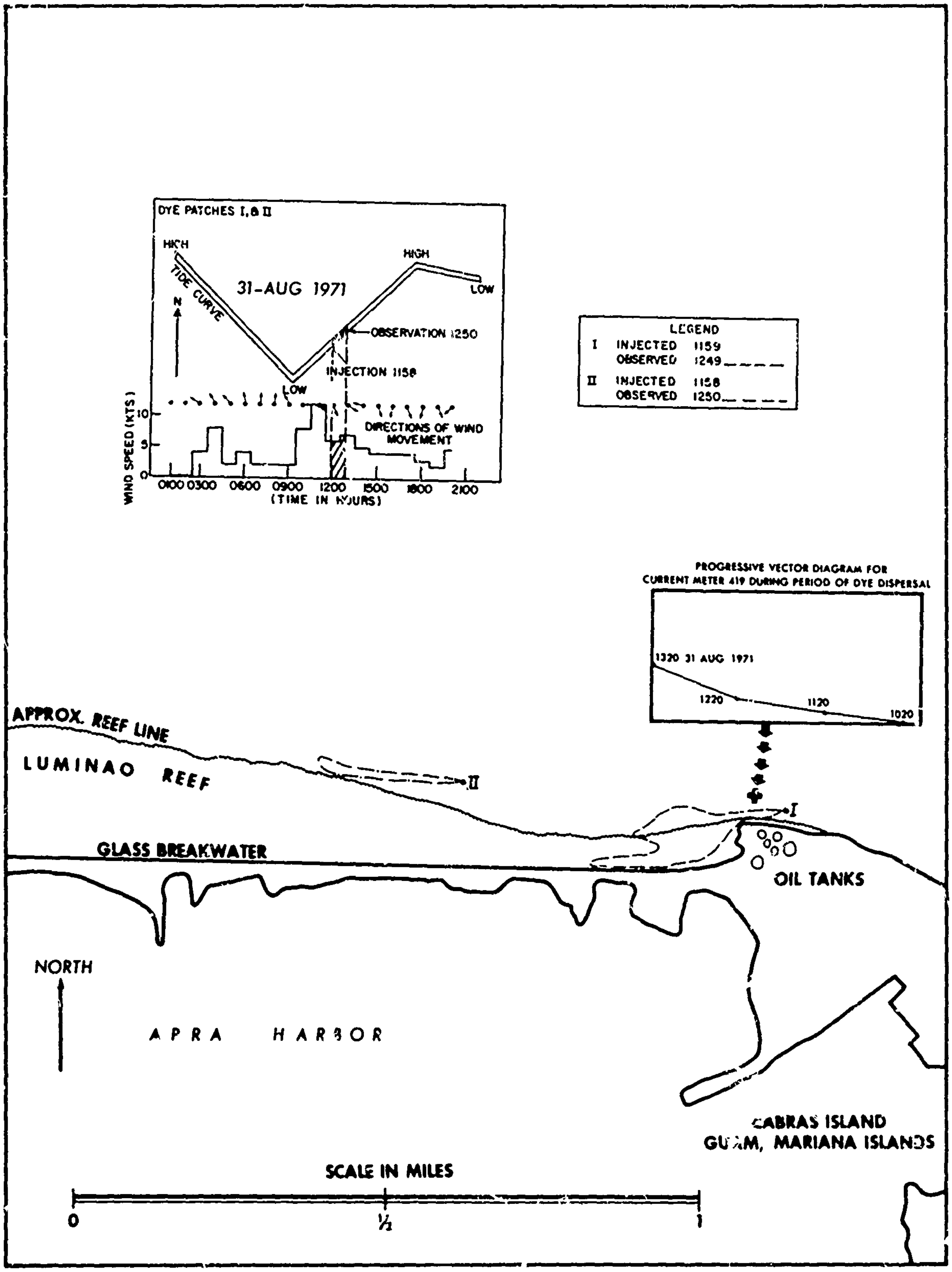


Figure 70. Dye movement at Cabras Island on 31 August 1971.

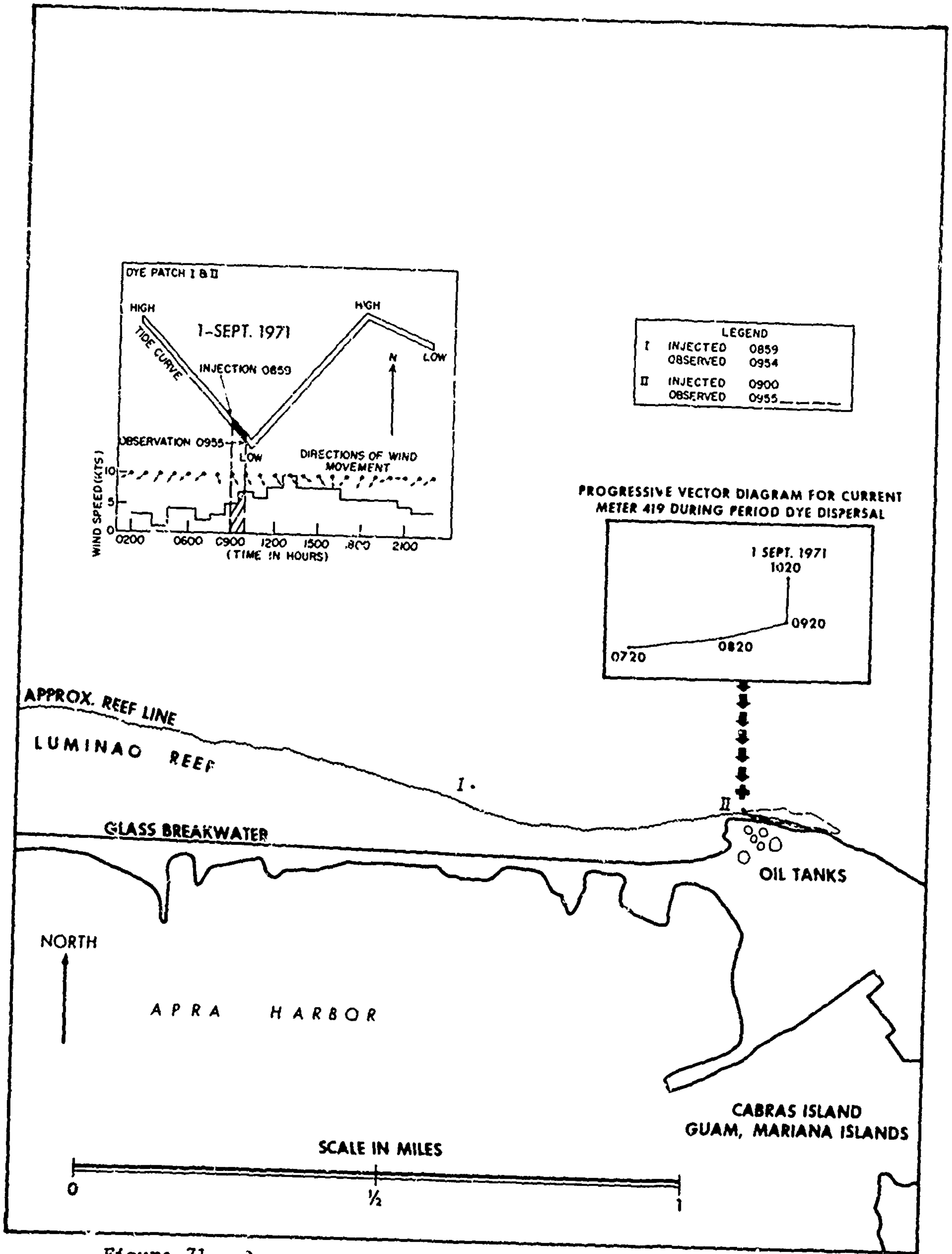


Figure 71. Dye movement at Cabras Island on 1 September 1971.

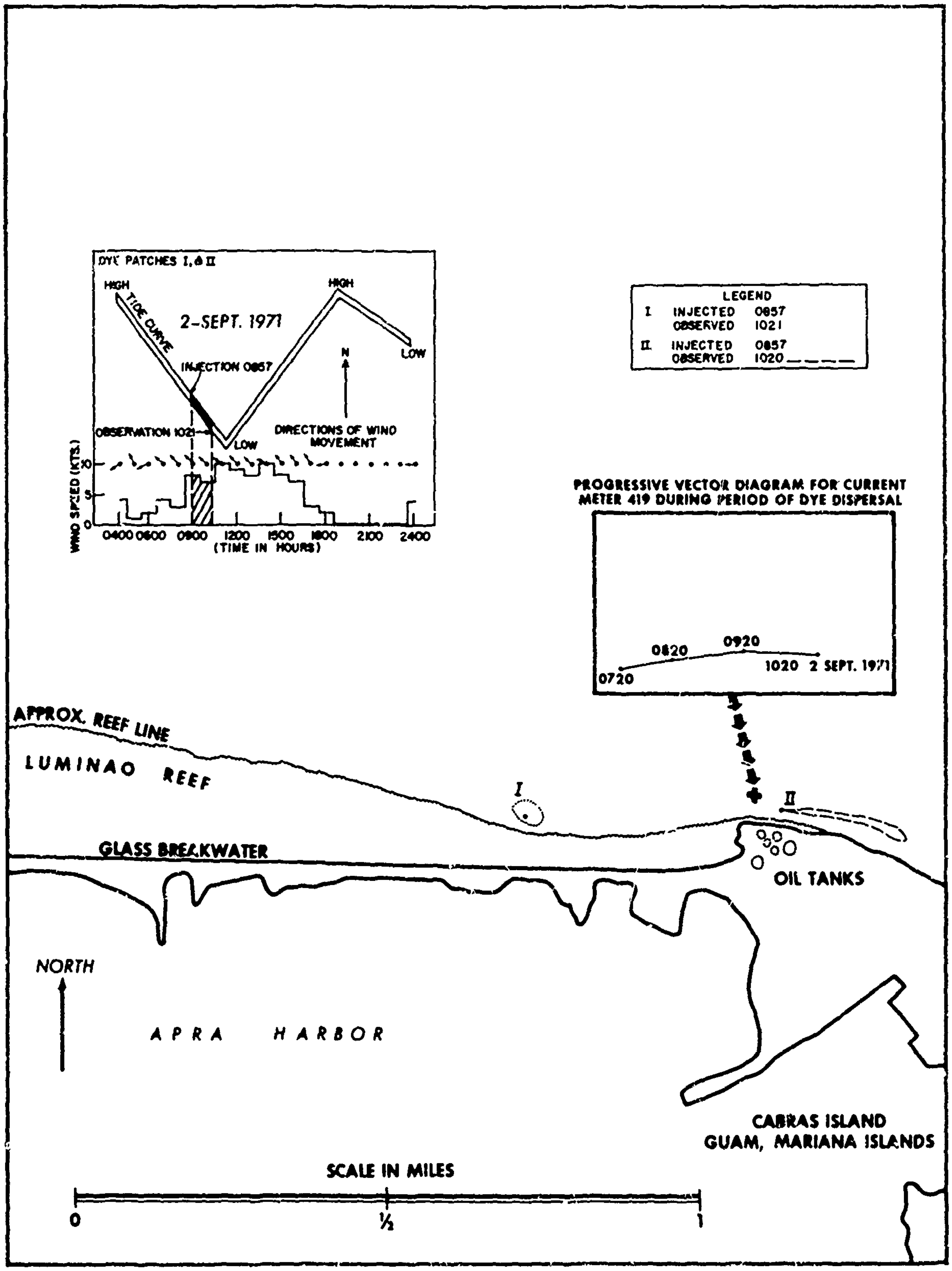


Figure 72. Dye movement at Cabras Island on 2 September 1971.

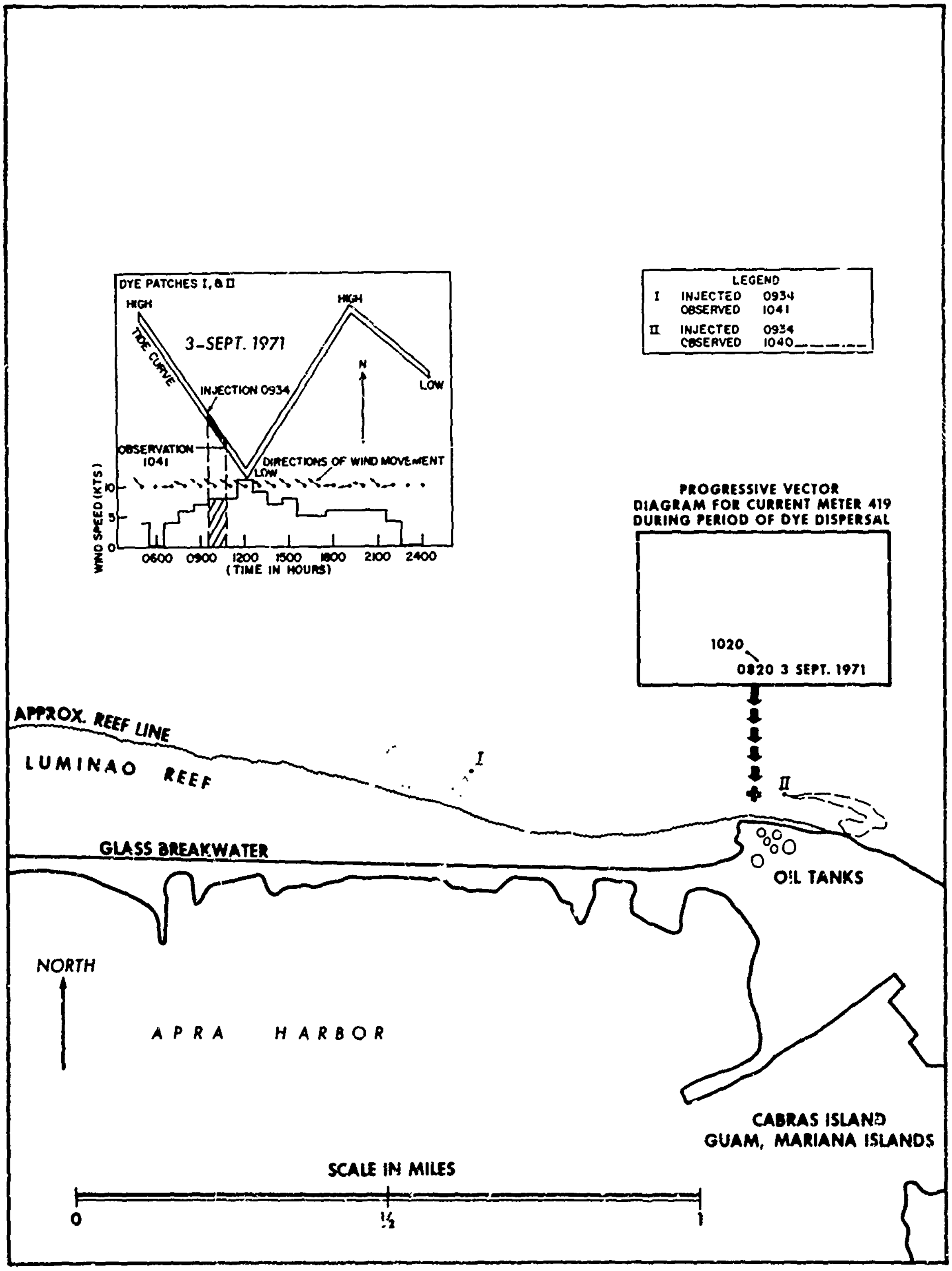


Figure 73. Dye movement at Cabras Island on 3 September 1971.

data show that currents were relatively consistent over the entire area; currents recorded at the meter corresponded closely to the movement of the dye patches.

Currents in Agana Bay were investigated by means of three current meter installations and dye and drogue tracking. Two current meters were installed during the winter survey. Meter #346 was placed on a bottom stand in 35 feet (10.7 meters) of water about 100 yards (91.4 meters) seaward of the reef margin. It was subjected to heavy surf that shook it off the stand about 3 days after installation. During the first 1-1/4 days this meter recorded moderate currents, averaging less than 0.2 knot (.10 m/sec), that oscillated generally east and west (fig. 74). Early on the afternoon of 17 February, current speeds increased to near 0.5 knot (.25 m/sec) with a constant flow toward the west and southwest (fig. 75). This strong southwesterly current persisted until the meter failed. Much of this strong current was due to higher wave action as water was carried over the reef margin onto the reef flat. The histograms illustrate the effect of these two differing data segments. The direction histogram shows a prominent spike toward the southwest caused by the strong surf-related currents. Smaller spikes toward the east and west represent the first 1-1/4 days of data. A similar situation exists in the speed histogram with the presence of a bimodal distribution.

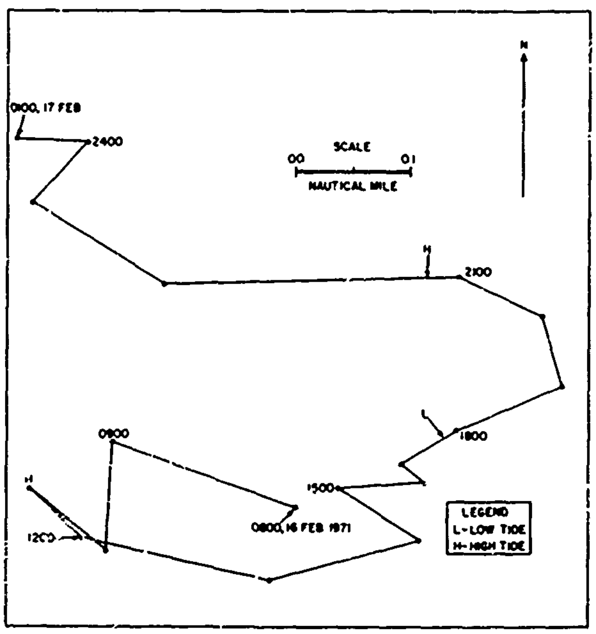


Figure 74. Progressive vector diagram of current from meter #346, 0800, 16 February to 0100, 17 February 1971.

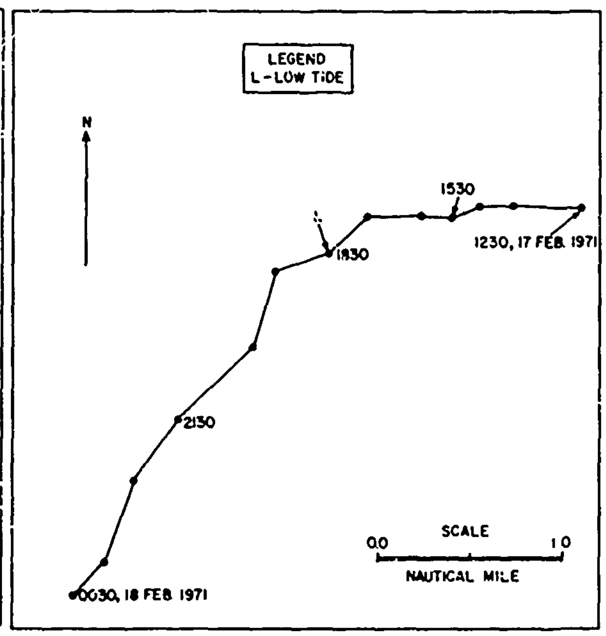


Figure 75. Progressive vector diagram of current from meter #346, 1230, 17 February to 0030, 18 February 1971.

Current meter #103 was installed on an array at the 50-foot (15.2-meter) depth. Water depth at this location was approximately 300 feet (91.4 meters). During the 25-day period, current speeds ranged up to 0.5 knot (.25 m/sec), but they were most frequent in the interval between 0.04 to 0.08 knot (.02 to .04 m/sec). Most currents flowed toward the east and northeast. Relatively few observations were recorded in a southerly direction. Three isolated segments of the data are shown in detail in figure 76. Data plotted as progressive vectors from the periods 7 through 8 February and 26 through 27 February show moderate to slight currents that flowed northeasterly during ebb and northwesterly during flood. The period 13 through 15 February was characterized by moderate currents that flowed consistently toward the east.

Current meter #406 was installed in Agana Bay during the summer survey. It was placed on a bottom stand in 65 feet (19.8 meters) of water near the location of the existing Agana sewer outfall. As shown in the speed and direction histograms, currents flowed primarily to the northeast at speeds ranging up to 0.36 knot (.18 m/sec), but they were most frequent between 0.04 and 0.01 knot (.02 and .005 m/sec). The first 2 days of these data are plotted as progressive vectors in figure 77. Speeds during this time averaged about 0.1 knot (.005 m/sec). Currents flowed generally northwest during the rising tide and northeast during the falling tide. This directional change in concert with tidal ebb and flood is in agreement with the data from meter #103 (fig. 76) installed during the winter season.

Figures 78 through 85 show the patterns of dye dispersal during the eight dye operations conducted in Agana Bay in August and September 1971. Also shown are the patterns of dispersal of sewage plumes from the Agana sewer outfall as observed and photographed from the air. Only two of the 13 dye patches were observed to travel in a westerly or southwesterly direction. Most moved easterly or northeasterly. The eddying nature of the currents in shallow water is illustrated by the patterns of dye dispersal and sewage dispersal seen on 1 September (fig. 82).

One drogue tracking operation was conducted in this vicinity during the summer survey (fig. 86). After initial movement toward the north, the drogues turned and travelled rapidly toward the east. This flow pattern apparently was a result of currents caused by strong westerly winds which began early on 9 September.

The Cabras Island location appears to have the most favorable characteristics within the section for placement of a sewage outfall. Currents there are relatively consistent and will tend to carry effluent out to sea. Here, as elsewhere, the outfall should be positioned to prevent the effluent from being carried onto the reef flat by surf action. Cabras Island has the added advantage of being far from recreational use areas and human habitation.

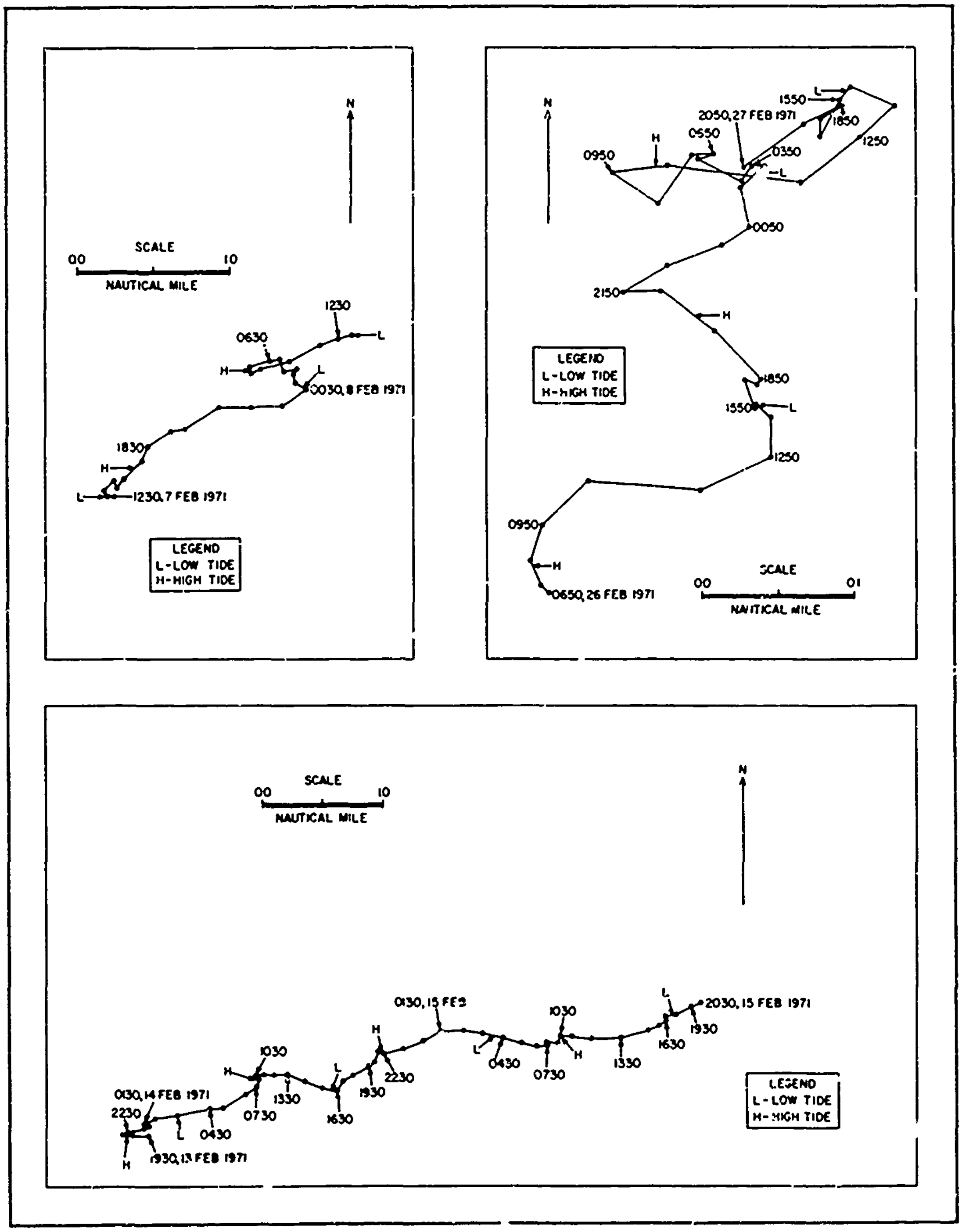


Figure 76. Progressive vector diagrams of current from meter #103, 1230, 7 February to 1330, 8 February; 0650, 26 February to 2050, 27 February; and 1930, 13 February to 2030, 15 February 1971.

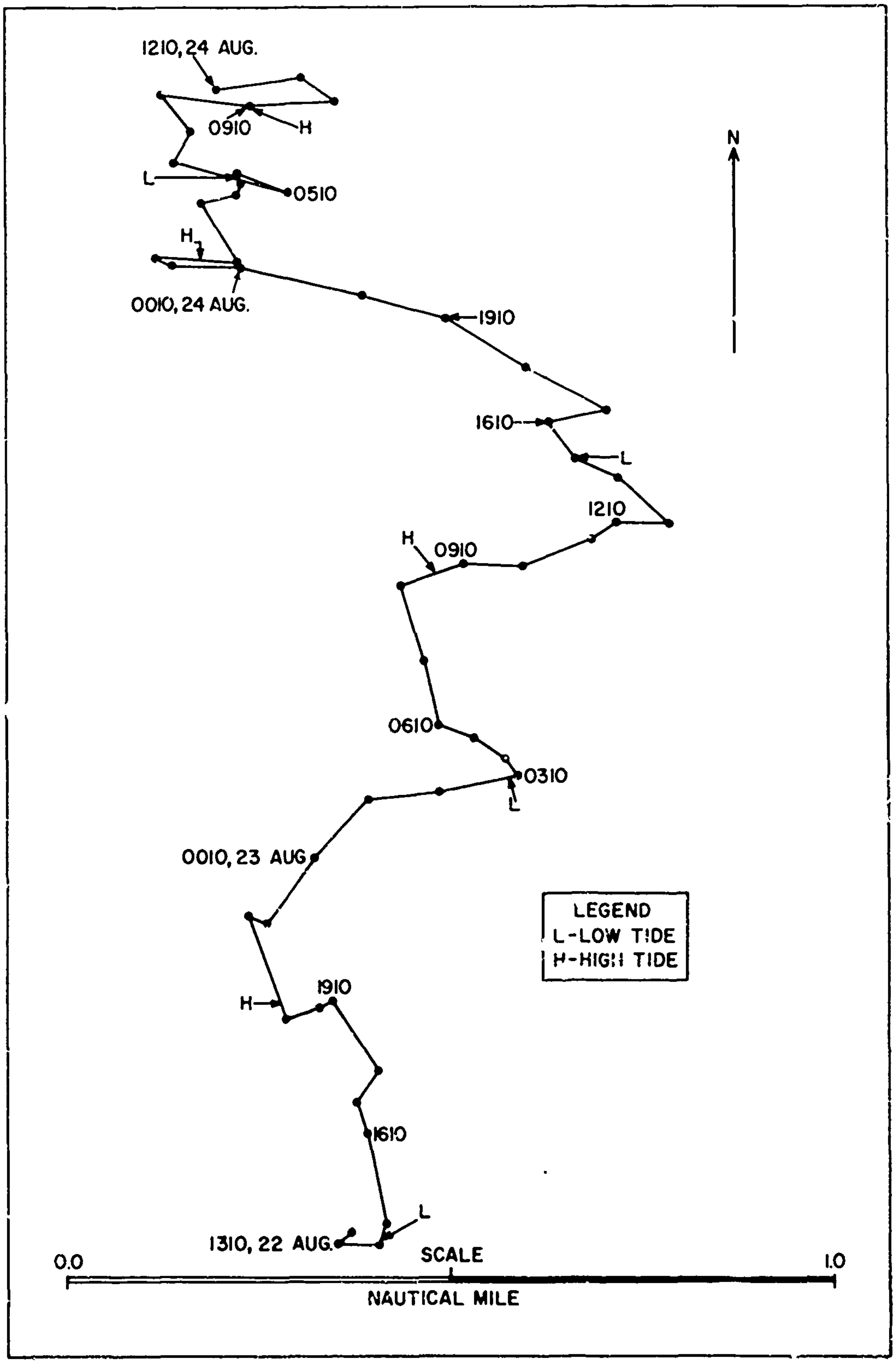


Figure 77. Progressive vector diagram of current from meter #406, 1210, 22 August to 1210, 24 August 1971.

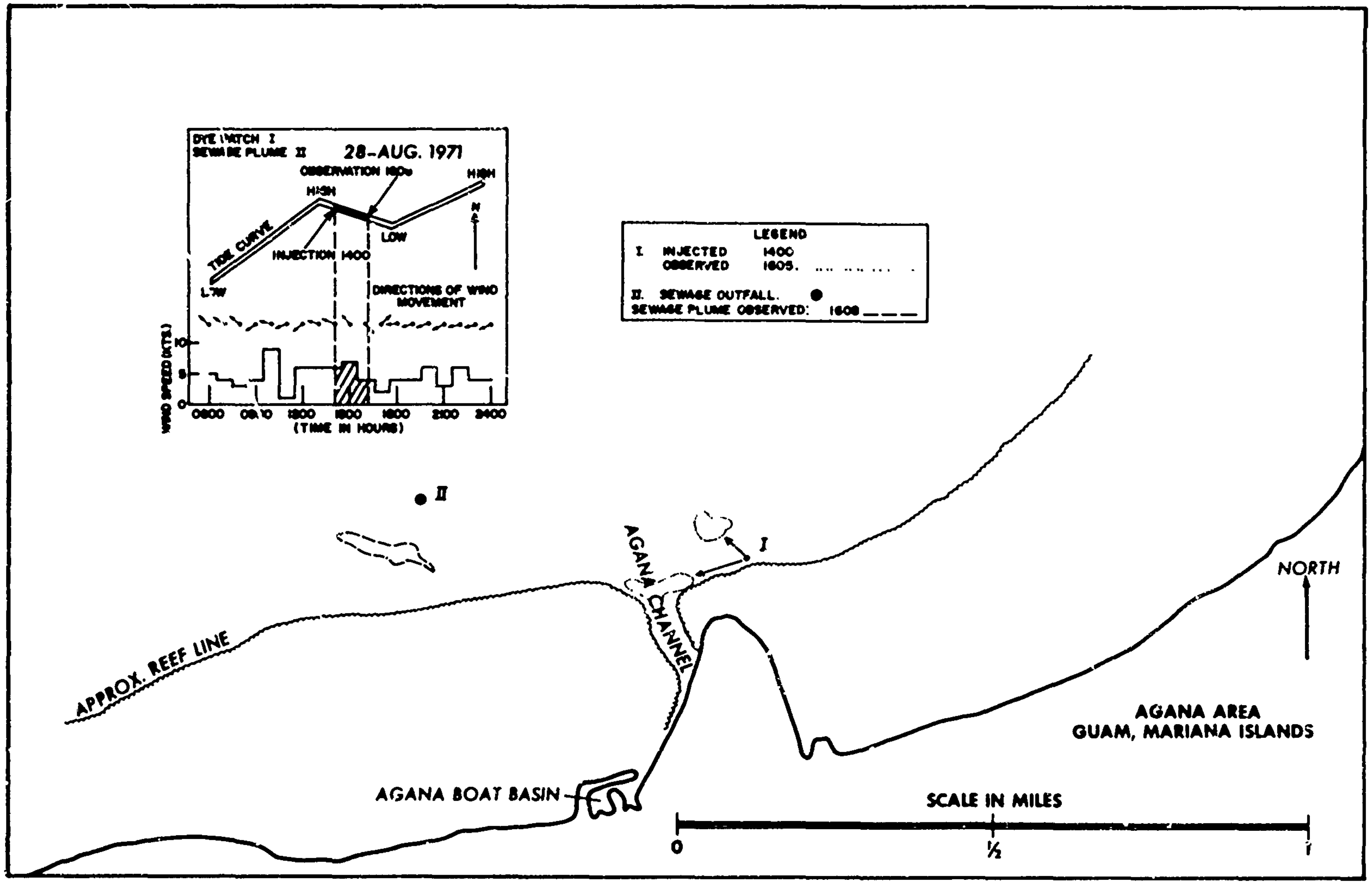


Figure 78. Dye movement at Agana Bay on 28 August 1971.

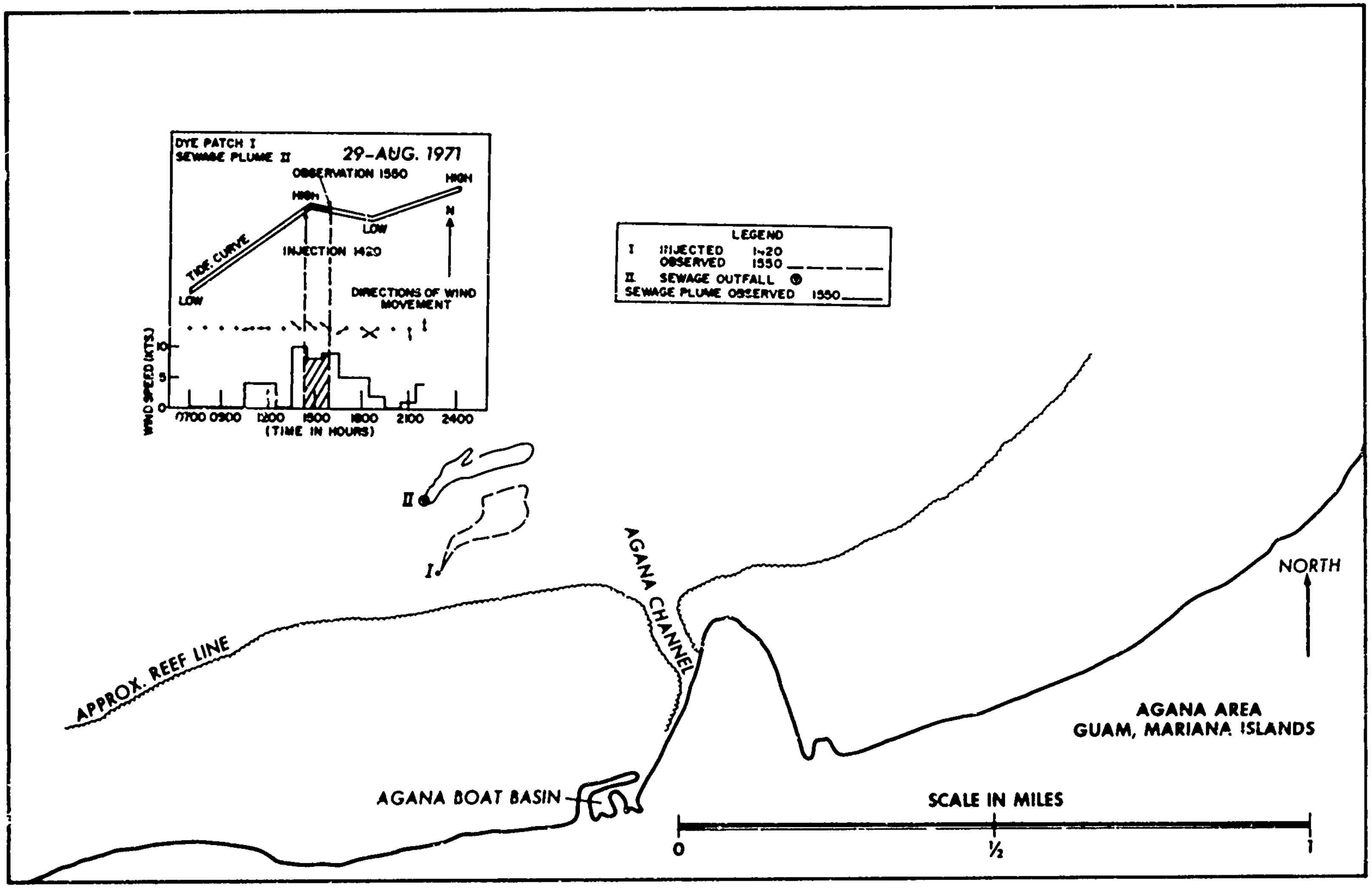


Figure 79. Dye movement at Agana Bay on 29 August 1971

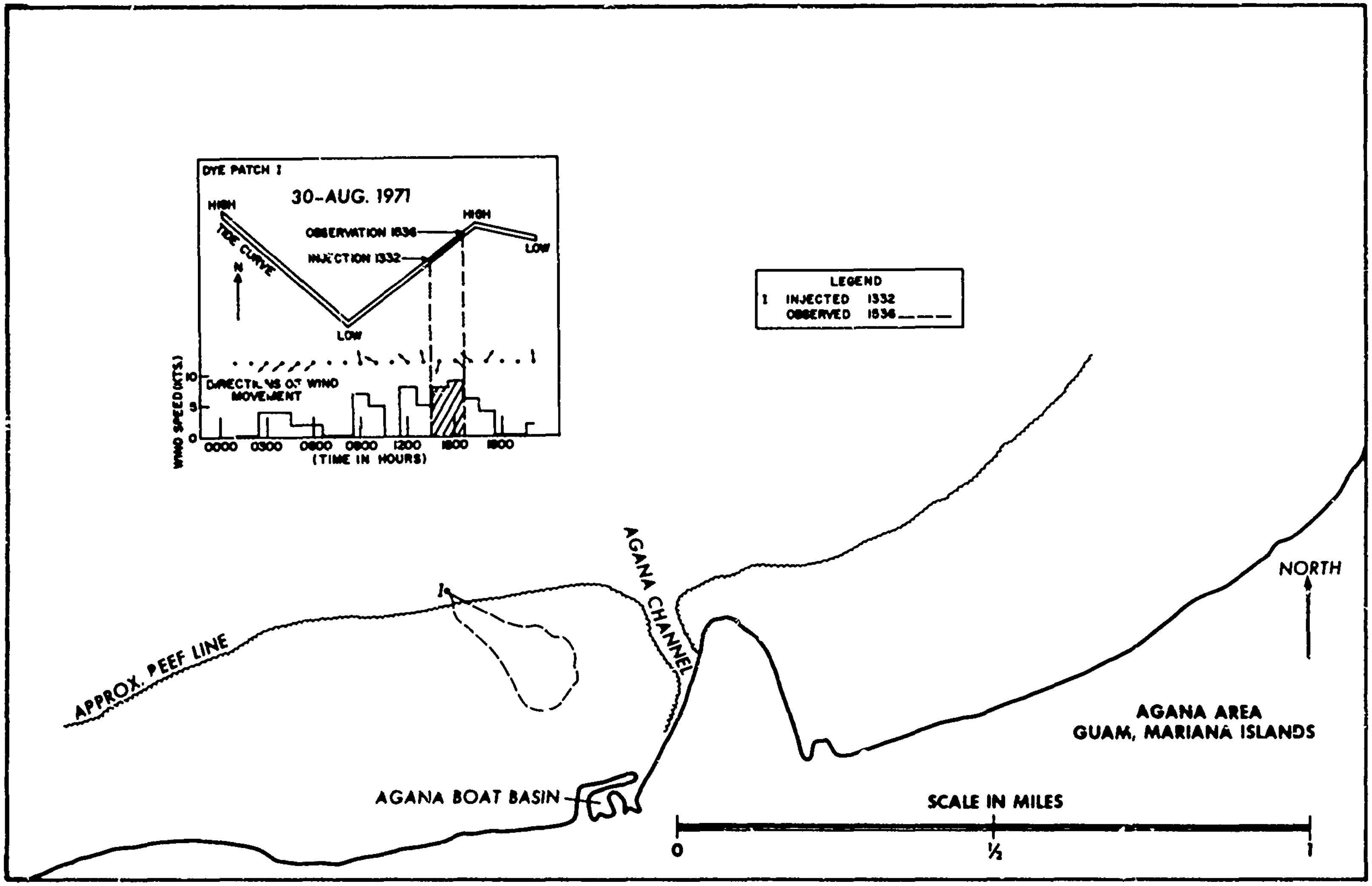


Figure 80. Dye movement at Agana Bay on 30 August 1971.

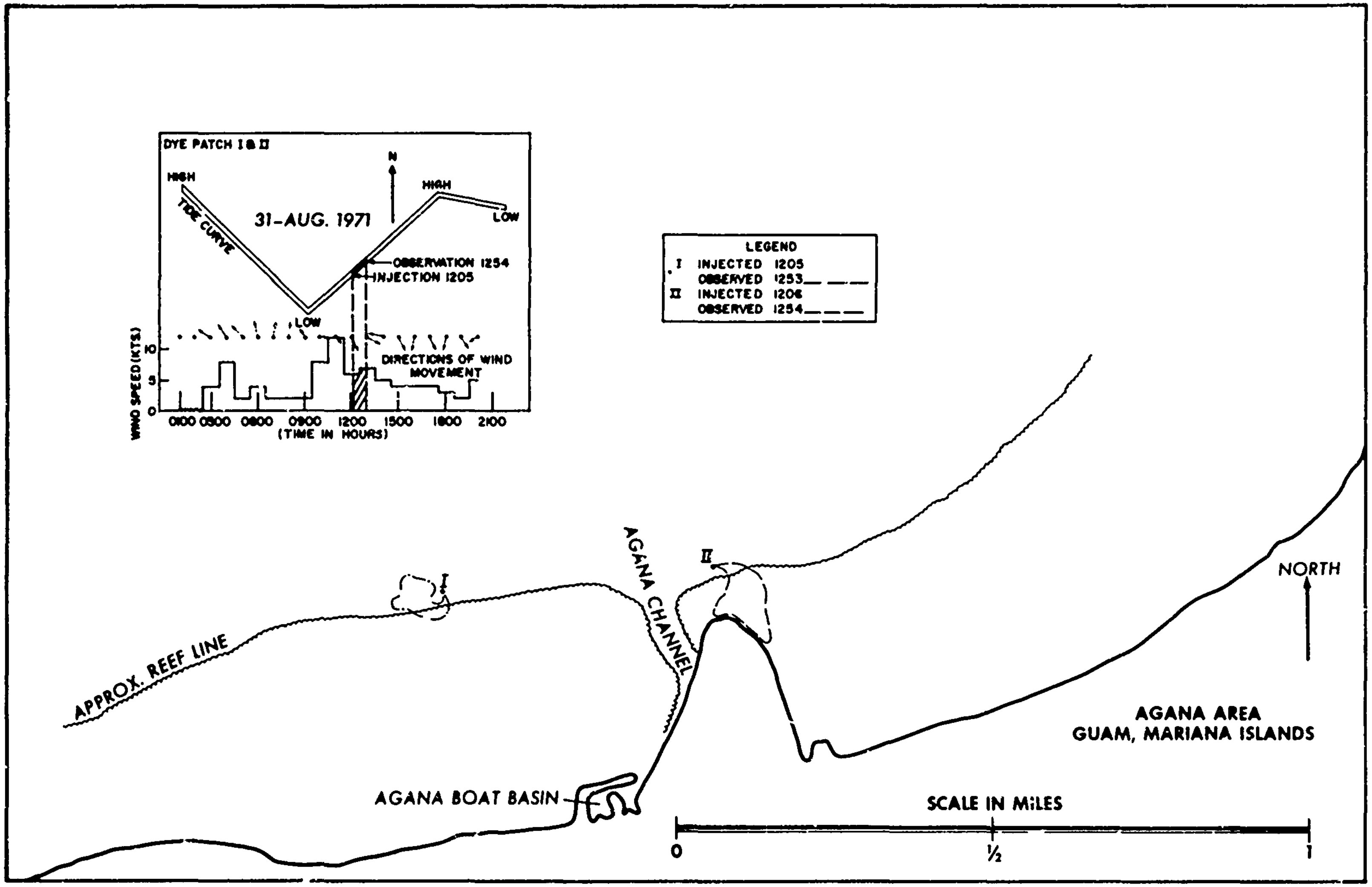


Figure 81. Dye movement at Agana Bay on 31 August 1971.

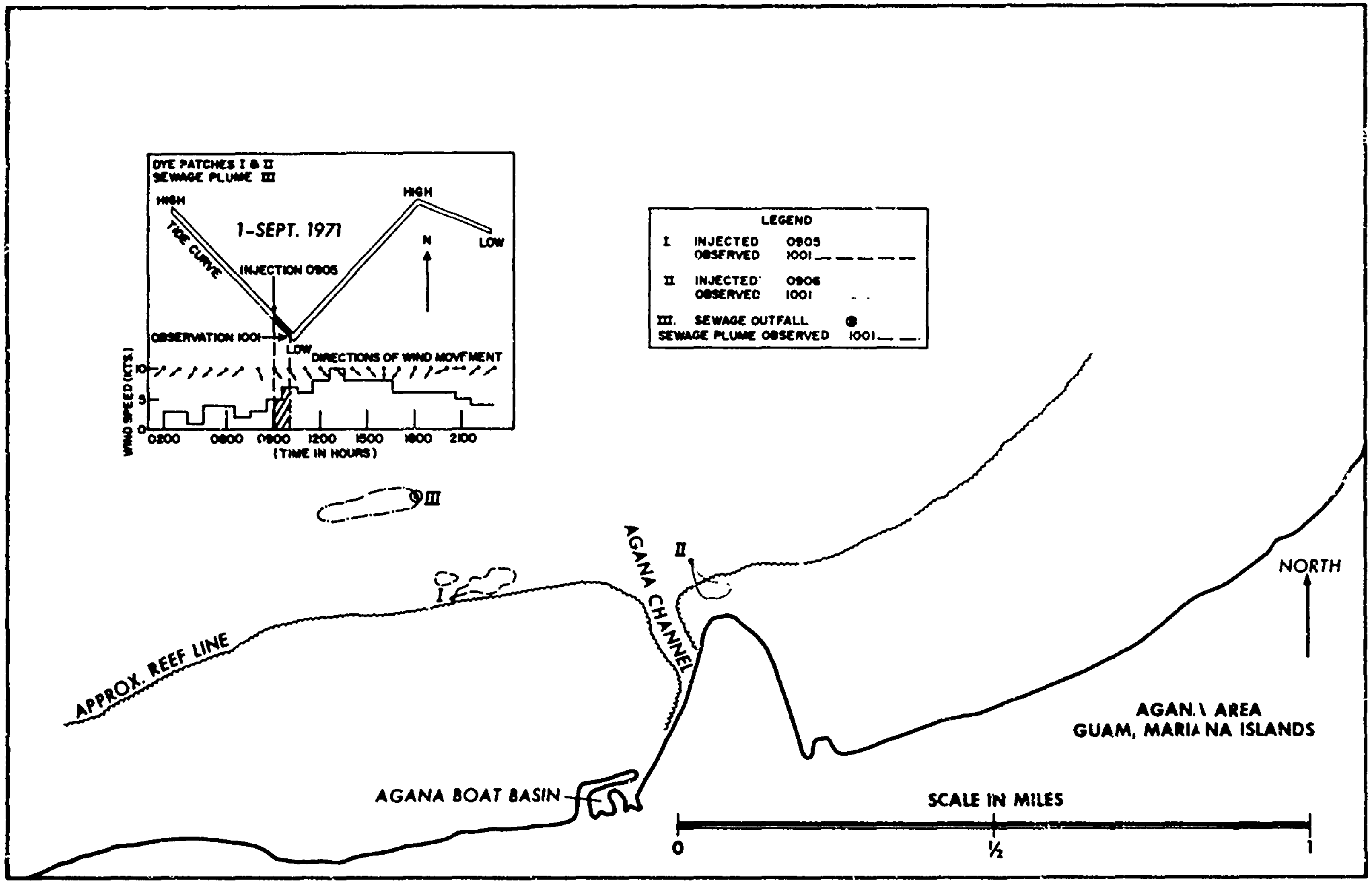


Figure 82. Dye movement at Agana Bay on 1 September 1971.

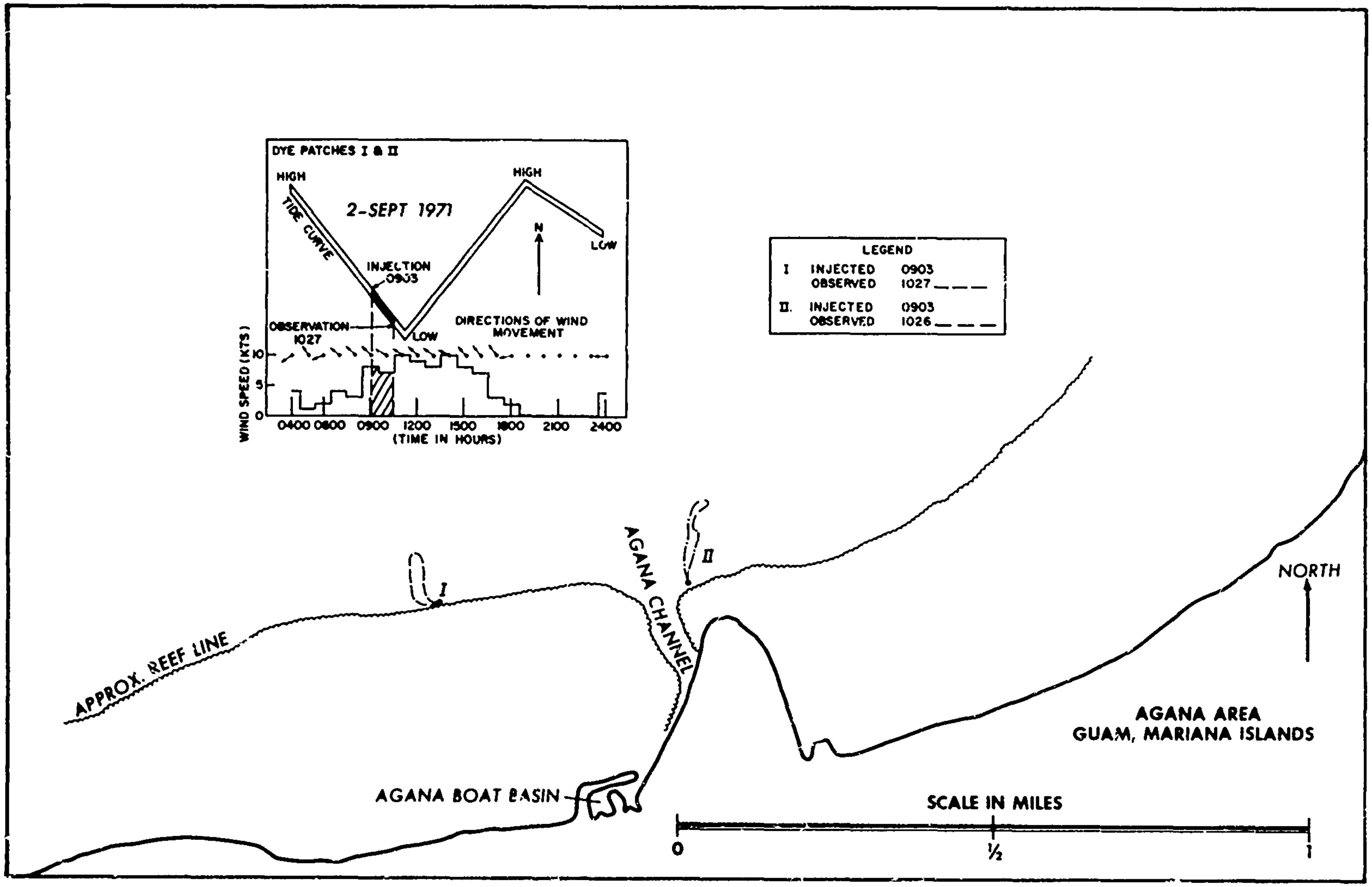


Figure 83. Dye movement at Agana Bay on 2 September 1971.

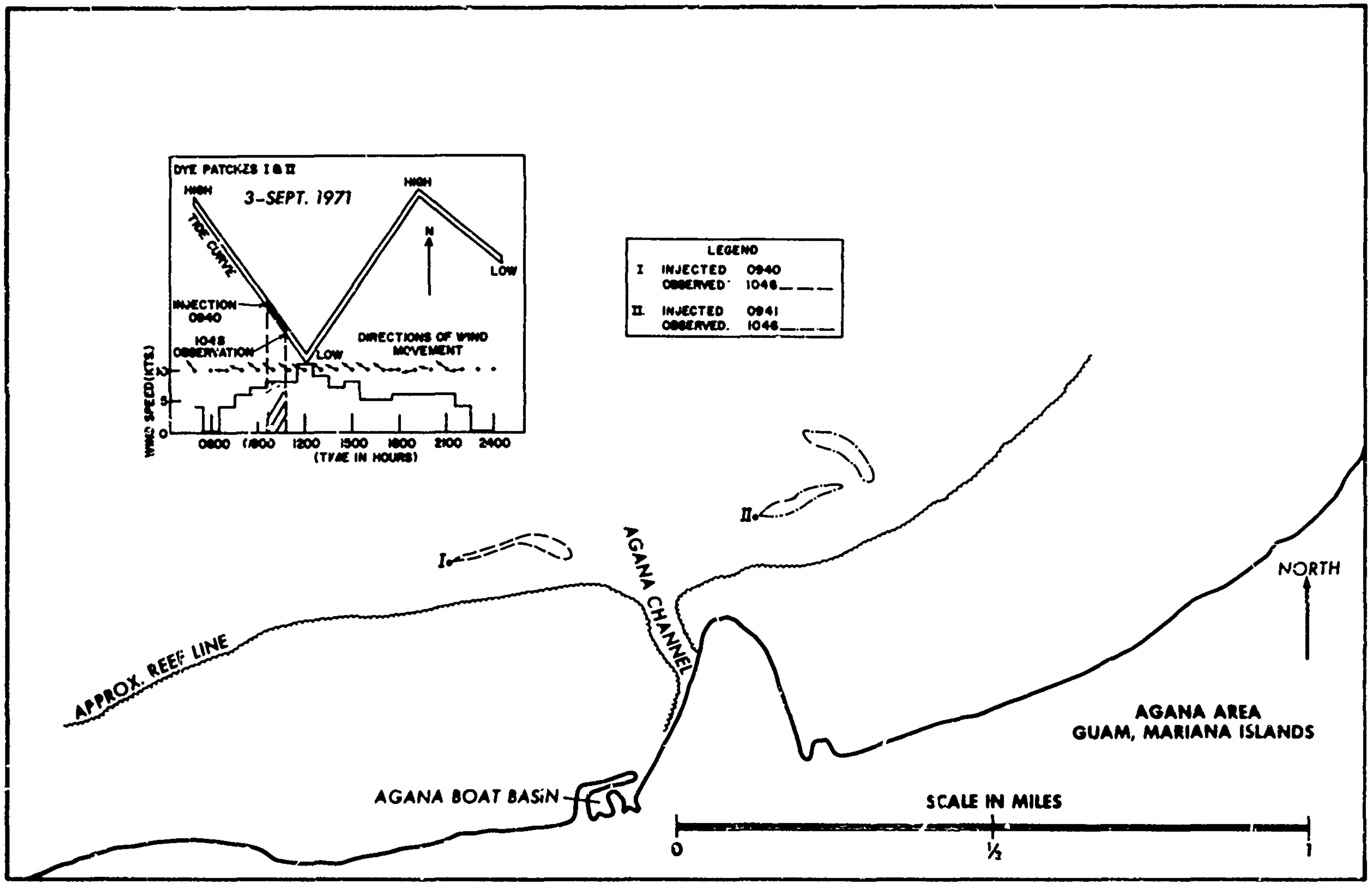


Figure 84. Dye movement at Agana Bay on 3 September 1971.

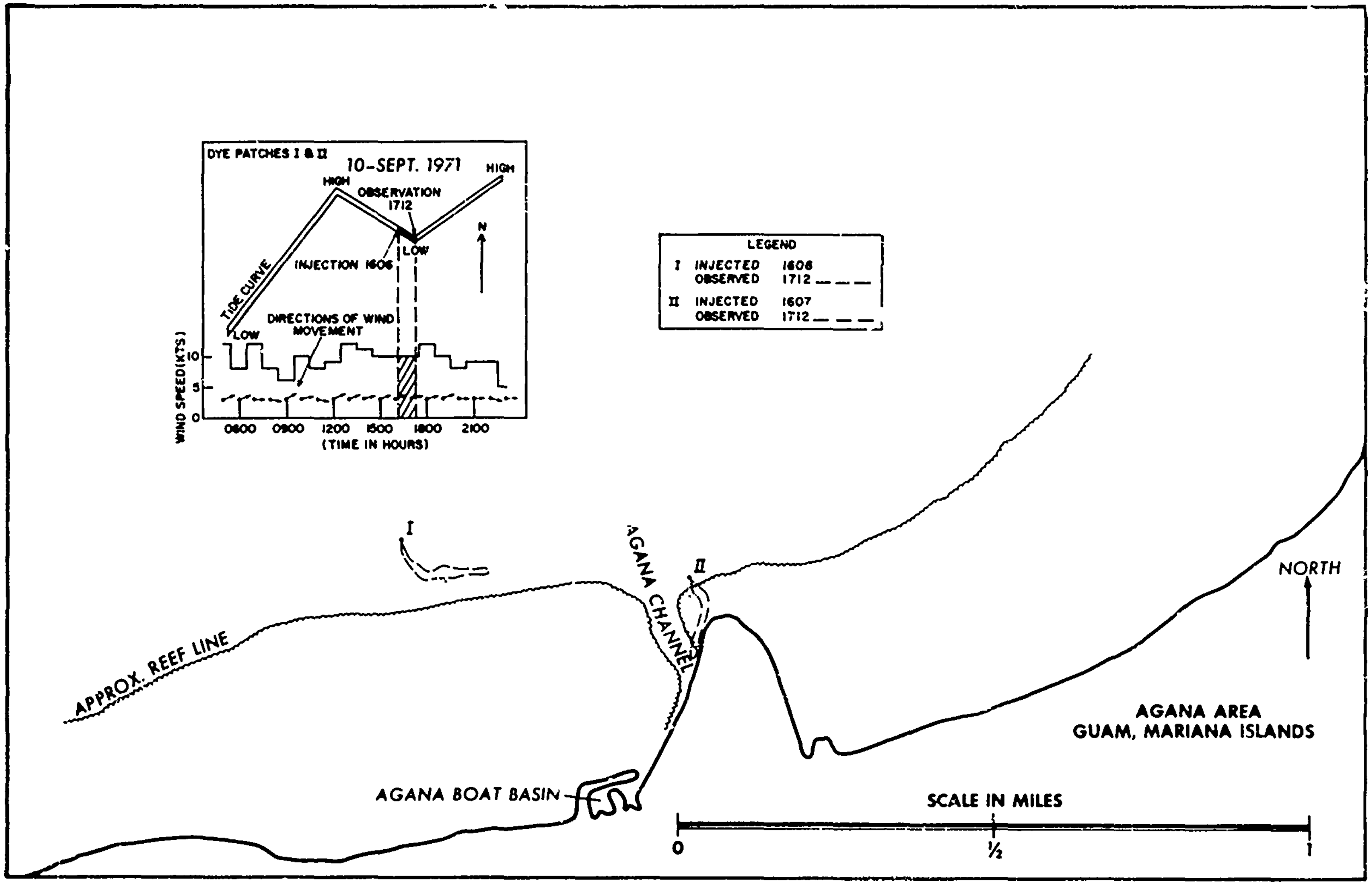


Figure 85. Dye movement at Agana Bay on 10 September 1971.

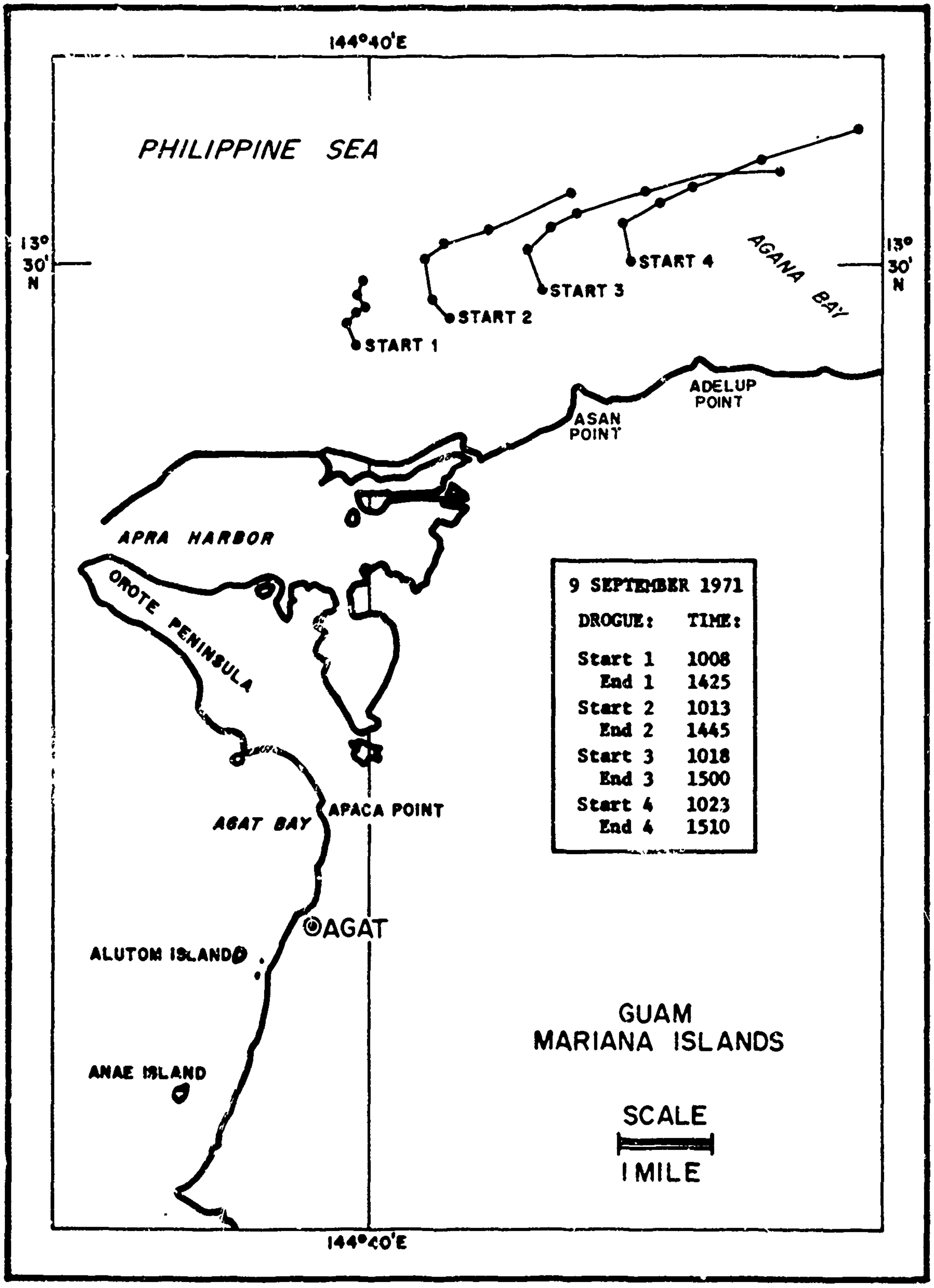


Figure 86. Drogue observations in Agana Section, 9 September 1971.

The Agana outfall location has the advantage of proximity to the sewage producing areas and resulting lower cost in pipeline construction. However, this outfall places the effluent close to areas of high recreational use. As discussed in the Bile and Agat sections, currents in bays tend to be weaker and to move in circular fashion. This tendency results in a longer residence time of the effluent in the coastal waters. Also contributing to the eddying nature of the circulation in Agana Bay is the presence of a wide reef flat. As reported by Jones and Randall (1971), water is fed to the reef flat by surf action across the reef margin creating a buildup of water which exits through openings in the reef at the northern and southern ends of the bay. Although Jones and Randall reported no present contamination of the reef flat by the outfall, the situation after the outfall reaches design capacity (approximately six times the present flow) may require a reevaluation of the suitability of Agana Bay as an outfall location or the upgrading of sewage treatment to prevent contamination of recreational areas.

4. Tumon Section

This section includes the coastline from Ypao Point at the southern end of Tumon Bay to Uruno Point. A sewer outfall exists at Haputo Point and plans are to construct an outfall in the Tanguisson Point area. A primary cause for concern is the possibility of sewage polluting the recreational beaches at Tumon Bay and NCS Beach.

Currents in this area were investigated using bottom-mounted and arrayed current meters, dye dispersals, and drogues.

During the winter field survey, current meters were installed on buoyed arrays at Tanguisson Point and Haputo Point. Both meters were placed at a depth of 50 feet (15.2 meters) in 300 feet (91.4 meters) of water (fig. 87). The Haputo Point meter (#166) recorded only a few hours of data before the instrument failed. These data are presented in the interim report of the winter survey. Current speeds from the Tanguisson Point meter (#356) ranged up to 0.75 knot (.375 m/sec), but they were most frequent between 0.05 and 0.25 knot (.025 and .125 m/sec). Most of the currents flowed northeast and southwest, with northeasterly flow being predominant. Progressive vector plots do not reveal any correlation between direction of flow and tidal phase.

Four current meters were installed in the section during the summer field survey. Their locations and the resultant data are shown in figure 88.

Meter #424 was placed on a bottom stand in 120 feet (36.6 meters) of water 200 yards (182.9 meters) north of Ypao Point. The meter recorded relatively slight currents mostly toward the northern half of the compass. Figure 89 shows 2 days of the data plotted as progressive vectors.

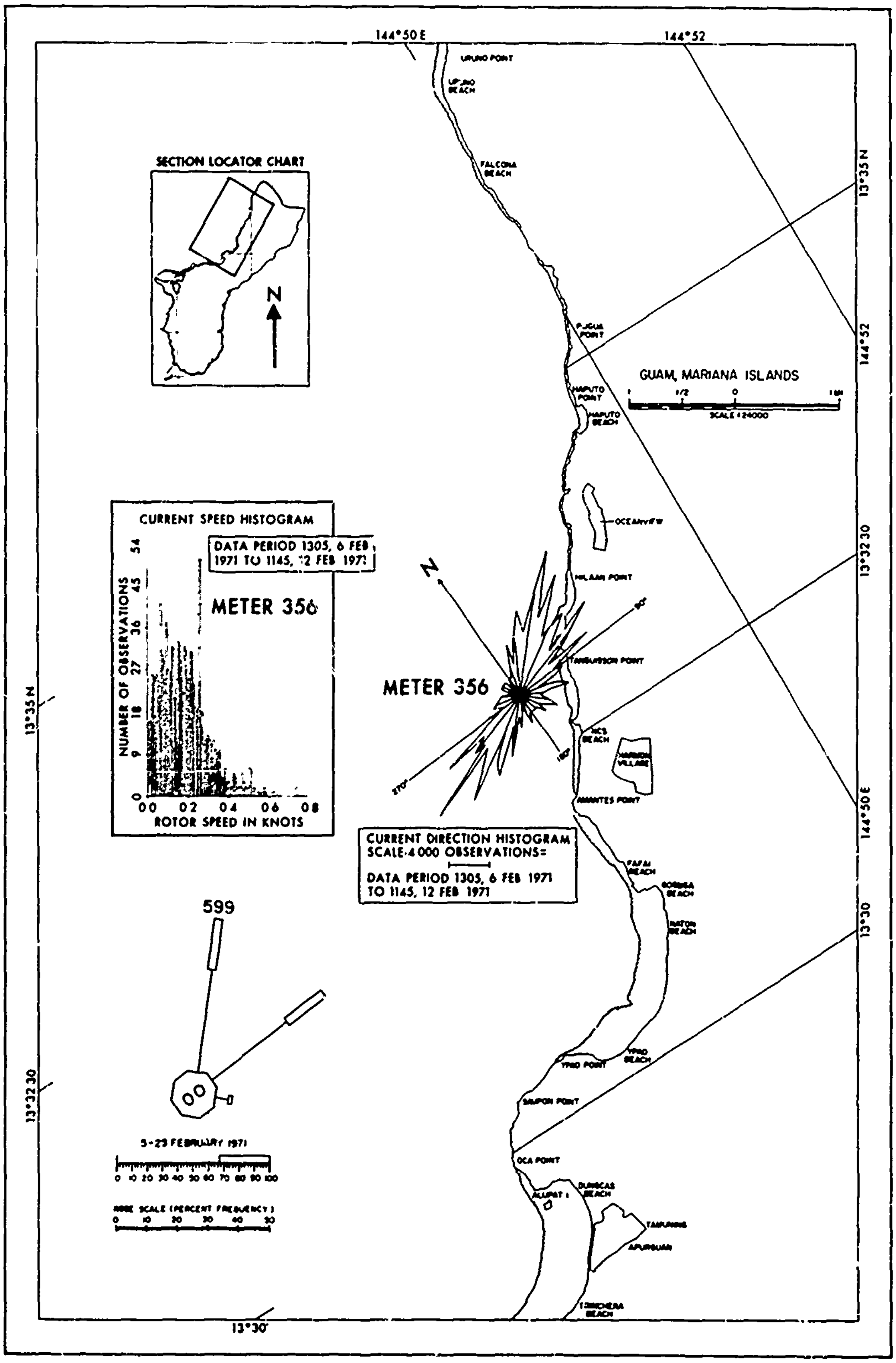


Figure 87. Current speed histogram and current direction histogram for the Tumon Section in winter including meter #356 and a wind rose for the data period.

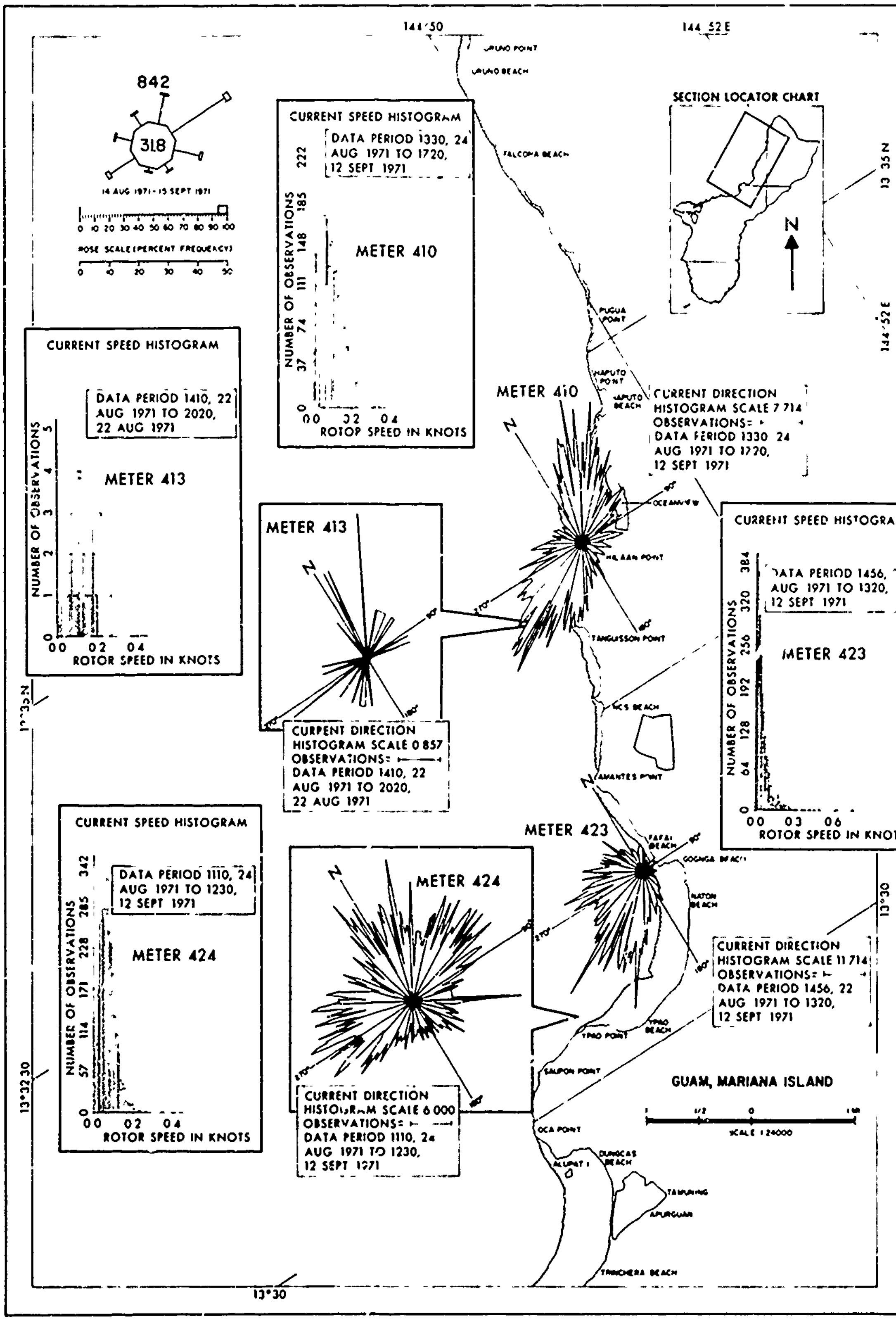


Figure 88. Current speed histograms and current direction histograms for the Tumon Section in summer including meters #410, #413, #423, and #424 and a wind rose for the data period.

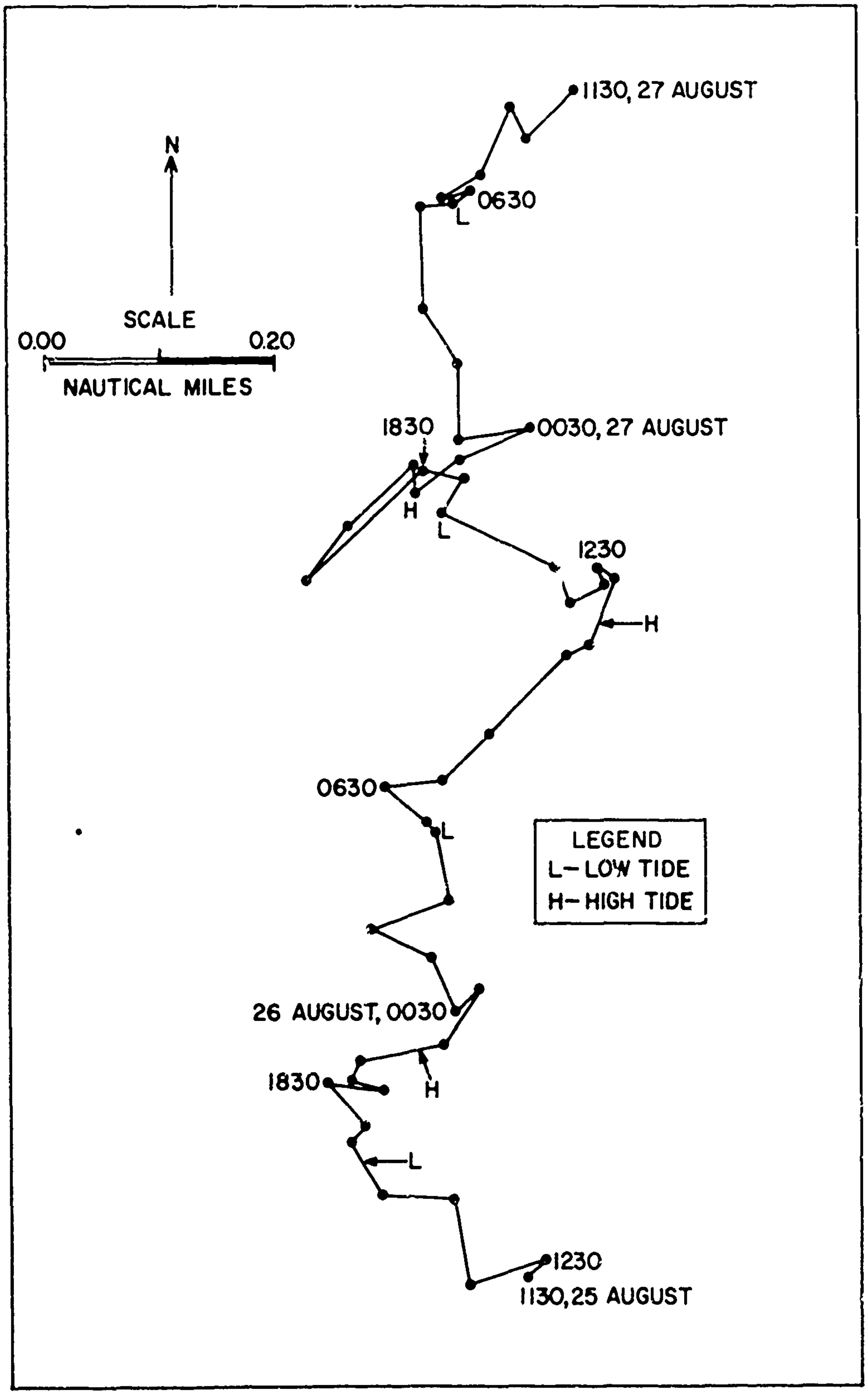


Figure 89. Progressive vector diagram of current from meter #424, 1130, 25 August to 1130, 27 August 1971.

During this period, net movement was to the north through an apparently random series of northerly, northwesterly, and northeasterly directions. Changes in direction or speed did not seem to be related to tidal cycles and were probably due to local meteorological effects.

Meter #423 was placed on a bottom stand off Fafai Beach. It was located on a submarine slope of about 20° at the 100-foot (30.5-meter) depth. Because the instrument malfunctioned, the data cannot be correlated to time except for start and end times. Most of the currents flowed southwesterly. Speeds were extremely low, with a majority of the observations at less than 0.1 knot (.05 m/sec) and very few greater than 0.3 knot (.15 m/sec).

Current meter #413, installed off Tanguisson Point, recorded only 6 hours of data. It was installed on a bottom stand in 50 feet (15.2 meters) of water. Although it was functional for only half of a tidal cycle, the frequency distribution of current directions is very similar to those of meters #356 and #410, which recorded data for 6 days and 19 days, respectively.

Current meter #410 was installed 200 yards (182.9 meters) off Hilaan Point on a bottom stand in 70 feet (21.3 meters) of water. Currents up to 0.4 knot (.20 m/sec) were recorded, but most of them were less than 0.2 knot (.10 m/sec). Current directions were roughly parallel to the coastline. A 65-hour period of the data is shown in figure 90.

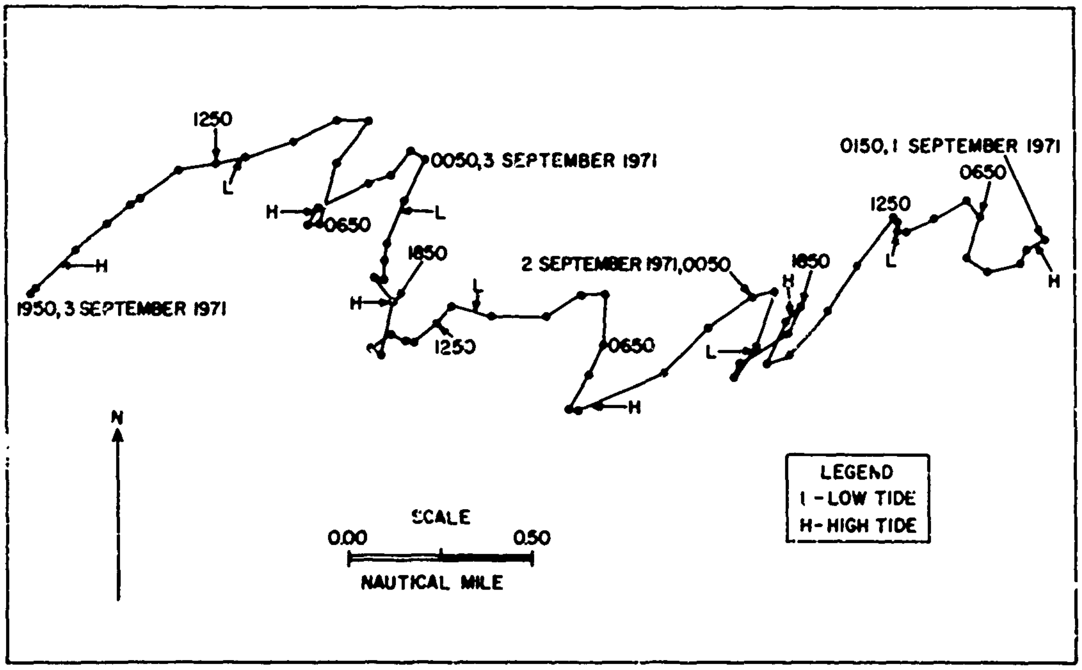


Figure 90. Progressive vector diagram of current from meter #410, 0150, 1 September to 1950, 3 September 1971.

During this period, directions shifted between southwest and north-northeast resulting in a net westerly drift. The general pattern was a southwest flow for 3 hours before and 6 hours after each lower low water of the day with less consistent flow at other times.

A total of 38 dye patches was tracked by helicopter between the NCS Beach and Haputo Point (figs. 91 through 104). They indicated currents flowing up to 0.4 knot (.20 m/sec) usually paralleling the shoreline. Between Oceanview and Haputo Point most of the currents moved northeast. Off the NCS Beach and Tanguisson Point, flow was almost equally divided between northeast and southwest. Off Hilaan Point, all but one of the dye patches moved southwest. The direction of movement was apparently unrelated to the tidal phase. Only one dye patch moved across the reef (fig. 98). This patch was from a dye cake placed off Tanguisson Point relatively near the reef. Dye was carried over the reef by wave action and dispersed on the reef flat. Dye placed off the NCS Beach on 29 and 30 August and 3 September (figs. 96, 97, and 103) showed the effects of the rip current which carried water out through a break in the reef. This current was present regardless of the tidal phase.

Four drogues were tracked on 1 September between Tanguisson Point and Amantes Point (fig. 105). They all moved southwesterly along the coast at approximately 0.4 knot (.20 m/sec).

An offshore southwesterly flow is apparent in the data from the current meters installed off Hilaan Point, Cabras Island, and Orote Point, and from the drogue tracks in figure 105. Nearshore currents are controlled by a complicated series of eddies from the offshore flow. The location and shape of the eddies at any particular time are determined by a combination of many factors, the most important being wind speed and direction, tidal phase, configuration of the coastline, topography of the bottom, wave height and direction, and the speed and direction of the offshore current. For sewage outfall placement, it is necessary to determine at what locations the eddies are most likely to carry pollutants away from shore and into the offshore current.

For an outfall located north of the NCS Beach, the most desirable location is one with a northerly current. Another consideration is the relatively wide reef flat located between Amantes Point and Hilaan Point. Water is supplied to the shallow reef flat primarily by the action of waves carrying water across the reef margin. This wave action creates a longshore current which travels along the reef flat until a break in the reef is encountered, like the one near NCS Beach. Sewage carried onto the reef flat would be likely to travel a considerable distance along the beach before being carried out to sea. The dye studies reveal that north of Oceanview currents are more likely to carry pollutants in the desired direction. The ideal location appears to be Ague Point. Ague Point is located at some distance from the broad reef flat south of Hilaan Point. Dye at this location consistently moved either northerly or directly out to sea.

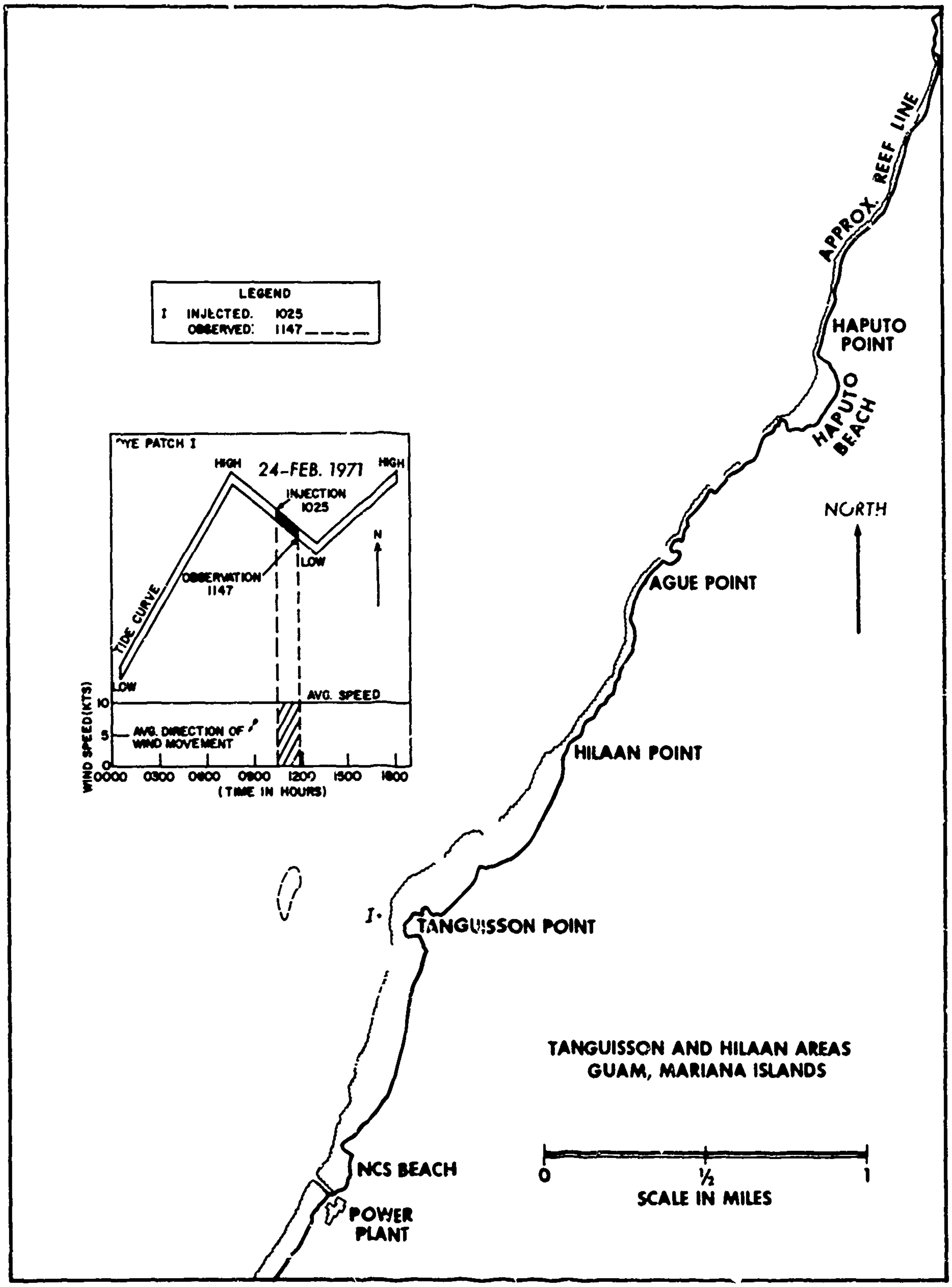


Figure 91. Dye movement at Tanguisson Point on 24 February 1971.

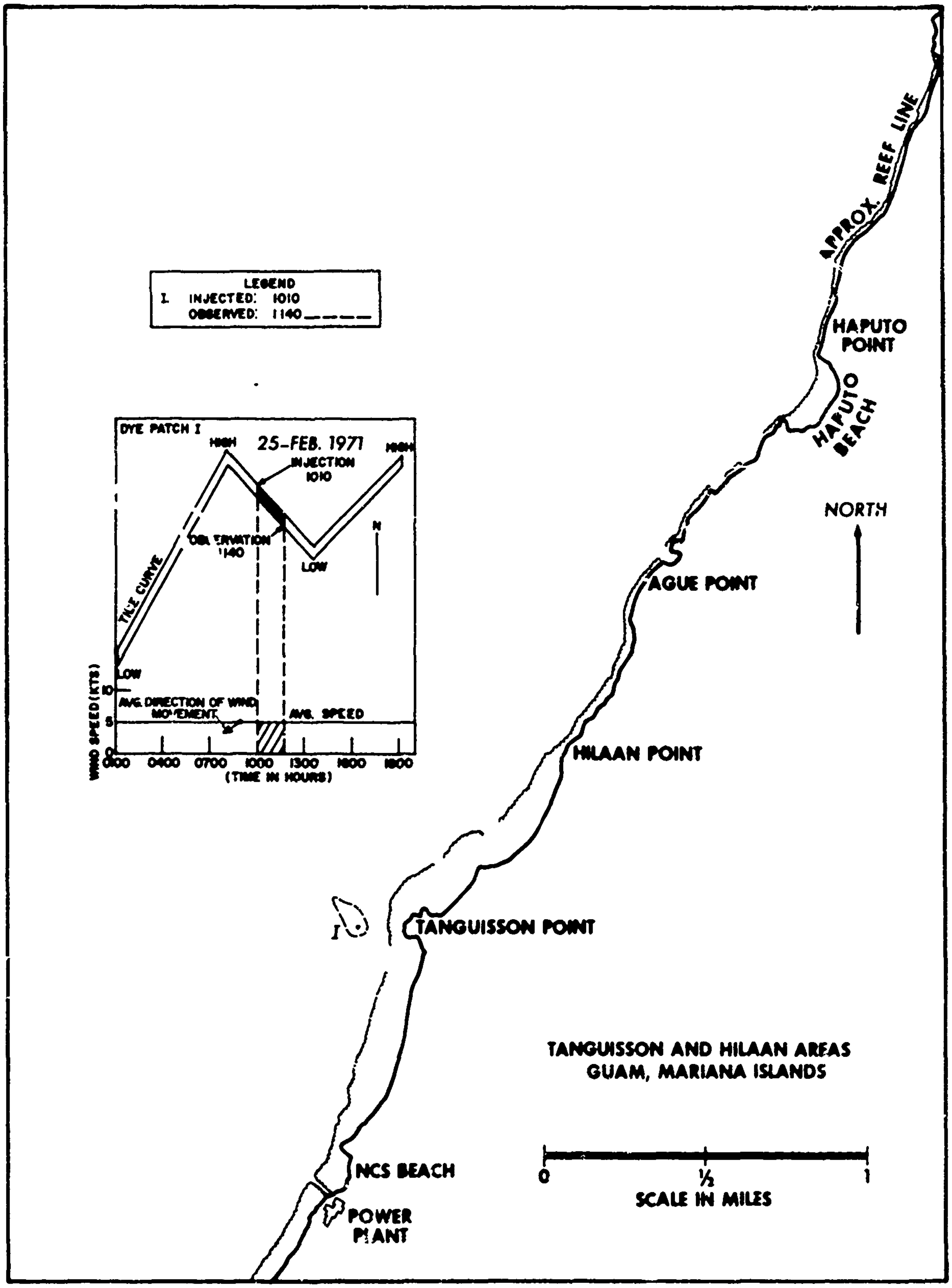


Figure 92. Dye movement at Tanguisson Point on 25 February 1971, A.M.

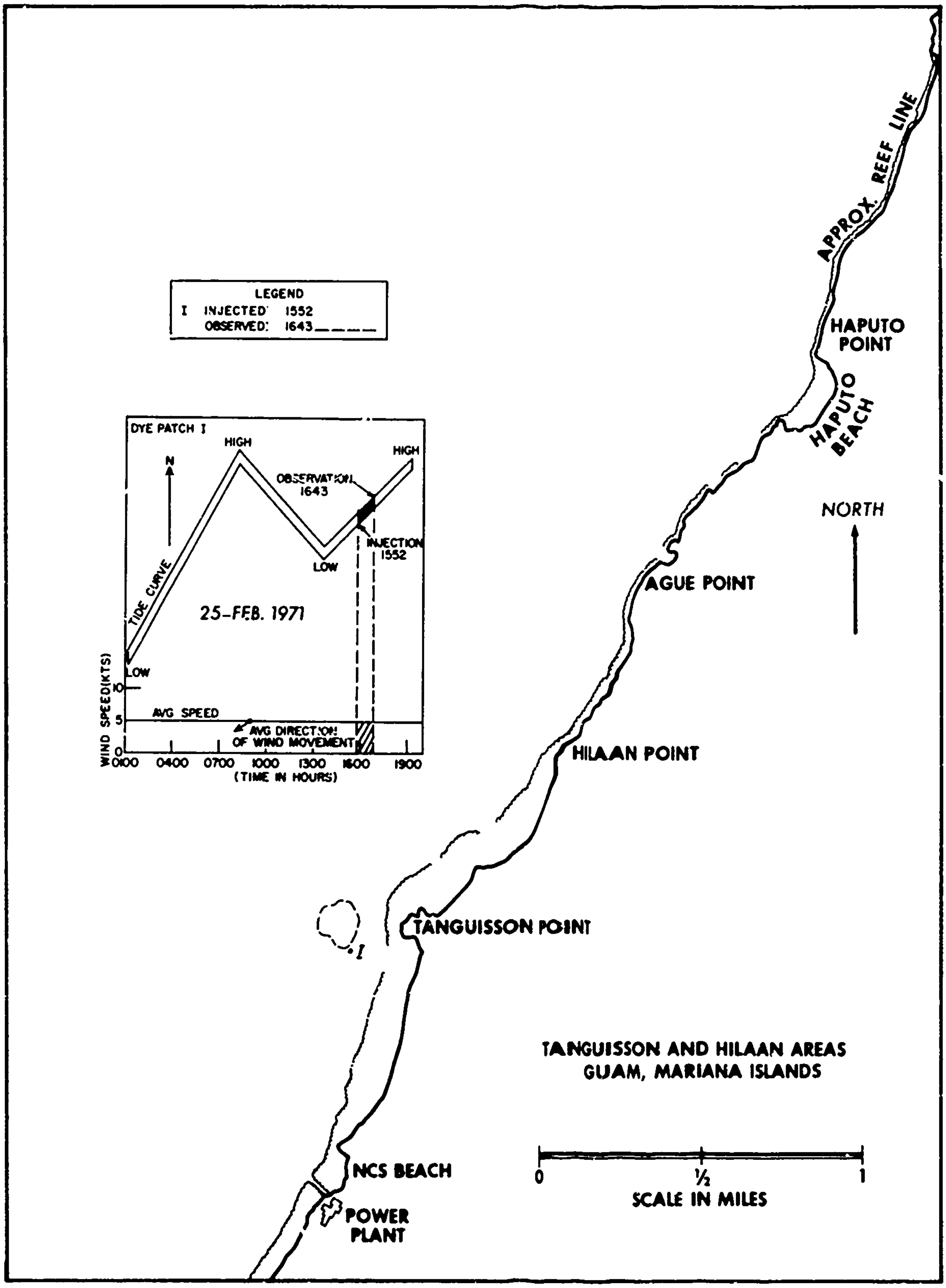


Figure 93. Dye movement at Tanguisson Point on 25 February 1971, P.M.

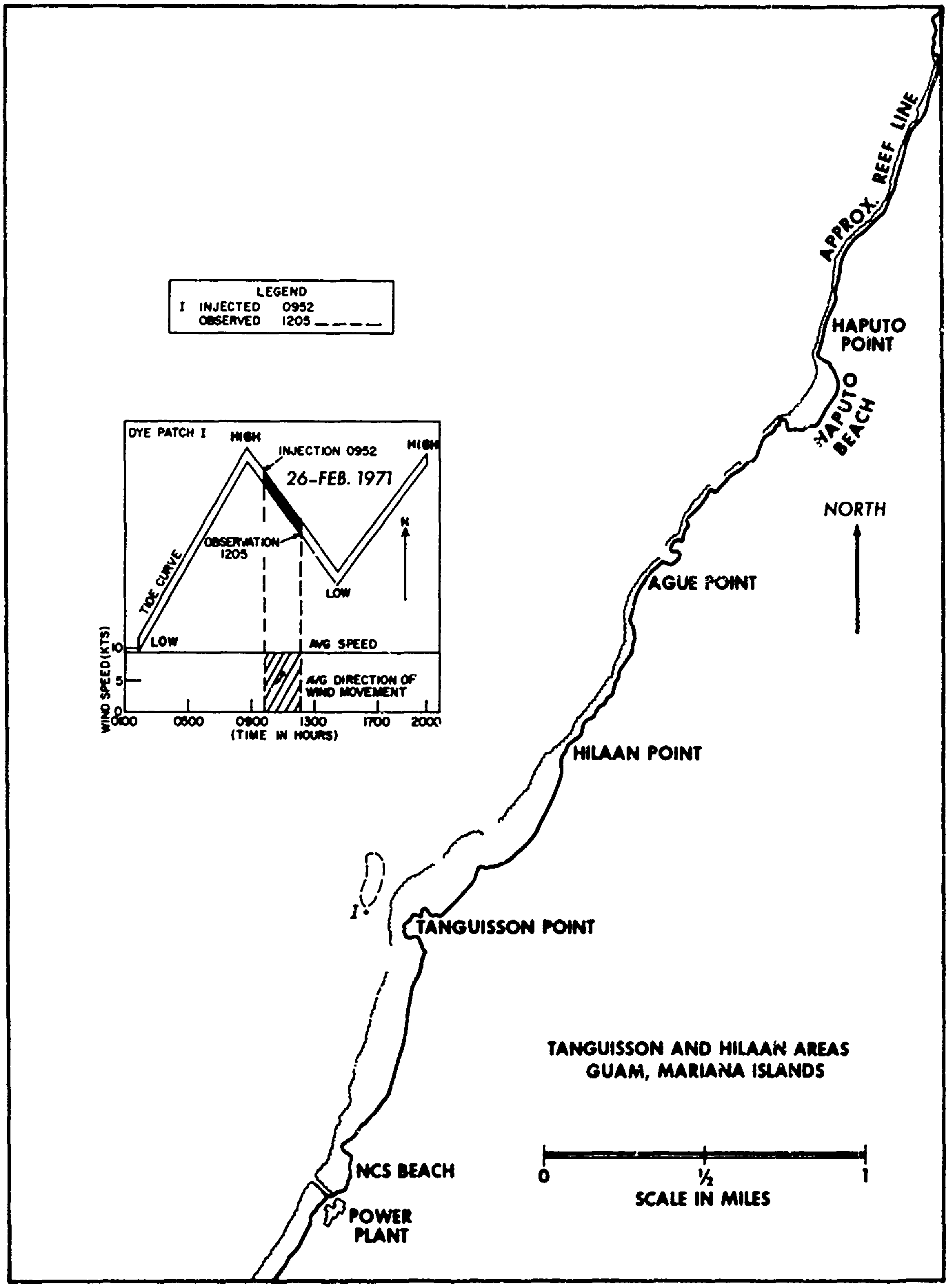


Figure 94. Dye movement at Tanguisson Point on 26 February 1971, A.M.

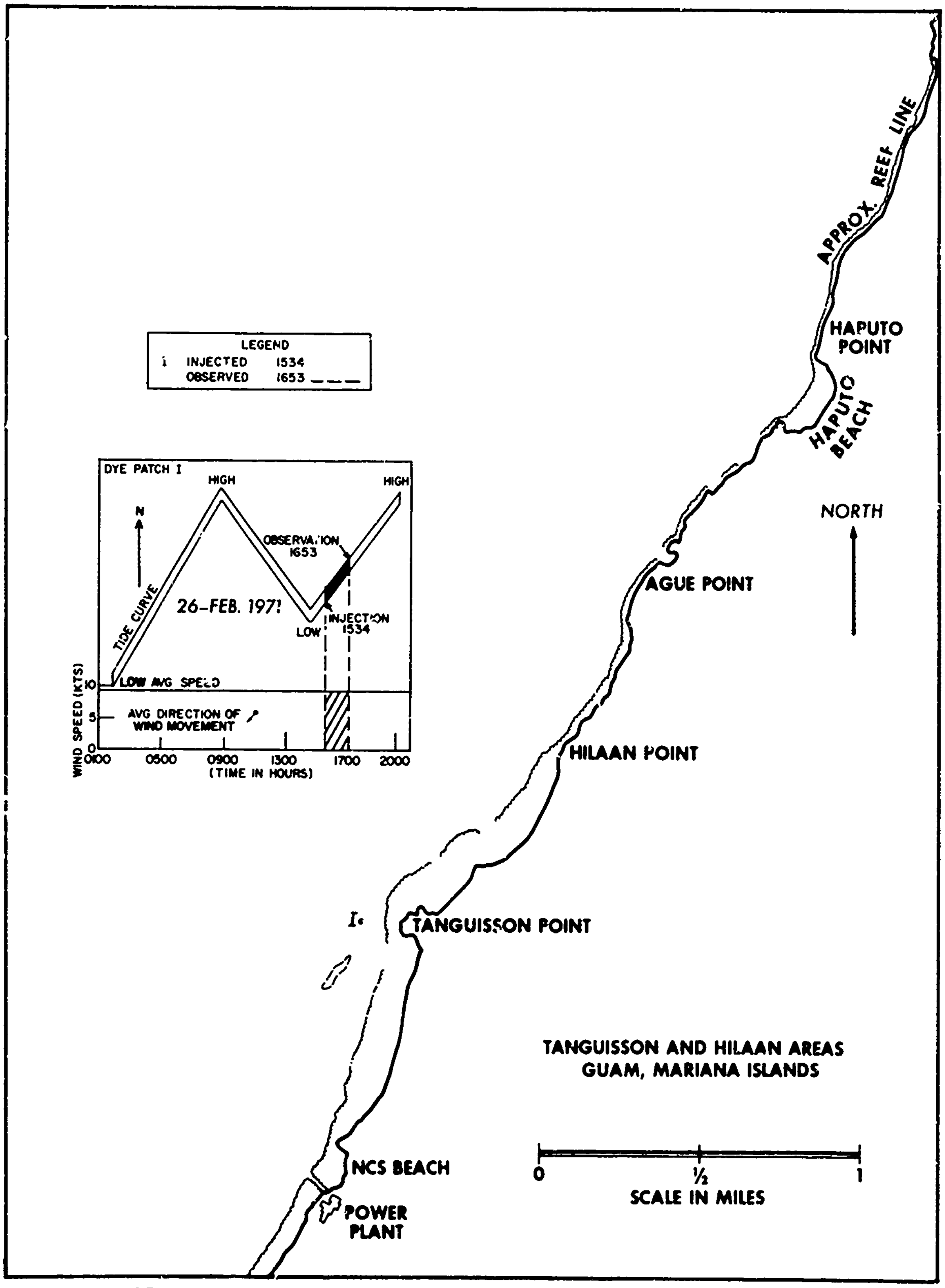


Figure 95. Dye movement at Tanguisson Point on 26 February 1971, P.M.

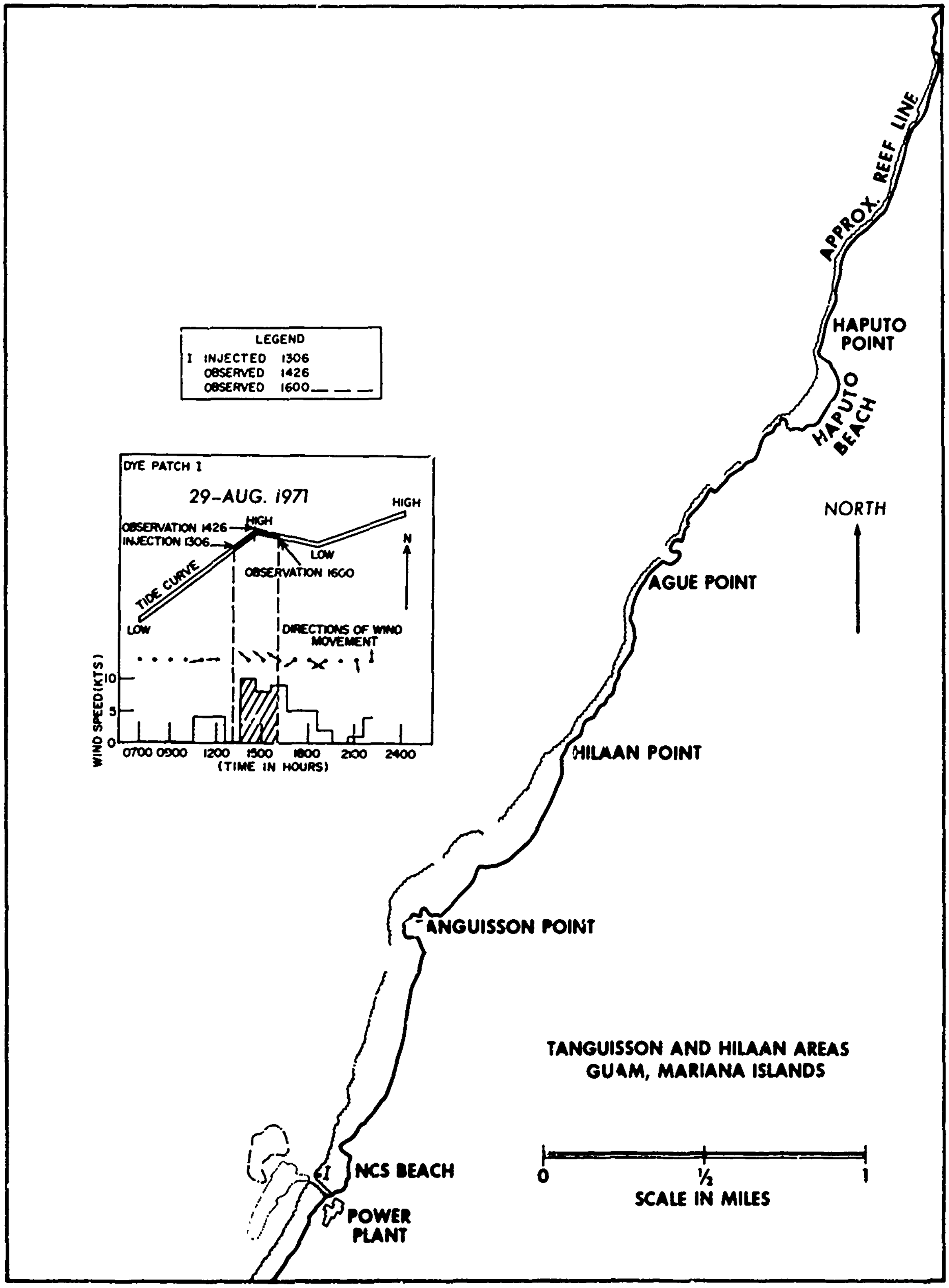


Figure 96. Dye movement at Tanguisson Point on 29 August 1971.

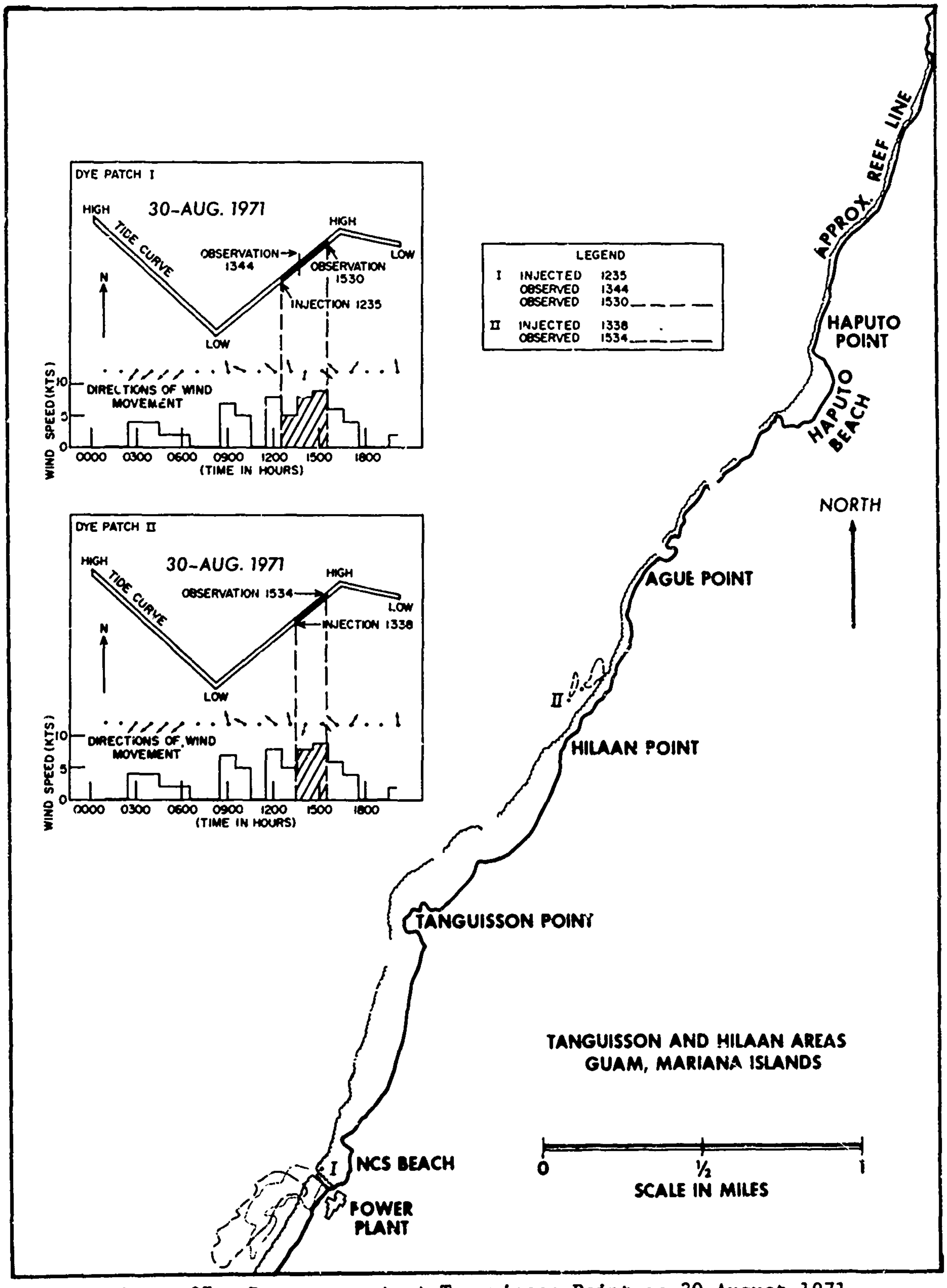


Figure 97. Dye movement at Tanguisson Point on 30 August 1971.

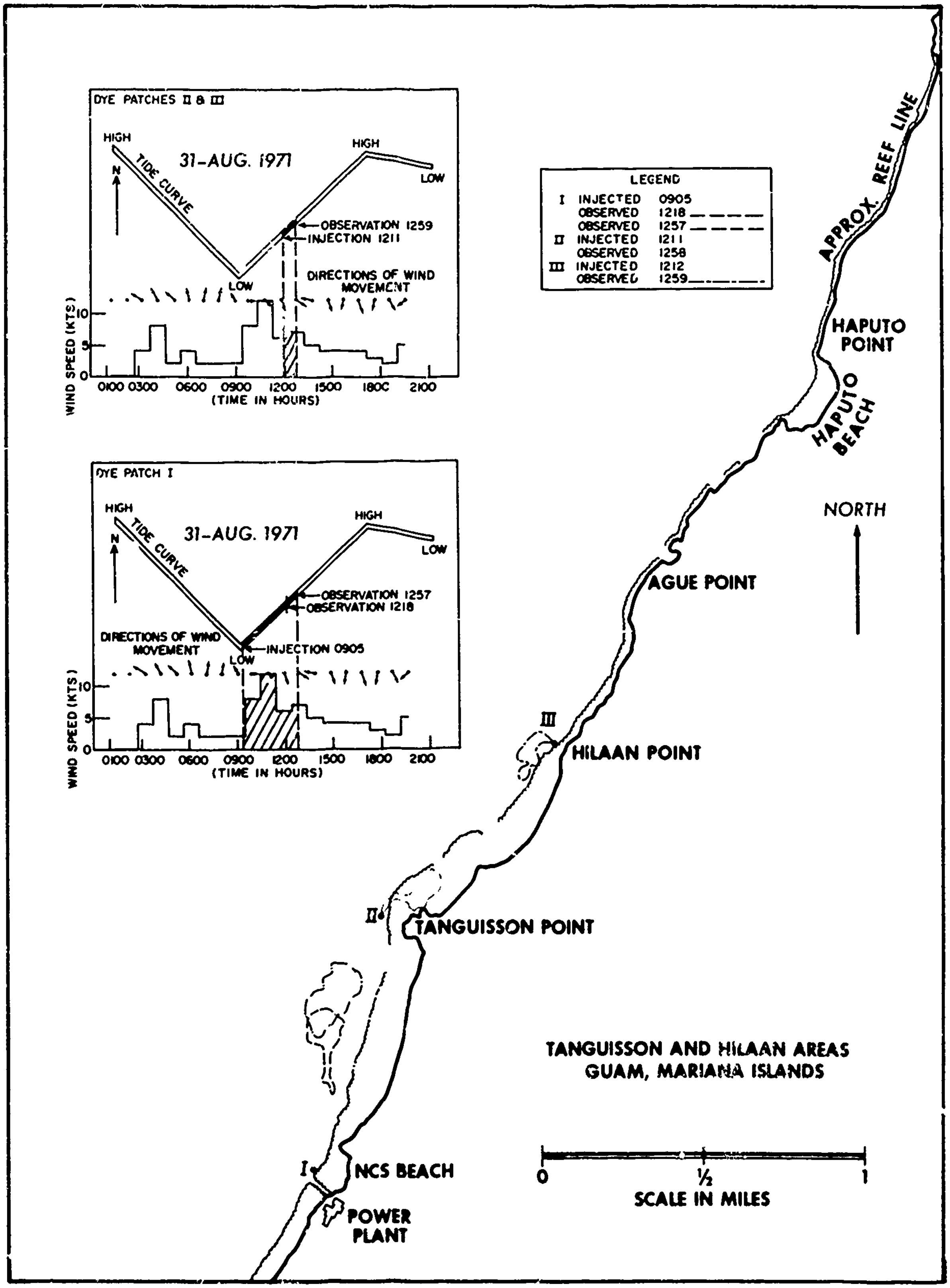


Figure 98. Dye movement at Tanguisson Point on 31 August 1971.

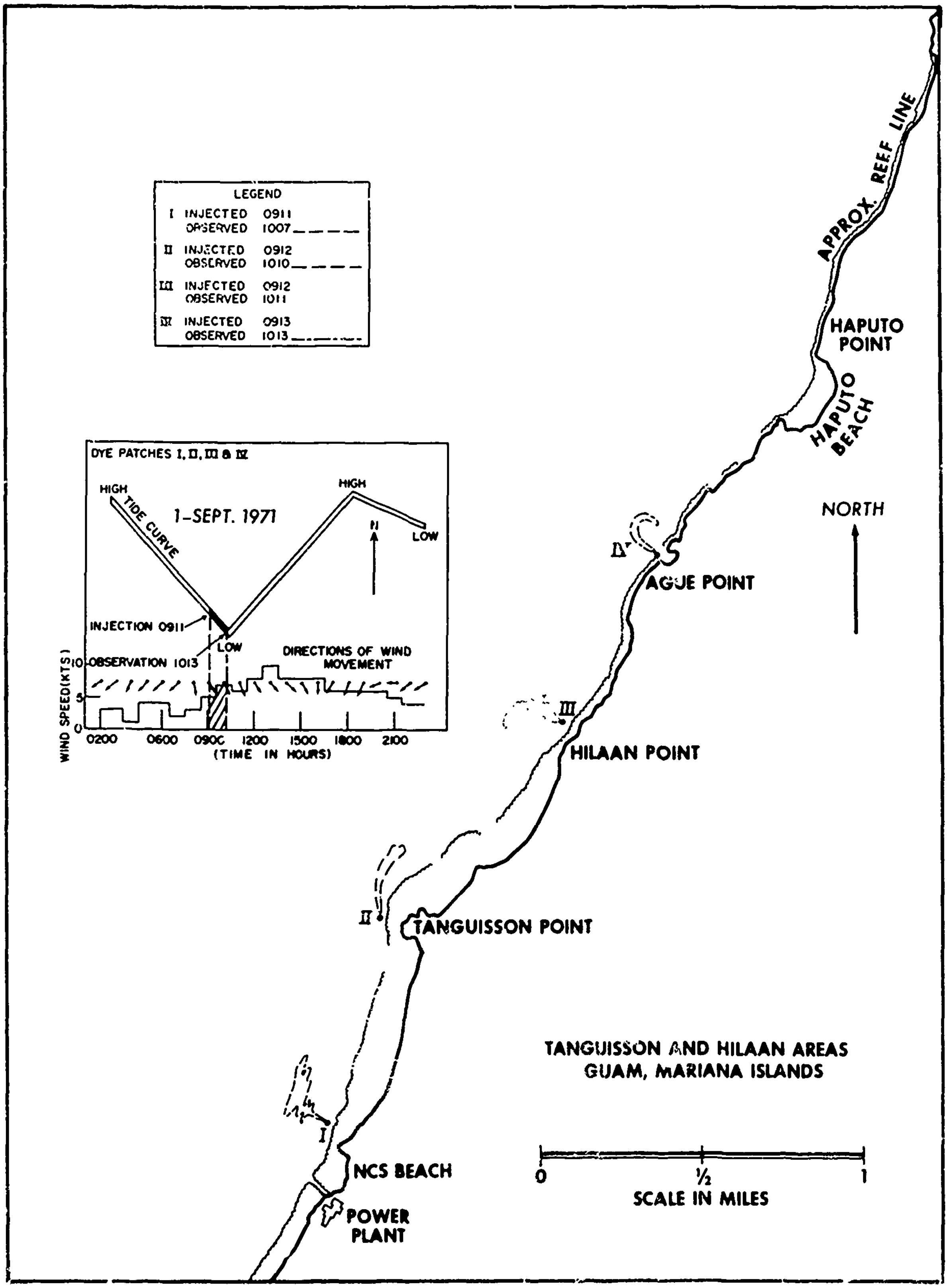


Figure 99. Dye movement at Tanguisson Point on 1 September 1971.

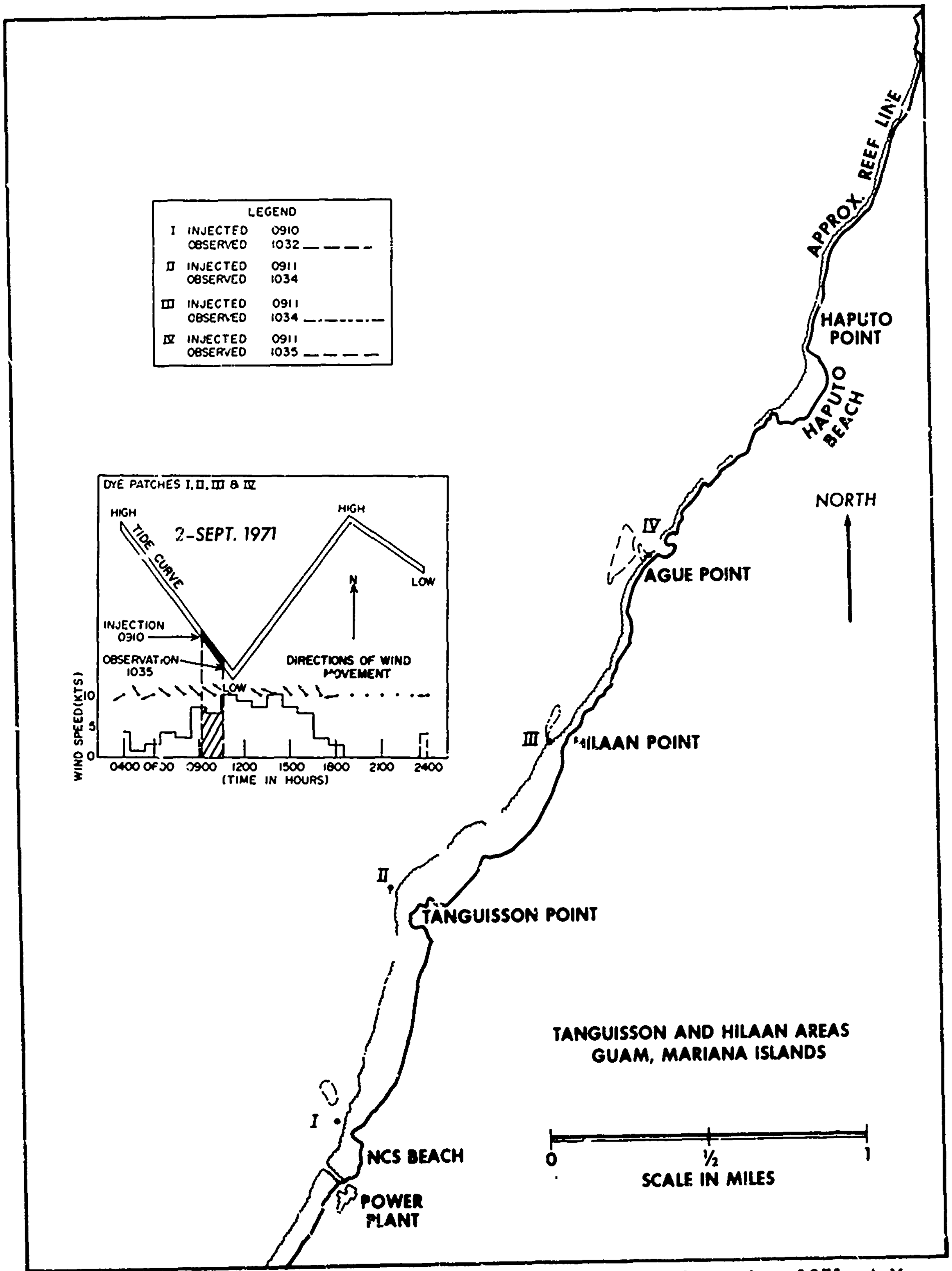


Figure 100. Dye movement at Tanguisson Point on 2 September 1971, A.M.

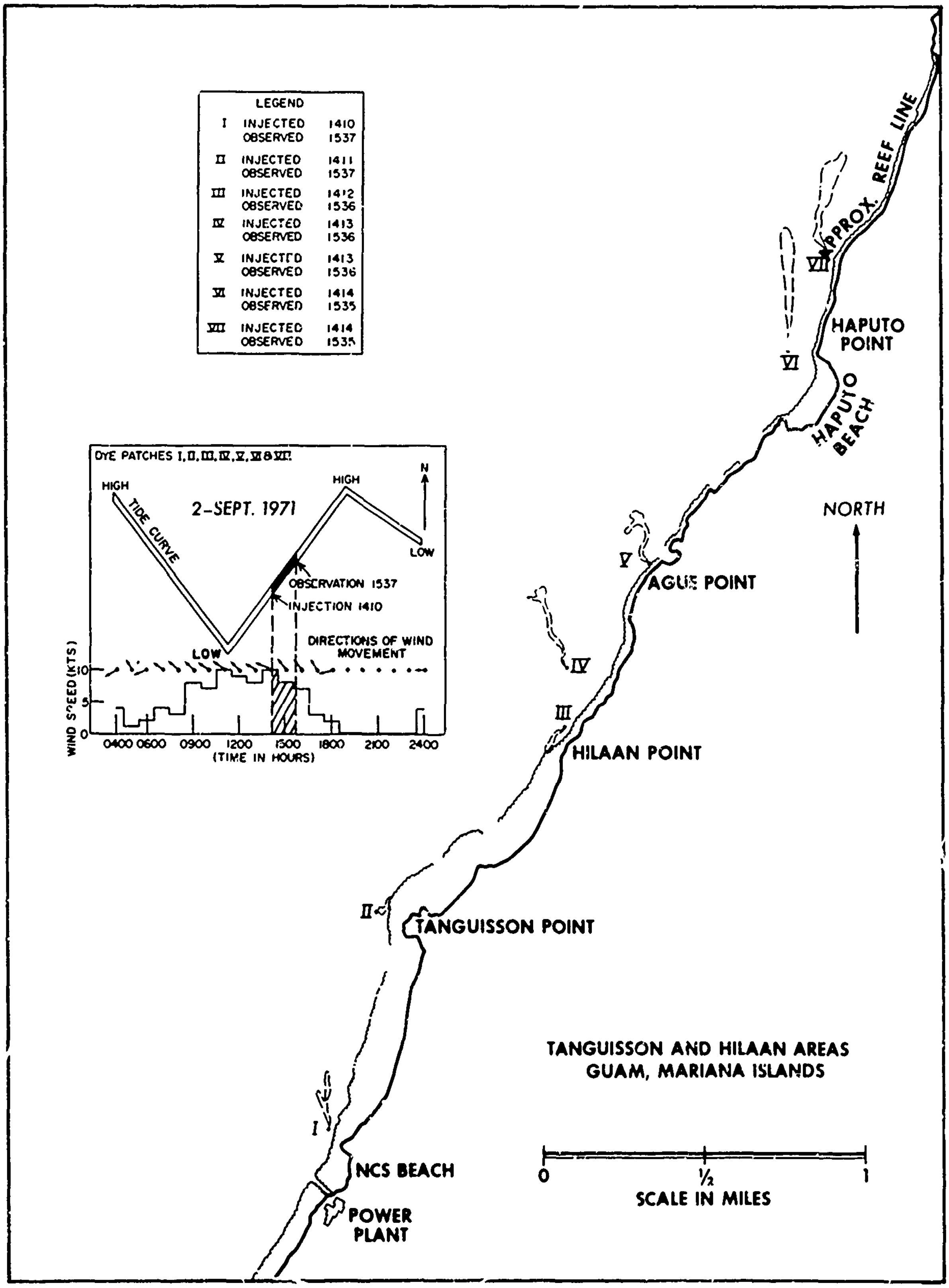


Figure 101. Dye movement at Tanguisson Point on 2 September 1971, P.M.

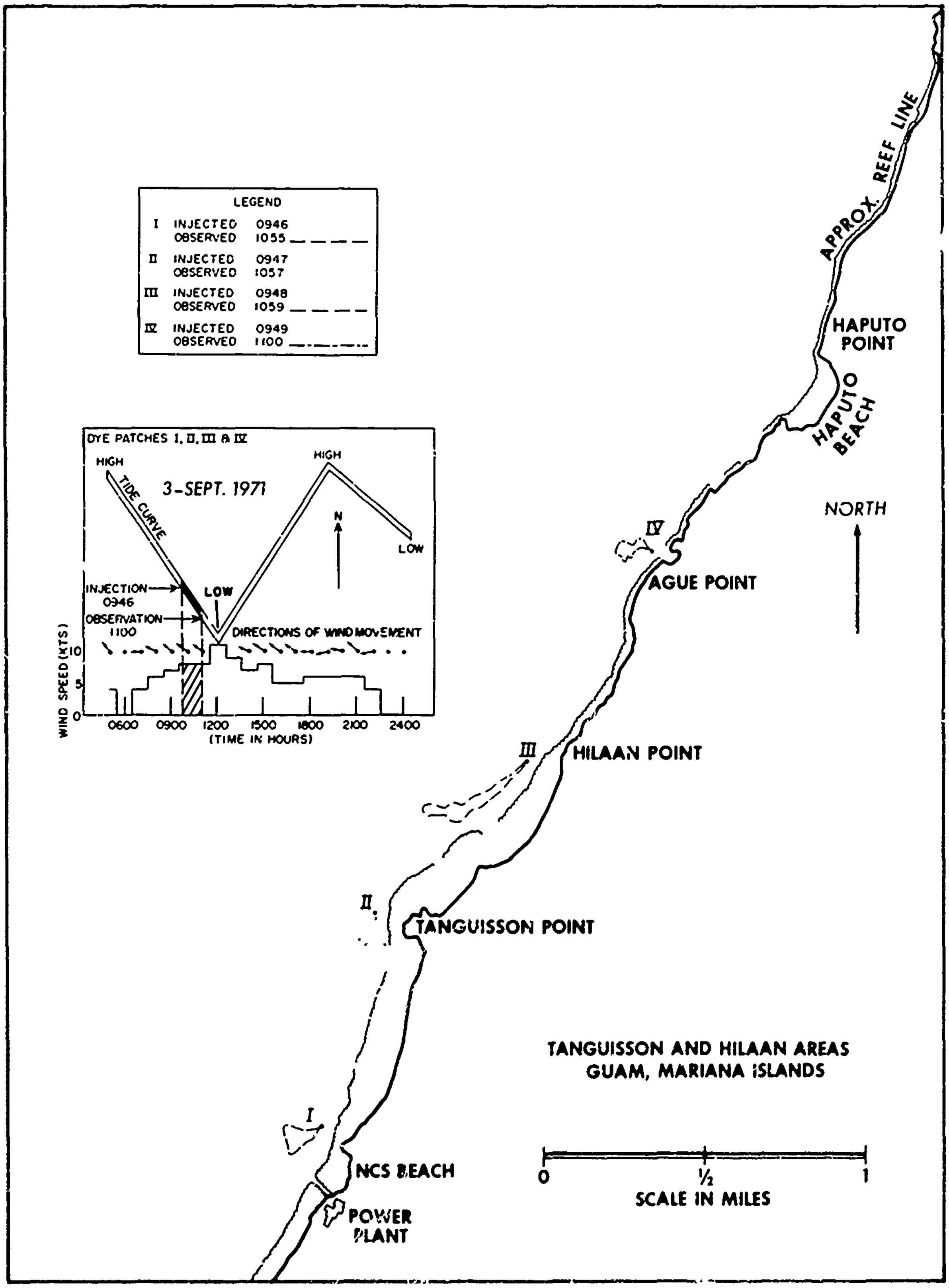


Figure 102. Dye movement at Tanguisson Point on 3 September 1971, A.M.

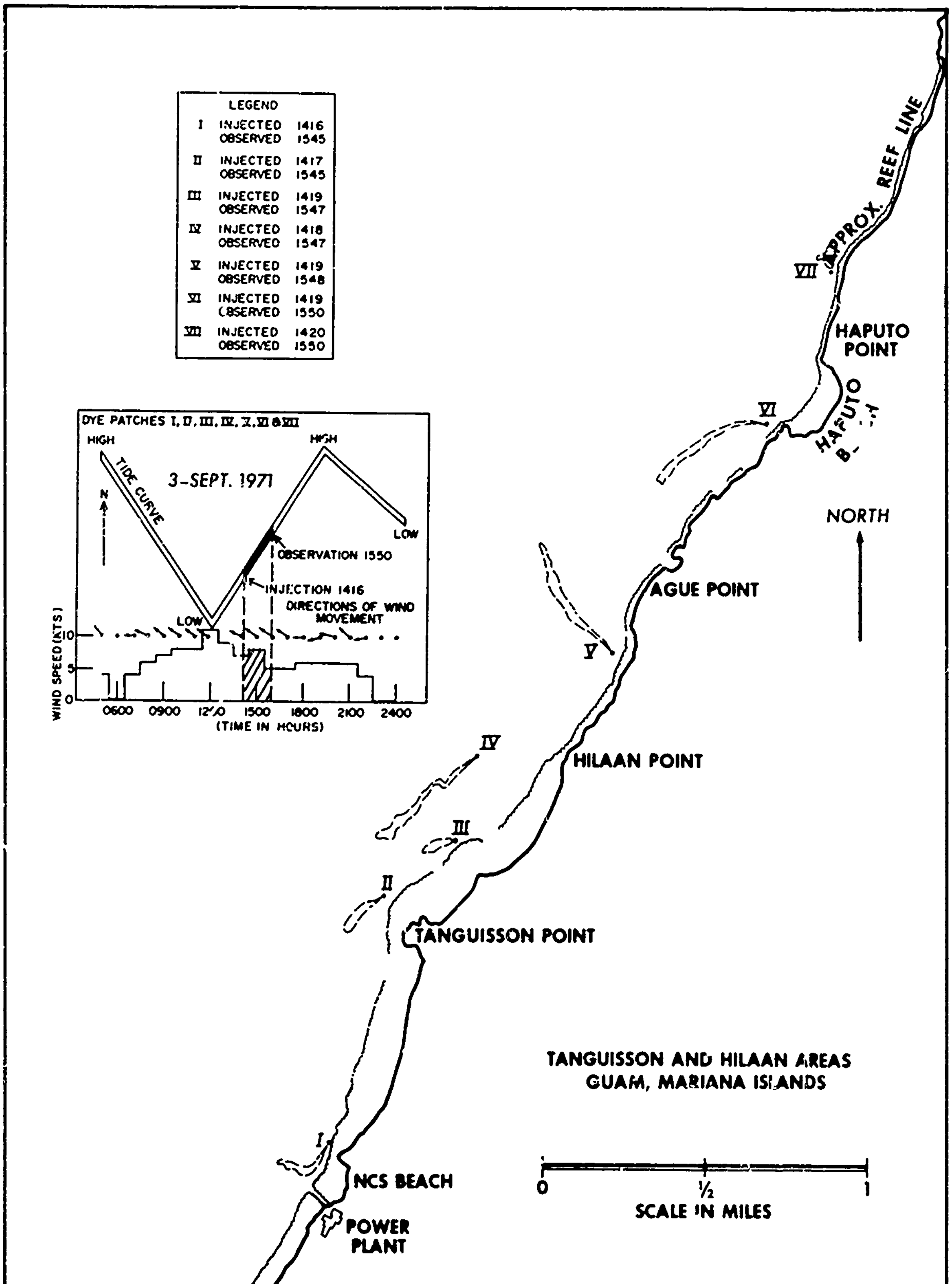


Figure 103. Dye movement at Tanguisson Point on 3 September 1971, P.M.

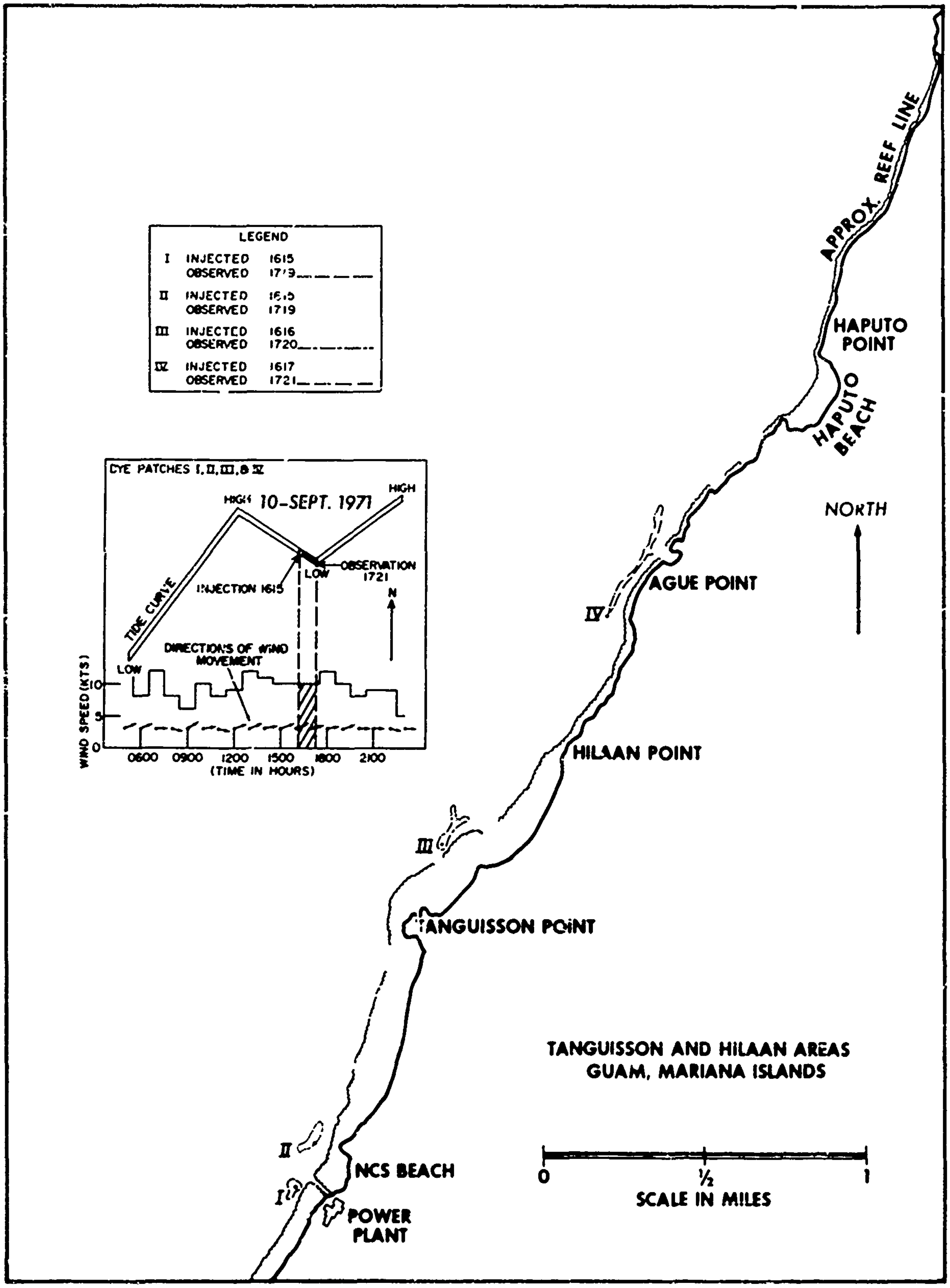


Figure 104. Dye movement at Tanguisson Point on 10 September 1971.

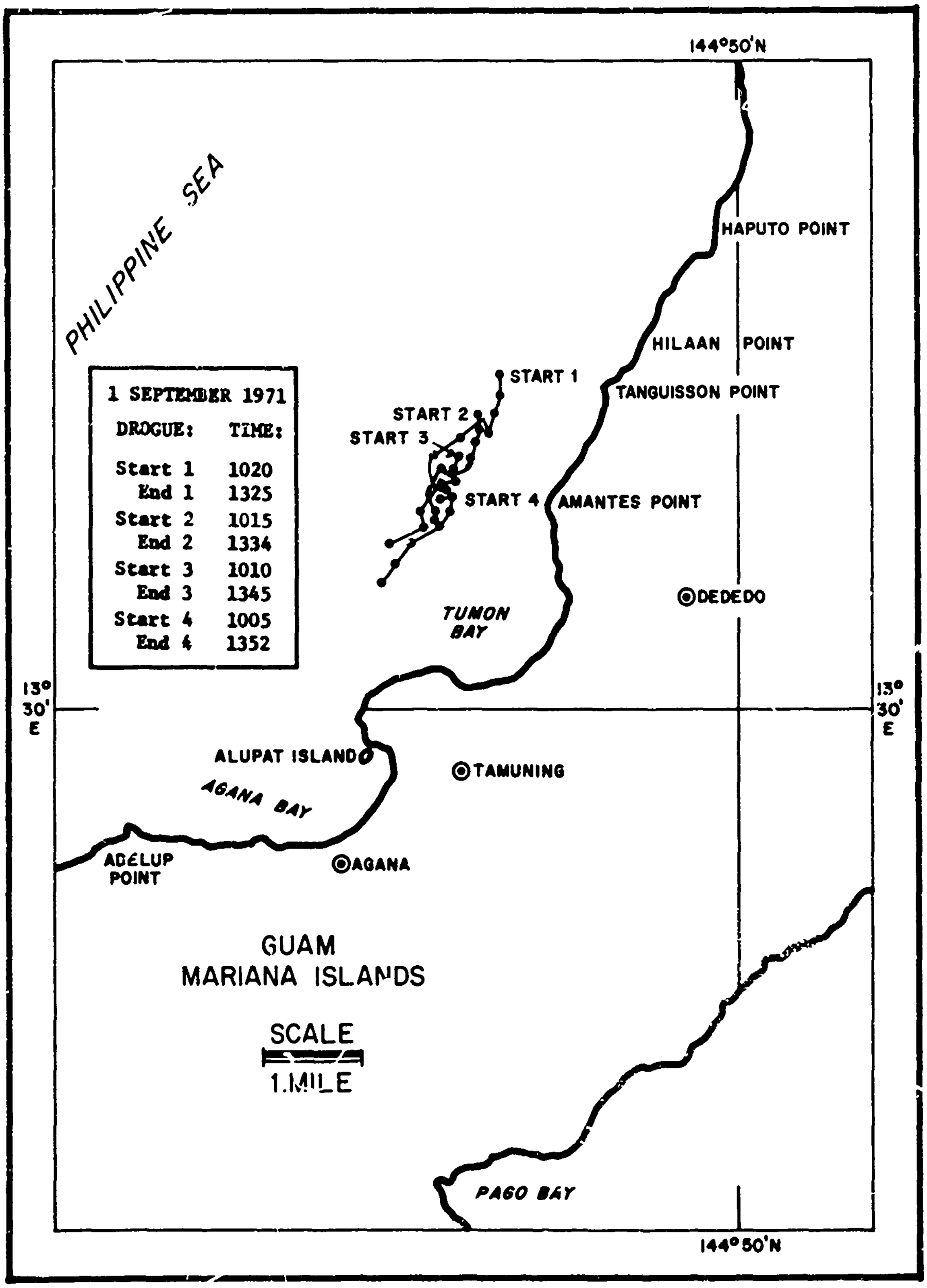


Figure 105. Drogue observations in Tumon Section, 1 September 1971.

5. Ritidian Section

A single array of current meters was planted 2 miles (3.22 km) north of Ritidian Point during the summer survey. The array contained three current meters configured as shown in figure 106. The purpose of this array was to define the currents passing the northern tip of the island with the possibility of discovering a strong offshore current which would carry sewage away from the coast of Guam. The data from these three meters illustrate the extreme variability with depth of the currents at this location, and leaves in doubt the existence of a consistent sewage-removing current.

Of the three current meters on this array, the bottommost meter recorded the most consistent and most interesting data. This meter (#417) was subjected to fast, rapidly reversing currents such as would be expected in a narrow channel with large tidal changes. The entire record of current speed from this meter is presented in figure 107. Shorter segments of the data are shown in more detail in figure 108. Currents at 1,165 feet (355 meters) were controlled almost entirely by the tides. Maximum speeds reached lows on 30 August and 12 September, 1 day after the moon reached first quarter and last quarter (quadrature) and the same day on which the maximum southerly and northerly declination of the moon occurred. Neap tides occurred at these times and are reflected in the currents. Maximum speeds gradually increased through the first week in September reaching a high on approximately 6 September, 1 day after the full moon (syzygy) and the same day the moon made its closest monthly approach to earth (perigee). Spring tides were associated with these phenomena. This bimonthly cycle of changing tidal ranges (fortnightly periodicity) is reflected with remarkable clarity in the current speeds. Maximum speeds describe a sine curve with a wavelength of about 14 days.

Currents flowed northwesterly during the rising tide and southeasterly during ebb. Changes in direction occurred within 10 or 20 minutes. If the currents were due entirely to tidal forces, the speed during ebb would equal that during flood. This was not the case. Currents were stronger during flood and resulted in a net northwesterly flow. The magnitude and direction of this net flow was determined by averaging the entire record through the fortnightly period of 29 August through 12 September. An average current of 0.157 knot (.079 m/sec) toward the north-northwest resulted. This net flow is interpreted as the influence of the North Equatorial Current.

The surface currents showed little similarity to those at depth. Speeds from current meters #420, at 89 feet (27.1 meters), and #404, at 200 feet (61 meters), were considerably lower, and directions were more variable. A predominance of currents flowed toward the east at both depths. Little correlation with tidal influences is apparent in the data from either current meter (figs. 109 and 110).

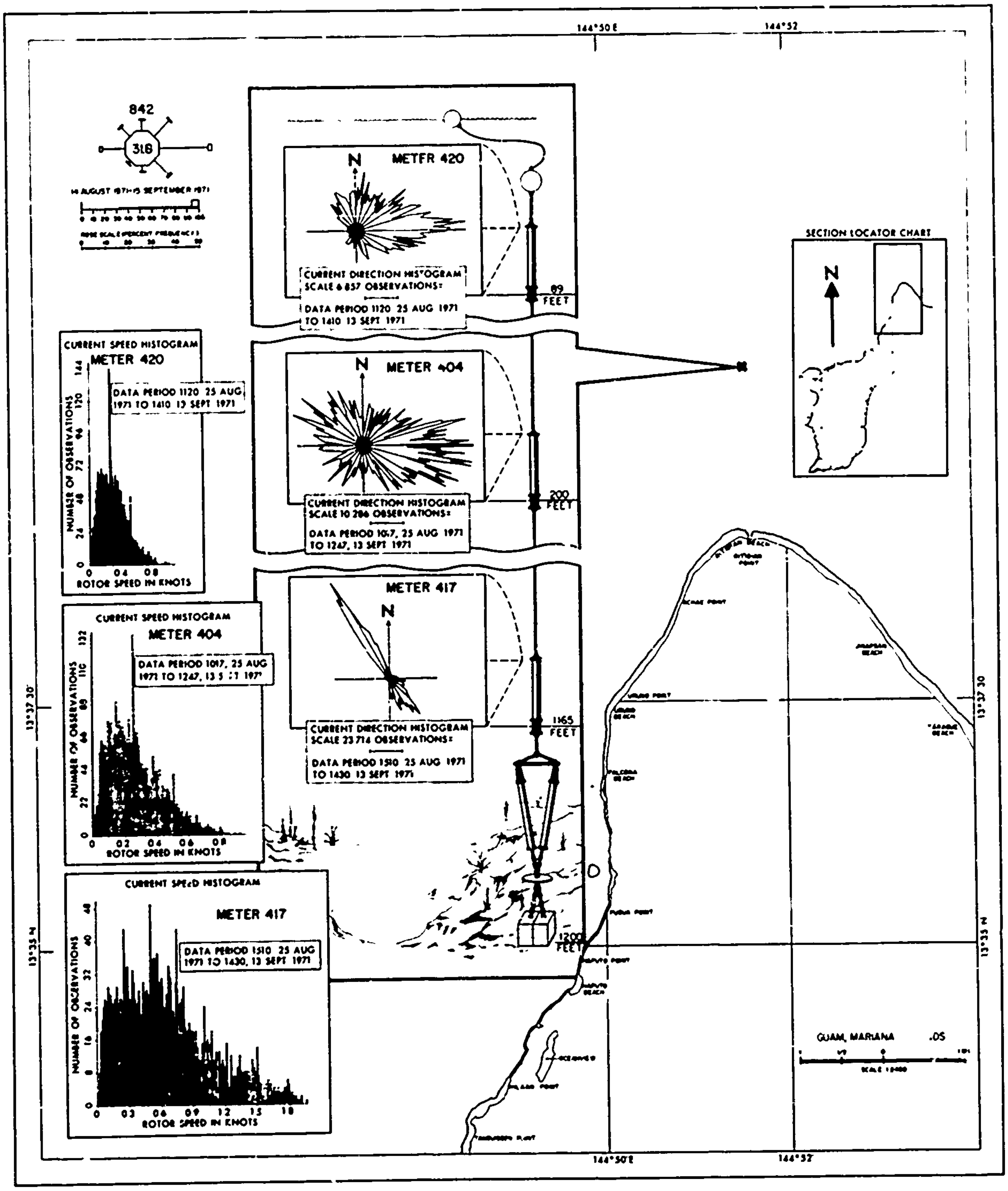


Figure 106. Current speed histograms and current direction histograms for the Ritidian Section in summer including meters #420, #404, and #417 and a wind rose for the data period.

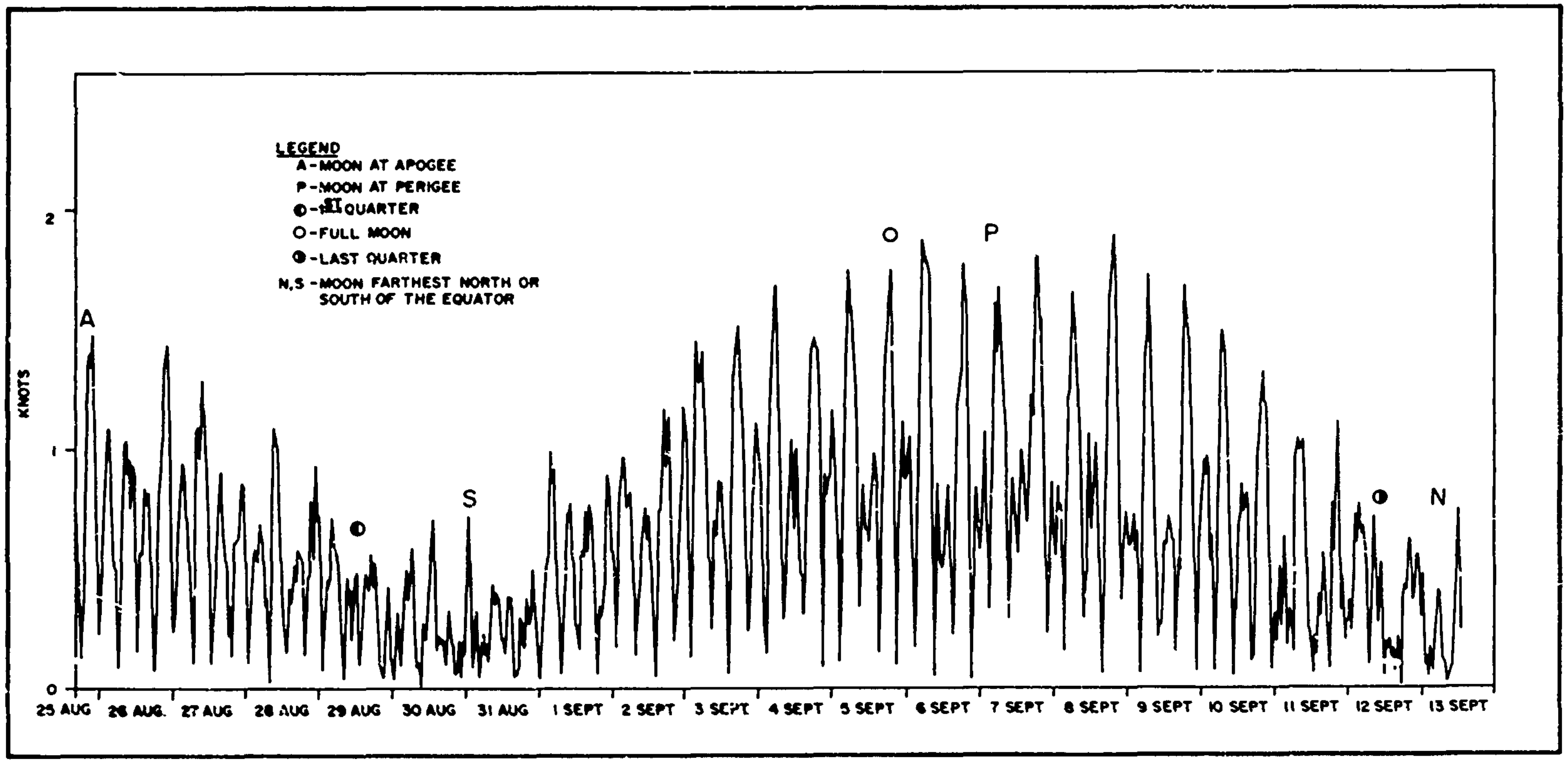


Figure 107. Current speed plot from meter #417, 25 August to 13 September 1971.

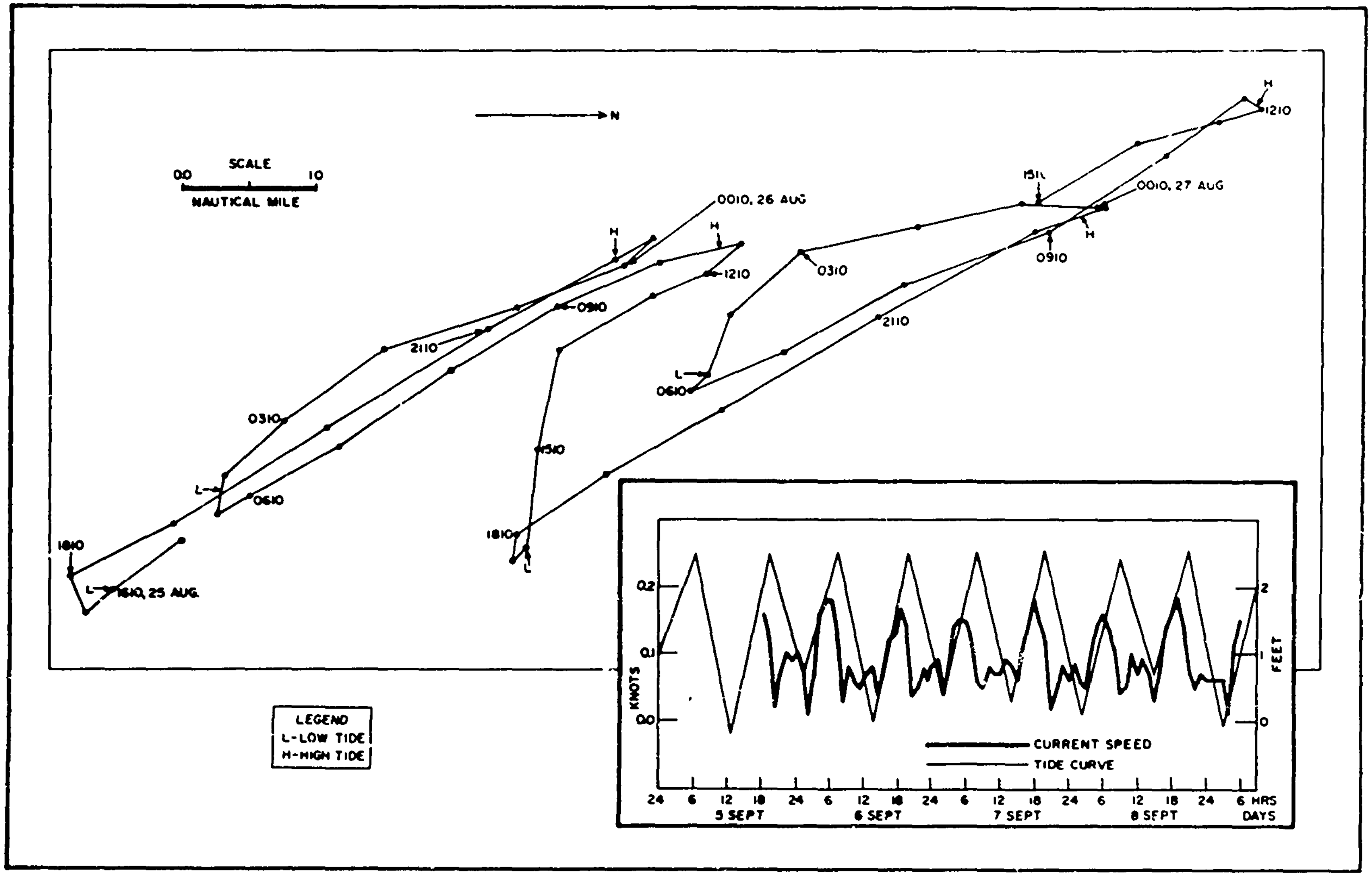


Figure 108. Progressive vector diagram of current from meter #417, 1610, 25 August to 1510, 27 August 1971, and current speeds versus tides, 0000, 5 September to 1200, 9 September 1971.

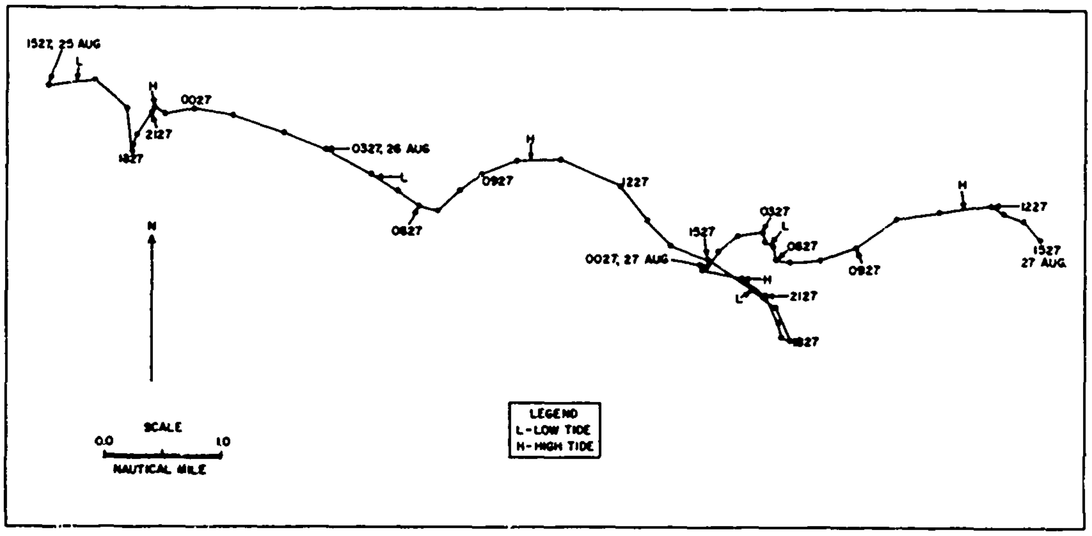


Figure 109. Progressive vector diagram of current from meter #420, 1527, 25 August to 1527, 27 August 1971.

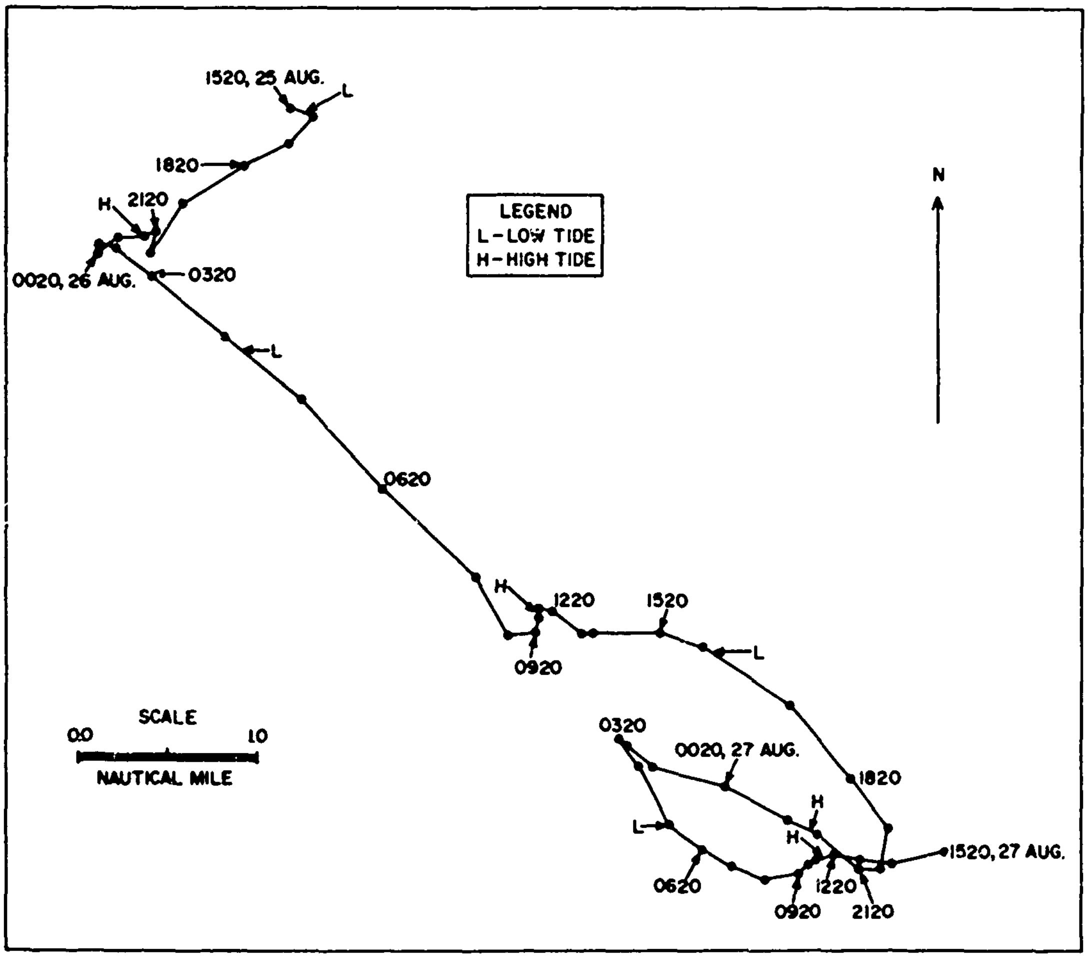


Figure 110. Progressive vector diagram of current from meter #404, 1520, 25 August to 1520, 27 August 1971.

The marked difference between currents near the surface and those close to the bottom is a result of the effects of bottom topography and the influence of winds and waves upon the surface layers. During August a homogeneous mixed layer existed from the surface to a depth of approximately 300 feet (91 meters). This water mass was separated from deeper layers by a steep thermocline which extended to approximately 1,300 feet (396 meters). This thermocline is an effective boundary separating surface currents from those at depth.

Surface drogues were tracked north of Ritidian Point during February and August (figures 111 and 112). During February surface currents appeared to be relatively weaker; no movement at all was observed 5 miles (8 km) north of the point. Currents within a mile of Ritidian Point showed a more easterly component during both winter and summer than the currents further from shore.

Surface currents north of Ritidian Point flowed against the prevailing winds and opposite to the North Equatorial Current as shown in both the current meter data and drogue tracking. Additional data covering longer periods of time will be necessary to resolve this apparent contradiction. Although the near bottom currents are of interest, they have little application in sewage pollution problems due to the tendency of sewage effluent to rise rapidly to the surface.

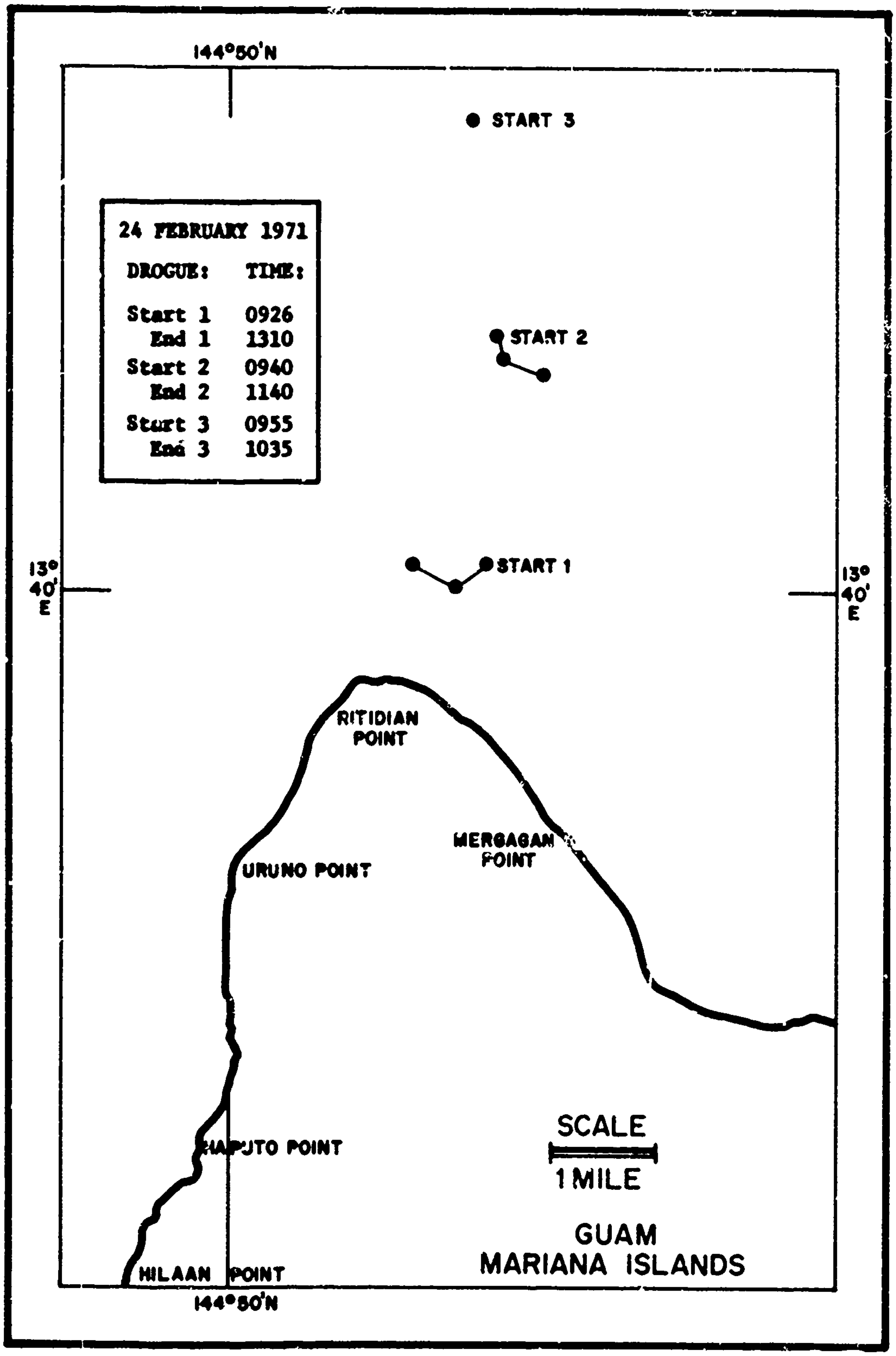


Figure 111. Drogue observations in Ritidian Section, 24 February 1971.

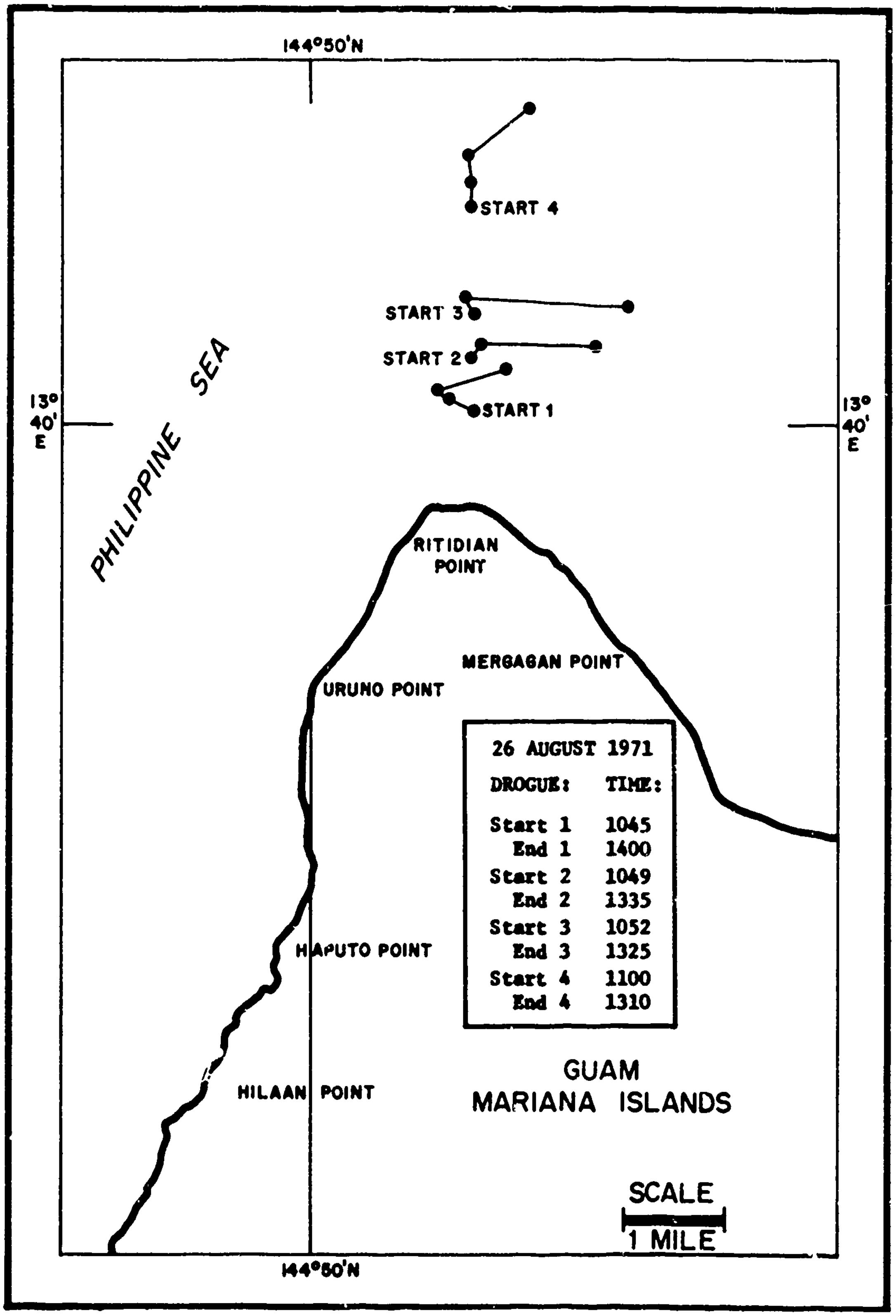


Figure 112. Drogue observations in Ritidian Section, 26 August 1971.

B. Ecology

The reefs studied are fringing types with similar topographic zones; each having a reef flat, reef margin, and reef front (terminology after Tracey et al., 1955). These study areas are representative of the various reef environments found at Guam, and they have two definable population characteristics: the genera that comprise the population, and the frequency in which the genera occur. Within a topographic zone the coral population consists of the same genera; however, the frequency of occurrence of these genera varies with the environment. Population characteristics were investigated by comparing the frequency histograms of the predominant corals within each quadrat. The population characteristics will serve as a baseline for defining environmental changes. These changes will be verified by correlating changes in the individual organisms with general population changes.

Figure 113 is a composite frequency histogram of corals in quadrats 1 and 3 located on the first terrace, and figure 114 is a composite frequency histogram of corals in quadrats 2, 4, and 5 located on the slope to the second terrace.

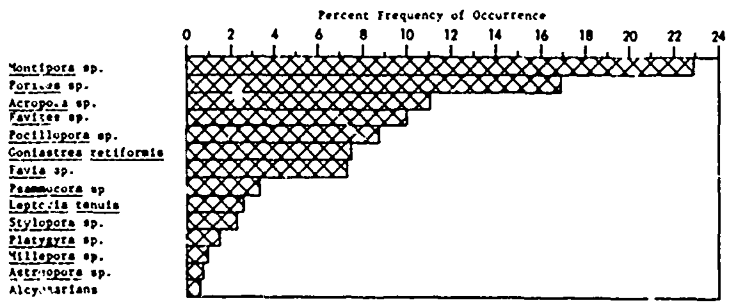


Figure 113. Frequency of occurrence of coral in quadrats on the first terrace of the reef front (quadrats 1 and 3).

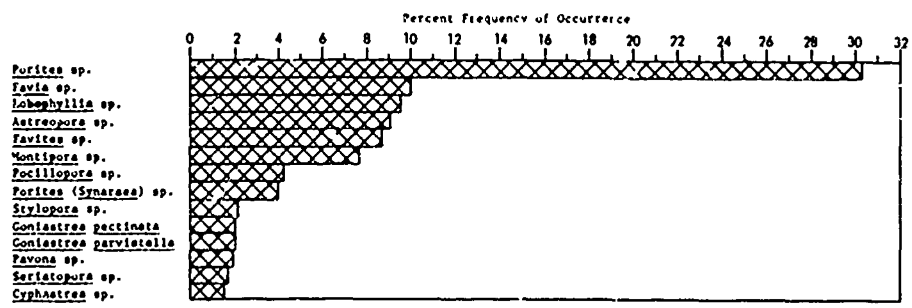


Figure 114. Frequency of occurrence of coral in quadrats on the second terrace of the reef front (quadrats 2, 4, and 5).

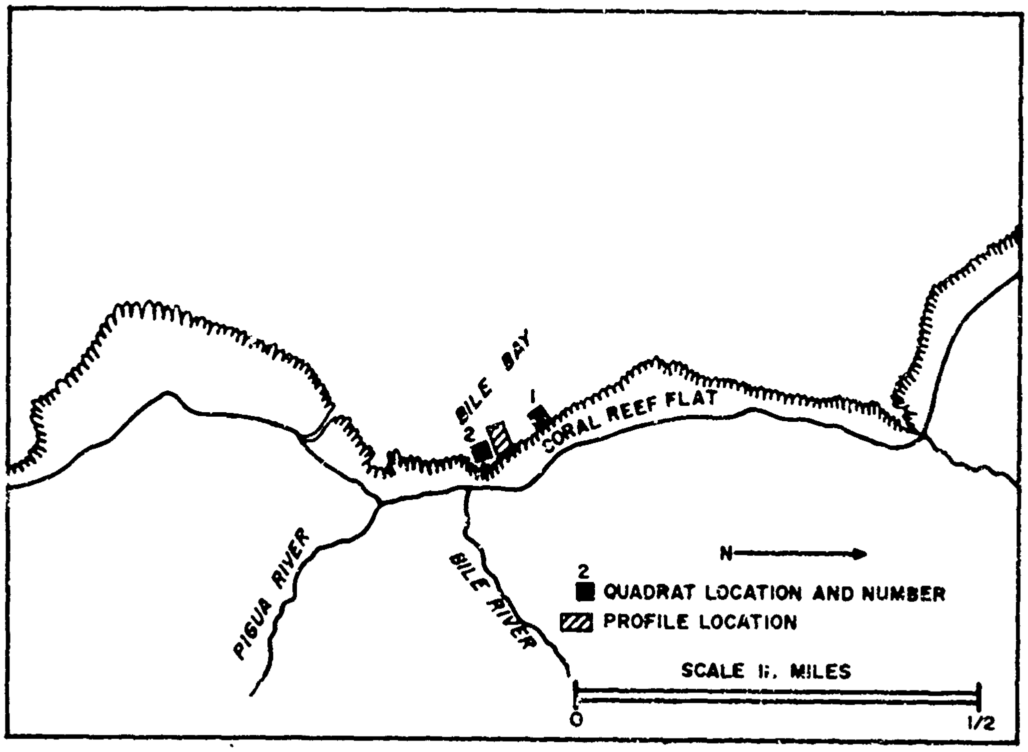
1. Bile Bay

Bile Bay lies in a protected location on the southwestern coast of the island. Sheltered inland by mountains and facing southwest, the bay receives few strong winds and is not subject to strong currents. Two streams, the Bile and Pigua, empty into the bay and physically divide it into three parts. Both streams flow through sparsely populated regions, and they are used by inhabitants for some waste removal. The streams are generally low volume; however, after heavy rains large sediment plumes extend into the bay. The streams have caused an impact sufficient to inhibit coral growth in their direct path of flow, and in adjacent areas they restrict coral growth to genera with some tolerance to silting. Figure 115 presents a profile and chart of the Bile Bay ecological study area.

The reef at Bile Bay is a narrow fringe 110 yards (100.6 meters) wide. The reef begins at the shore vegetation line and at its seaward limit it meets a sand and silt bottom at the 60-foot (18.3-meter) depth. The reef of the bay center, modified by the outflow of the streams, is narrow and broken by channels; whereas, the reef at each end of the bay is broader and more uniform.

A depth of 1 to 2.5 feet (.3 to .75 meter) of water is present over the reef flat, and because of a poorly developed algal ridge, this water is constantly recirculated. As a result, coral growth is relatively abundant. Growths of calcareous algae are predominant throughout, with corals of the genera Pocillopora and Goniastrea scattered in the recesses. At its seaward edge the algal ridge, subjected to surf action, is broken by spur and groove formations that extend down the abrupt reef margin and onto the first terrace. The floors of the grooves are paved with loose cobbles and boulders. The walls of the grooves and recesses between the boulders provide shelter for coral and numerous molluscs. At either end of the bay the first terrace extends from the 10-foot (3.0-meter) to the 20-foot (6.1-meter) depths and spans 10 to 15 yards (9.1 to 13.7 meters). The energy of the environment is moderate to high with little sediment present. Coral growth covers about 50 percent of the reef surface. Near the mouth of the streams the terrace is eroded and irregular, coral growth is less, and sediment carpets large areas of the bottom. The slope to the second terrace begins at a depth of 20 feet (6.1 meters) and is 7 to 10 yards (6.4 to 9.1 meters) wide. It supports a luxurious coral community but is restricted to genera tolerant of the more turbid conditions and proximity to the silt bottom of the second terrace.

The primary impact by man on this environment has been through fishing and shell collecting. Since much of the luxurious reef is rugged in appearance and occurs in less than 30 feet (9.1 meters) of clear water, it is appealing and easily accessible to the swimmers and snorklers who visit the bay.



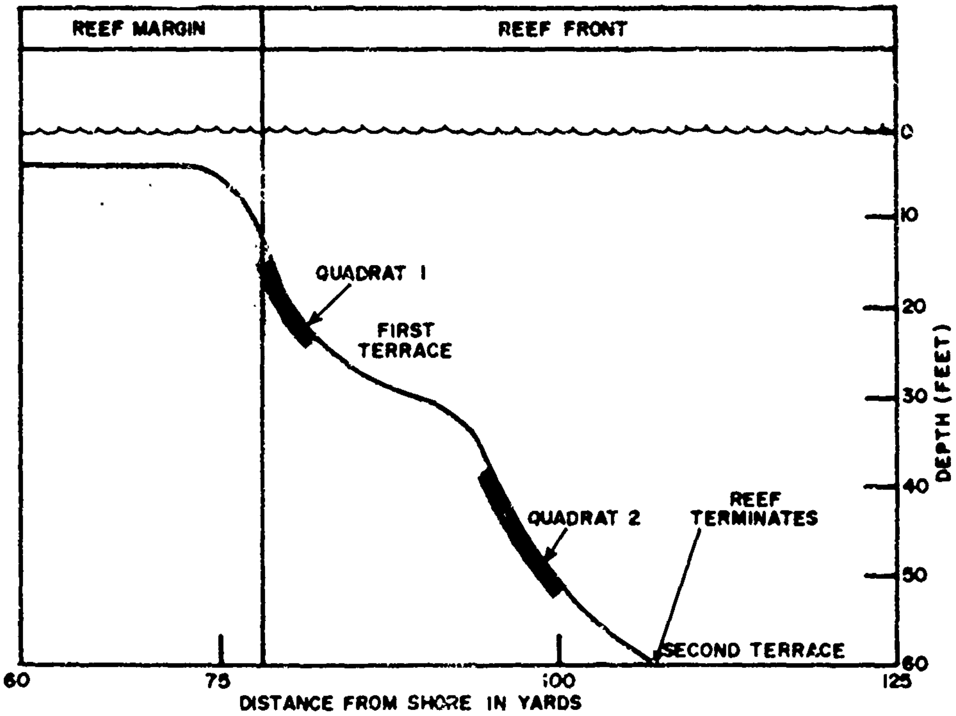


Figure 115. Area chart and reef profile for Bile Bay ecological study.

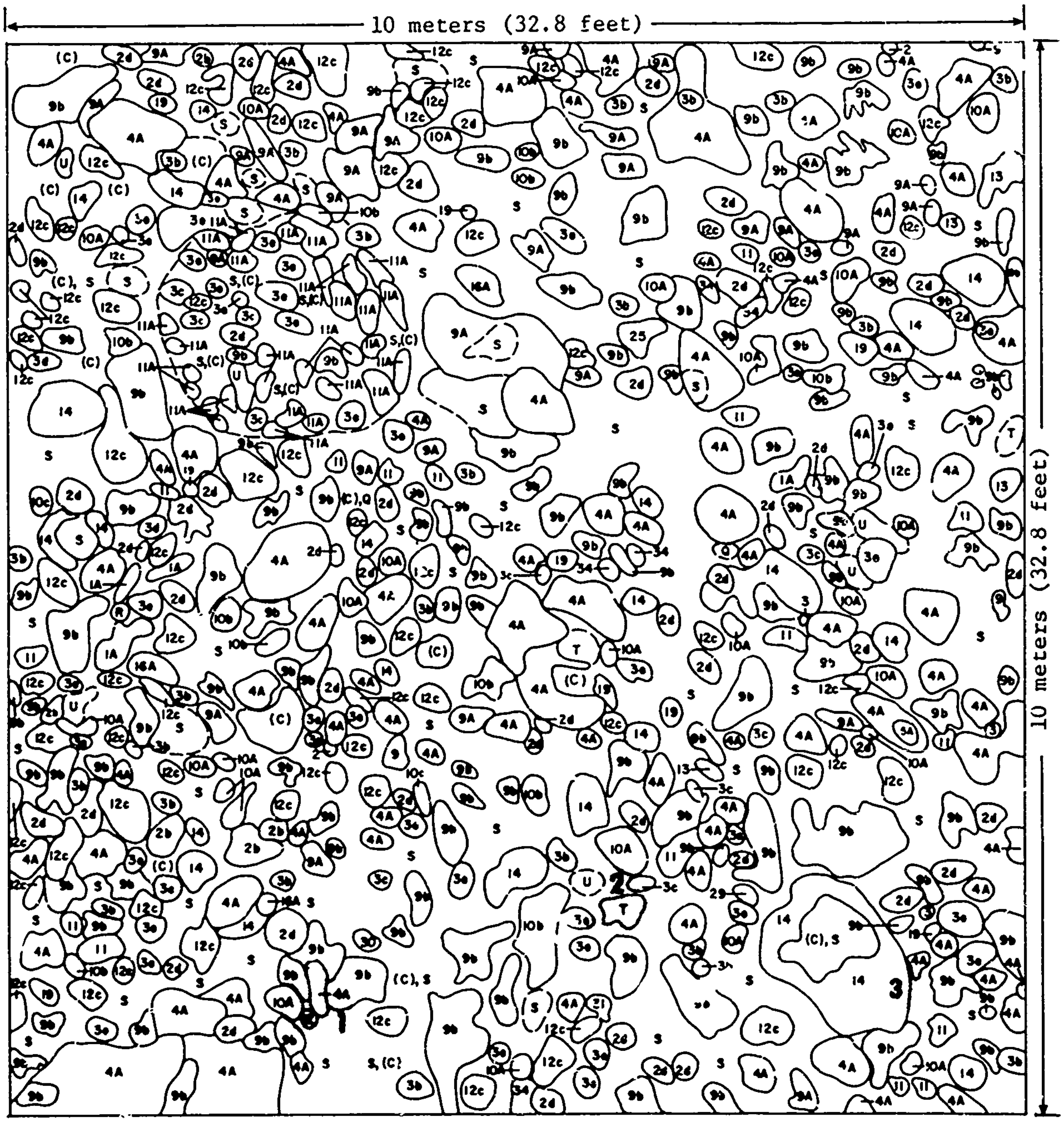
The effect of pollution on this environment is minimal and probably serves as an additional nutrient source. Small amounts of oil and waste pollutants originate from the use of the bay for recreation and some is probably carried in from Cocos Lagoon, a high-use recreation area.

Quadrat 1 is on the shallow first terrace at depths of 10 to 15 feet (3.0 to 4.6 meters) in the northern section of the bay (fig. 115). Little sand or silt is present on the rocky substrate. The distribution of genera within the quadrat is presented in figure 116. The prominent coral genera are those that thrive in a silt-free moderate to high energy environment, and they included Montipora, Porites, Acropora, Pocillopora, and Goniastrea. Histograms of the coral population are presented in figure 117.

Photographs of individual corals were made to monitor natural changes in the reef population and to detect changes that could occur from pollution. Plates 1 and 2 show the present condition of two small coral communities. Plate 3 shows the state of repair of a damaged section of a Leptoria head. The locations of these photographs are shaded on the species distribution chart.

Quadrat 2 is adjacent to the Bile River channel on the slope to the second terrace at depths of 35 to 50 feet (10.7 to 15.2 meters) (fig. 115). The slope at the quadrat consists of irregular spurs and grooves with a steep seaward gradient. Considerable sediment blankets the area and is especially heavy in the grooves and deeper sections of the quadrat. This sediment has a controlling influence on the population of the quadrat. Coral coverage in the quadrat is moderate and confined to a few genera (fig. 118). The three prominent genera are Lobophyllia, which has about a 25 percent frequency of occurrence, and Porites and Porites (Synaraea), which total 26 percent frequency of occurrence (fig. 119). The remaining occurrences are by 31 different species, each with fewer than 8 percent frequency.

The predominance of a few genera within a population indicates the controlling influences of the environment, and an alteration in this population structure will indicate environmental changes. Individual specimens were selected as environmental indicators, and they were documented for monitoring on future periodic surveys. Specific examples are presented in plates 4, 5, 6, and 7.



KEY TO QUADRAT

1A. Millepora platyphylla (Hempr
1b. M. tenera Boschma
2 . Pocillopora sp. Lamarck
2A. cf. P. cespitosa (Dana)
2b. cf. P. meandrina (Dana)
2c. cf. P. damicornis (Linna
2d. cf P. verrucosa (Ellis
3 Acropora sp. Oken
3A. cf. A. palifera (Lamarck)
3b. cf. A. hyacinthus (Dana)
3c. cf. A. hebes (Dana)
3d. cf. A. corymbosa (Lamarc
3e. cf. A. leptocyathus (Bro
4A. Porites lobata Dana
4b. P. (Synaraea) Verrill
5 . Galaxea sp. Oken
5A. G. fascicularis (Linnaeu
6 . Lobophyllia corymbosa (Fors
7A. Fungia scutaria (Lamarck)
7b. F. echinata (Pallas)
8 . Herpolitha limax (Esper)
9 . Montipora sp. de Blainville
9A. M. verrucosa (Lamarck)
9b. M. marshallensis Wells
10 . Favia sp. Oken
10A. F. speciosa (Dana)
10b. F. pallida (Dana)
10c. F. hombroni (Rousseau)
10d. F. hawaiiensis Vaughan
11 . Favites sp. Link
11A. F. abdita (Ellis and Sol
11b. F. halicora (Ehrenberg)
12 . Coniastrea sp. M. Edwards
12A. C. parvistella (Dana)
12b. C. pectinata (Ehrenberg)
12c. C. retiformis (Lamarck)
13 . Platygyra rustica (Dana)
14 . Leptoria tenuis (Dana)
15 . Leptoseris M. Edwards and
16A. Pavona decussata (Dana)
16b. P. frondifera Lamarck
17 . Euphyllia glabrescens h
18 . Pachyseris speciosa (Dana)
19 . Stylopora mordax (Dana)
20 . Polyphyllia talpina (Lamarc
21 . Oulophyllia crispa (Lamarc
22 . Echinophyllia aspera (Elli
23 . Alveopora sp. de Blainvill
24 . Polyastra sp. Ehrenberg
25 . Cyphastrea sp. M. Edwards
26 . Hydnophora sp. Fischer de
27 . Goniopora sp. de Blainvill
28 . Coscinaraea sp. M. Edward
29 . Diploastrea sp. Matthai
30 Psammocora sp. Dana
31 . Heliopora coerulea (Palla
32 . Tubipora sp. Linnaeus
33 . Seriatopora angulata (Klu
34 . Astreopora myriophthalma
35 . Merulina sp. Ehrenberg
E . Sea urchin
G . Sponge
H . Holothurian
P . Turbinaria sp. Lamouroux
Q . Halimeda sp. Lamouroux
R . Soft green algae
S . Soft gray algae
T . Fleshy Alcyonarian
U . Gonolithon sp. Foslie
V . Porolithon sp. Foslie
X . Unidentified hard coral
Y . Anemone
(C). Dead coral
(r). Rock
(S). Sand

(3) Photo location and plat

Figure 116. Species distribution chart, quadrat 1, Bile Bay.

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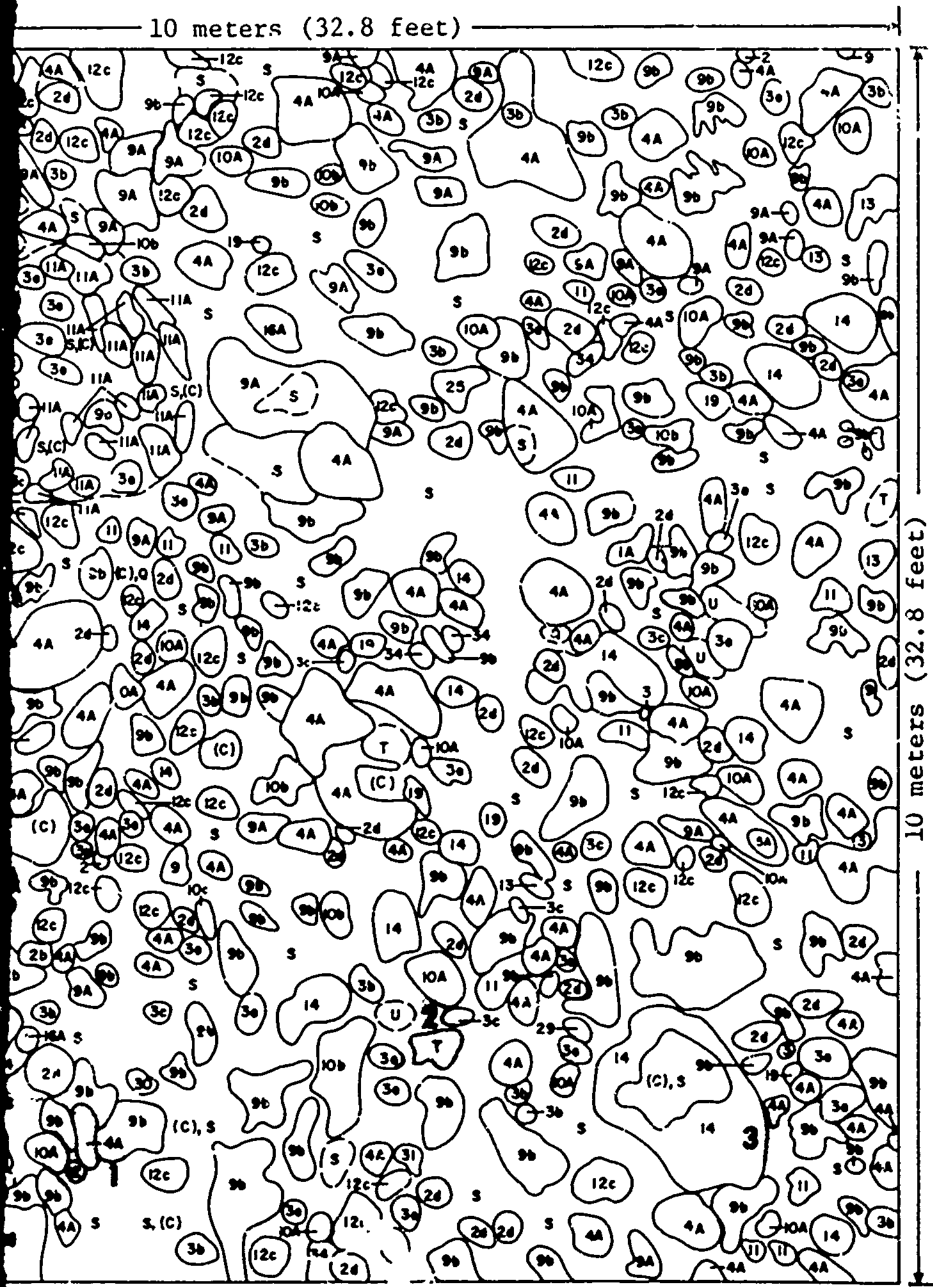

KEY TO QUADRAT SKETCHES

1A. Millepora platyphylla (Hemprich and Ehrenberg)
1b. M. tenera Boschma
2 . Pocillopora sp. Lamarck
2A. cf. P. caespitosa (Dana)
2b. cf. P. meandrina (Dana)
2c. cf. P. damicornis (Linnaeus)
2d. cf. P. verrucosa (Ellis and Solander)
3 . Acropora sp. Oken
3A. cf. A. palifera (Lamarck)
3b. cf. A. hyacinthus (Dana)
3c. cf. A. hebes (Dana)
3d. cf. A. corymbosa (Lamarck)
3e. cf. A. leptocyathus (Brook)
4A. Porites lobata Dana
4b. P (Synaraea) Verrill
5 . Galaxea sp. Oken
5A. G. fascicularis (Linnaeus)
6 . Lobophyllia corymbosa (Forskaal)
7A. Fungia scutaria (Lamarck)
7b. F. echinata (Pallas)
8 . Herpolitha limax (Esper)
9 . Montipora sp. de Blainville
9A. M. verrucosa (Lamarck)
9b. M. marshallensis Wells
10 . Favia sp. Oken
10A. F. speciosa (Dana)
10b. F. pallida (Dana)
10c. F. hombroni (Rousseau)
10d. F. hawaiiensis Vaughan
11 . Favites sp. Link
11A. F. abdita (Ellis and Solander)
11b. F. halicora (Ehrenberg)
12 . Goniastrea sp. M. Edwards and Haime
12A. G. parvistella (Dana)
12b. G. pectinata (Ehrenberg)
12c. G. retiformis (Lamarck)
13 . Platygyra rustica (Dana)
14 . Leptoria tenuis (Dana)
15 . Leptoseris M. Edwards and Haime
16A. Pavona decussata (Dana)
16b. P. frondifera Lamarck
17 . Euphyllia glabrescens (Chamisso and Eysenhardt)
18 . Pachyseris speciosa (Dana)
19 . Stylopora mordax (Dana)
20 . Polyphyllia talpina (Lamarck)
21 . Oulophyllia crispa (Lamarck)
22 . Echinophyllia aspera (Ellis and Solander)
23 . Alveopora sp. de Blainville
24 . Polyastra sp. Ehrenberg
25 . Cyphastrea sp. M. Edwards and Haime
26 . Hydnophora sp. Fischer de Waldheim
27 . Goniopora sp. de Blainville
28 . Coscinaraea sp. M. Edwards and Haime
29 . Diploastrea sp. Matthai
30 . Psammocora sp. Dana
31 . Heliopora coerulea (Pallas)
32 . Tubipora sp. Linnaeus
33 . Seriatopora angulata (Klunzinger)
34 . Astreopora myriophthalma (Lamarck)
35 . Merulina sp. Ehrenberg
F . Sea urchin
G . Sponge
H . Holothurian
P . Turbinaria sp. Lamouroux
Q . Halimeda sp. Lamouroux
R . Soft green algae
S . Soft gray algae
T . Fleshy Alcyonarian
U . Goniolithon sp. Foslie
V . Porolithon sp. Foslie
X . Unidentified hard coral
Y . Anemone
(C). Dead coral
(r). Rock
(S). Sand

(3) Photo location and plate number

6. Species distribution chart, quadrat 1, Bile Bay.

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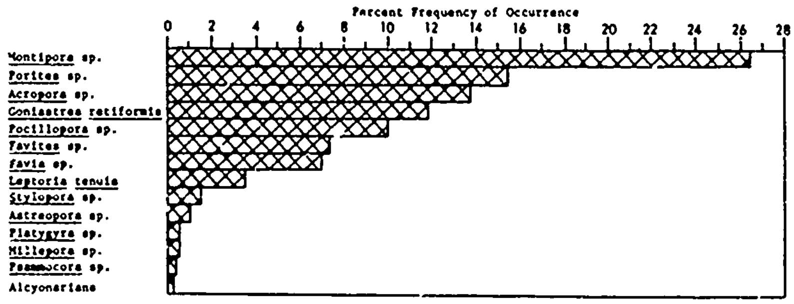

Figure 117. Frequency of occurrence of coral in quadrat 1, Bile Bay.

Plate 1. Photo 9-8 in Quadrat 1, Bile Bay - Species of <u>Montipora</u>, <u>Porites</u>, and <u>Goniastrea</u> growing in close spacial association.

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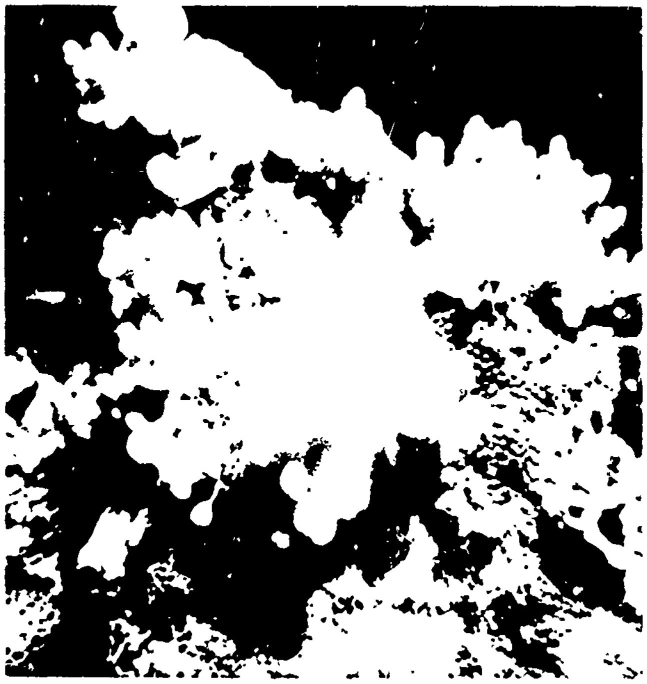
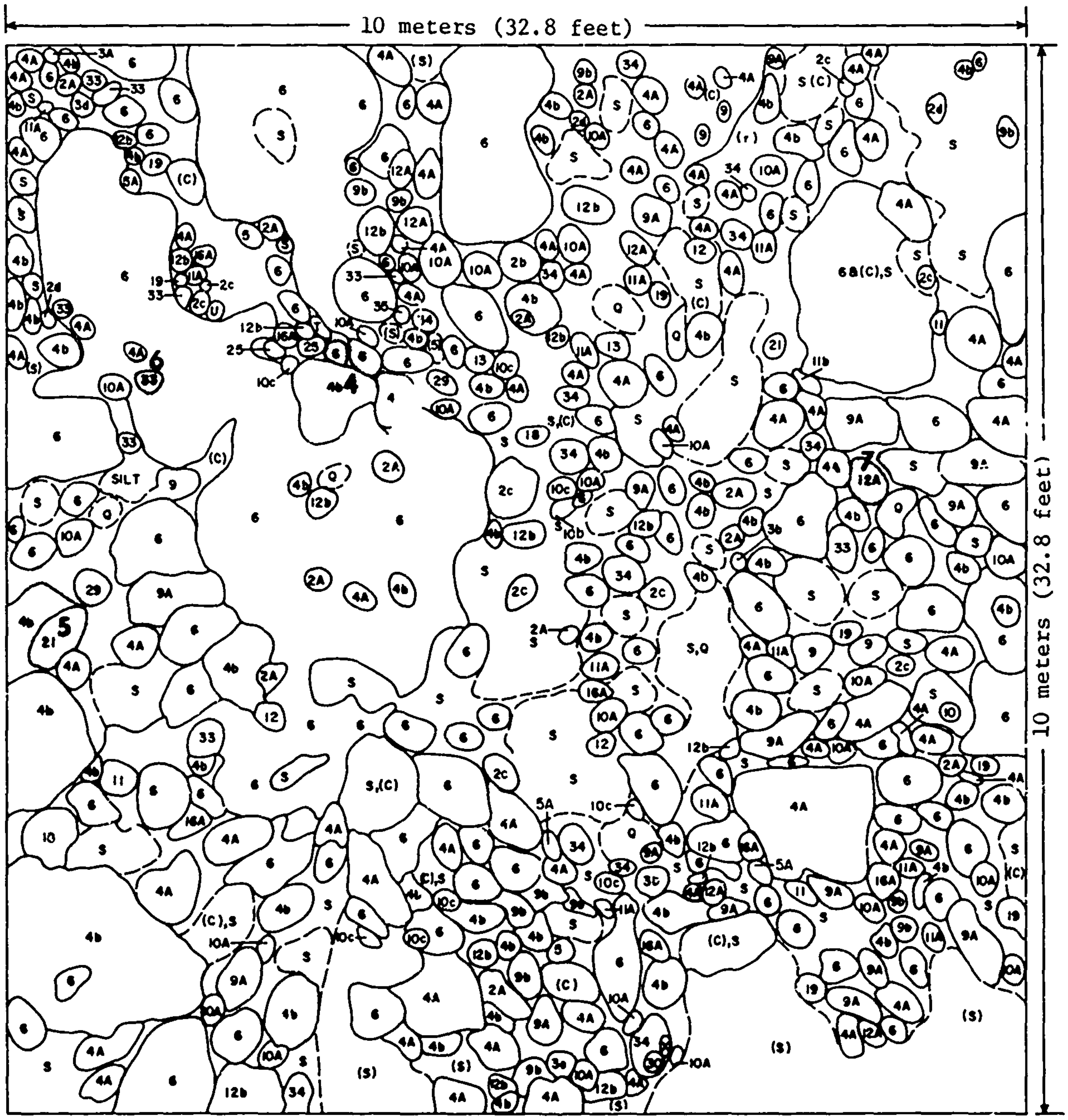


Plate 2. Photo 9-9 in Quadrat 1, Bile Bay - Young growth of soft corals growing around the hard coral Astreopora, center and lower left.

Plate 3. Photo 9-11 in Quadrat 1, Bile Bay - Enormous Leptoria head showing scar of repaired damaged section.

A

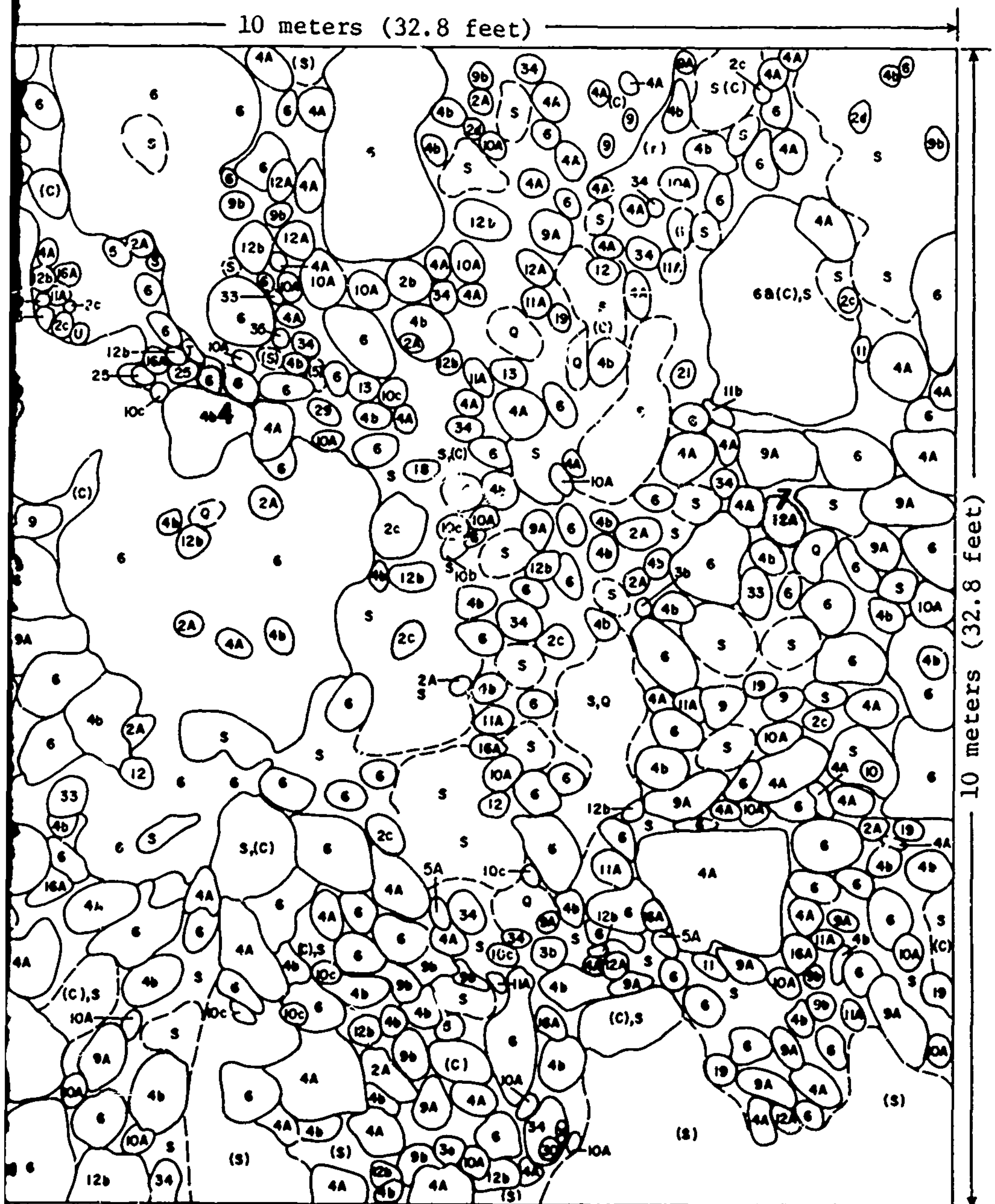


KEY TO QUADRAT SKE

1A. Millepora platyphylla (Hemprich
1b. M. tenera Boschma
2 . Pocillopora sp. Lamarck
2A. cf. P. cespitosa (Dana)
2b. cf. P. meandrina (Dana)
2c. cf. P. damicornis (Linnaeus)
2d. cf. P. verrucosa (Ellis and S
3 . Acropora sp. Oken
3A. cf. A. palifera (Lamarck)
3b. cf. A. hyacinthus (Dana)
3c. cf. A. hebes (Dana)
3d. cf. A. corymbosa (Lamarck)
3e. cf. A. leptocyathus (Brook;
4A. Porites lobata Dana
4b. P. (Synaraea) Verrill
5 . Galaxea sp. Oken
5A. G. fascicularis (Linnaeus)
6 . Lobophyllia corymbosa (Forskal
7A. Fungia scutaria (Lamarck)
7b. F. echinata (Pallas)
8 . Herpolitha limax (Esper)
9 . Montipora sp. de Blainville
9A. M. verrucosa (Lamarck)
9b. M. marshallensis Wells
10 . Favia sp. Oken
10A. F. speciosa (Dana)
10b. F. pallida (Dana)
10c. F. hombroni (Rousseau)
10d. F. hawaiiensis Vaughan
11 . Favites sp. Link
11A. F. abdita (Ellis and Soland
11b. F. halicora (Ehrenberg)
12 . Goniastrea sp. M. Edwards and
12A. G. parvistella (Dana)
12b. G. pectinata (Ehrenberg)
12c. G. retiformis (Lamarck)
13 . Platygyra rustica (Dana)
14 . Leptoria tenuis (Dana)
15 . Leptoseris M. Edwards and Haim
16A. Pavona decussada (Dana)
16b. P. frondifera Lamarck
17 . Euphyllia glabrescens (Chamiss
18 . Pachyseris speciosa (Dana)
19 . Stylopora mordax (Dana)
20 . Polyphyllia talpin (Lamarck)
21 . Oulophyllia crispa (Lamarck)
22 . Echinophyllia aspera (Ellis an
23 . Alveopora sp. de Blainville
24 . Polyastra sp. Ehrenberg
25 . Cyphastrea sp. M. Edwards and
26 . Hydnophora sp. Fischer de Wald
27 . Goniopora sp. de Blainville
28 . Coscinaraea sp. M. Edwards and
29 . Diploastrea sp. Matthai
30 . Psammocora sp. Dana
31 . Heliopora coerulea (Pallas)
32 . Tubipora sp. Linnaeus
33 . Seriatopora angulata (Klunzin
34 . Astreopora myriophthalma (Lam
35 . Merulina sp. Ehrenberg
F . Sea urchin
G . Sponge
H . Holothurian
P . Turbinaria sp. Lamouroux
Q . Halimeda sp. Lamouroux
R . Soft green algae
S . Soft gray algae
T . Fleshy Alcyonarian
U . Gonolithon sp. Foslie
V . Porolithon sp. Foslie
X . Unidentified hard coral
Y . Anemone
(C). Dead coral
(r). Rock
(S). Sand

(3) Photo location and plate nu

Figure 118. Species distribution chart, quadrat 2, Bile Bay.



KEY TO QUADRAT SKETCHES

- 1A. Millepora platyphylla (Hemprich and Ehrenberg)
- 1b. M. tenera Boschma
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- 14 . Leptoria tenuis (Dana)
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- 16A. Pavona decussada (Dana)
- 16b. P. frondifera Lamarck
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- 18 . Pachyseris speciosa (Dana)
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- 28 . Coscinaraea sp. M. Edwards and Haime
- 29 . Diploastrea sp. Matthai
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(3) Photo location and plate number

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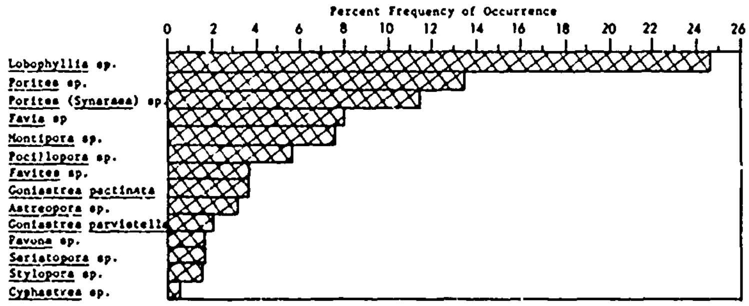

Figure 119. Frequency ot occurrence of coral in quadrat 2, Bile Bay.

Plate 4. Photo 5-2 in Quadrat 2, Bile Bay - Porites (Synaraea) and calcareous algae growth establishing on an old growth of Lobophyllia.

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Plate 5. Photo 5-8 in Quadrat 2, Bile Bay - Oulophyllia, Porites (Synaraea), and calcareous algae growing over an old coral rock base.

Plate 6. Photo 5-10 in Quadrat 2, Bile Bay - Seriatopora growing on a section of Lobophyllia head.

Plate 7. Photo 6-5 in Quadrat 2, Bile Bay - Species of Goniastrea with basal portions shrouded with calcareous algae.

2. Sella Bay

Two rivers, the Sella and the Asmafines, flowing into Sella Bay created distinct inner and outer reef environments. These environments are an inner bay with limited coral growth, low salinities, and generally turbid waters, and an outer bay with luxurious coral communities and relatively clear water.

The inner bay is defined as that part of the reef which is severely modified by the streams. Included in the inner bay are a debris-laden rocky flat, a low algal ridge, and a steep reef margin dissected by channels and caverns. Nearshore, sediment from the streams inhibits coral growth on the rocky flat. At the reef margin the sand and sediment are carried through holes and into the channels. The walls of the channels and caverns, where sediment does not collect, support calcareous algae and the hard coral Porites, which is tolerant of turbid conditions and high sedimentation rates. In the deeper portions of the inner bay (greater than 20 feet (6.1 meters)) the silt covered bottom is unsuitable for coral growth.

Within 500 feet (152.4 meters) from the mouths of the streams (the center of the bay) where turbidity diminishes considerably, coral growth is more varied with Pocillopora, Montipora, and Favites joining the ever-present Porites. In the deeper areas of 20 to 30 feet (6.1 to 9.1 meters) Porites (Synaraea) and Lobophyllia are found.

At the entrance to the bay, 1,000 feet (305 meters) from the mouths of the streams, horizontal visibility ranges up to 100 feet (30.5 meters) and water clarity has become sufficient to support vigorous coral growth to depths of 60 feet (18.3 meters). Here, the corals are far enough from the mouths of the streams to be unaffected by silting.

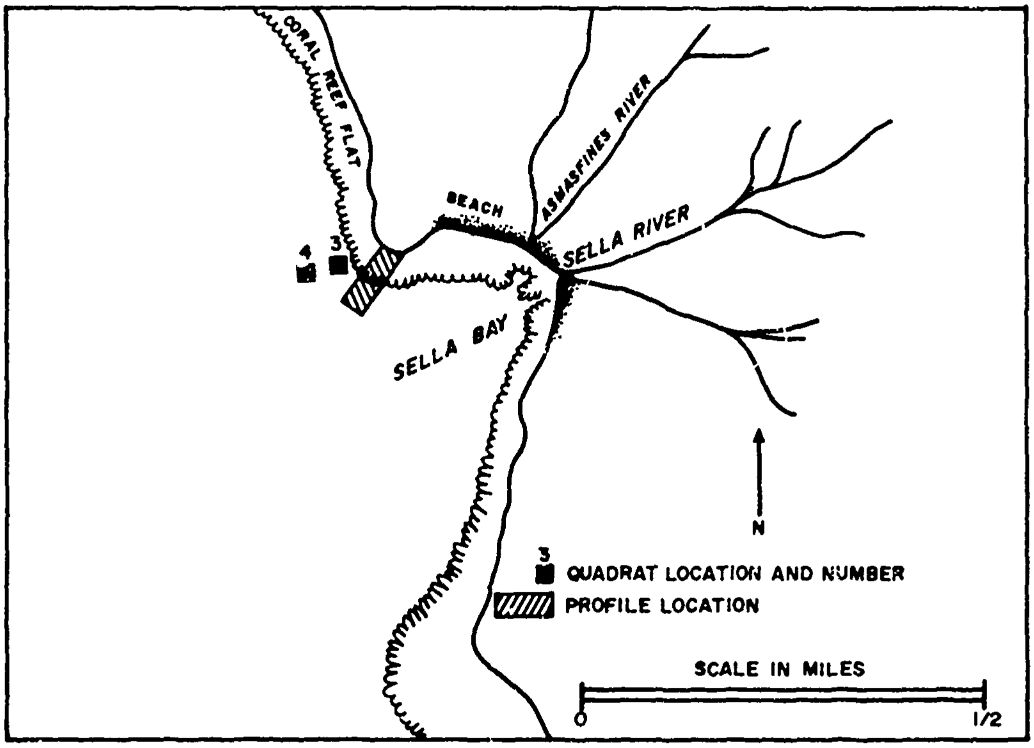
The first terrace beyond the reef margin of the outer bay is at 20- to 30-foot (6.1- to 9.1-meter) depths and several hundred feet wide. On this terrace the most abundant genera are Montipora, Acropora, Pocillopora, Favites, and enormous heads of Porites. These genera indicate a medium- to high-energy environment as produced by waves on the slope. Reef growth continues down a gradual slope to a sand and silt terrace at 60 feet (18.3 meters).

Because of the relative remoteness of this area, there is little human impact on the bay. A few people visit the bay for sightseeing and skin diving. The possibility of marine construction in Sella Bay and the development of the Sella River valley is a primary concern. Building roads and shore facilities with subsequent denudation of the land would substantially increase the volume of water and sediment load carried by the rivers. This would result in major changes to the Sella Bay reef community.

Two quadrats established in Sella Bay on the reef front are representative of the shallow- and deep-water environments (fig. 120). Quadrat 3, in 5 to 15 feet (1.5 to 4.6 meters) of water, is on the first terrace near the edge of the reef margin. The substrate of the quadrat is rock with some grooves and holes containing small amounts of sand. A photomosaic of the quadrat is shown in plate 8. Figure 121 shows the distribution of sessile organisms within the quadrat.

The coral communities of this upper reef front, typical of most of the first terrace, consists of many Montipora, Acropora, Favites, and Pocillopora. Figure 122 presents histograms of the frequency of occurrence of corals in this quadrat. These corals are also common to the first terrace at Bile Bay; however, the predominance in quadrat 3 of the silt-tolerant Favites and the fewer Goniastrea (not tolerant to silting) indicates an environment more influenced by silting. Examples of the specimens selected as environmental indicators for this quadrat are pictured in plates 9, 10, and 11.

Quadrat 4, in 35 to 50 feet (10.7 to 15.2 meters) of water, is about 100 yards (91.4 meters) west of quadrat 3 on the slope to the second terrace. At the quadrat the reef is a rounded slope of 30° to 40°, relatively uncontaminated by sediment or debris.



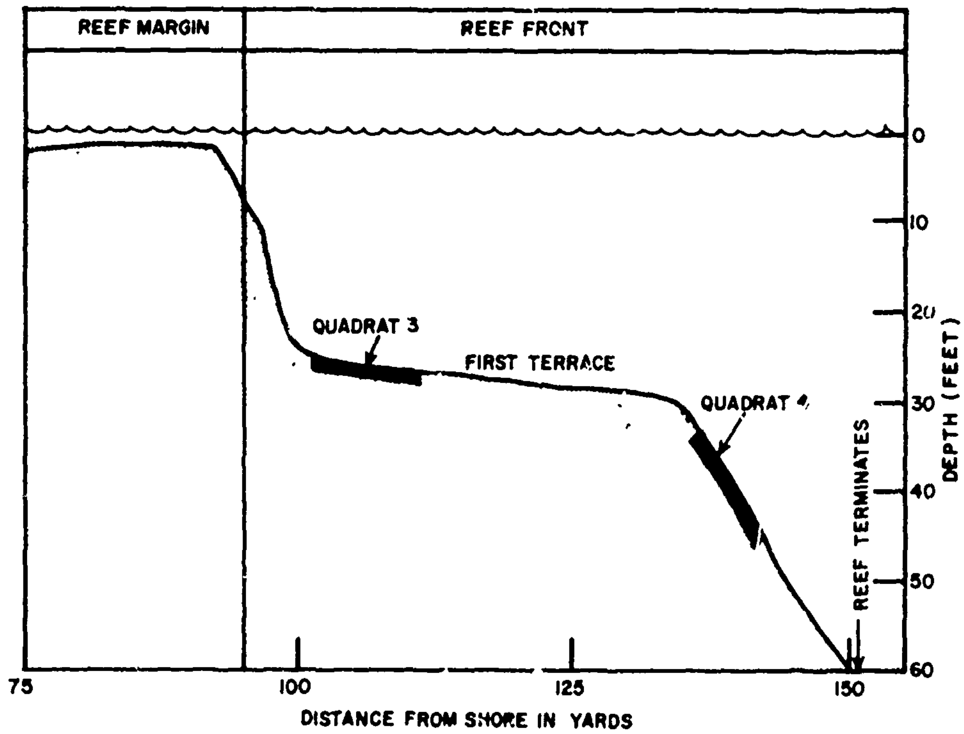


Figure 120. Area chart showing quadrats and reef profile of Sella Bay.

Plate 8. Photomosaic of Quadrat 3, Sella Bay.

A

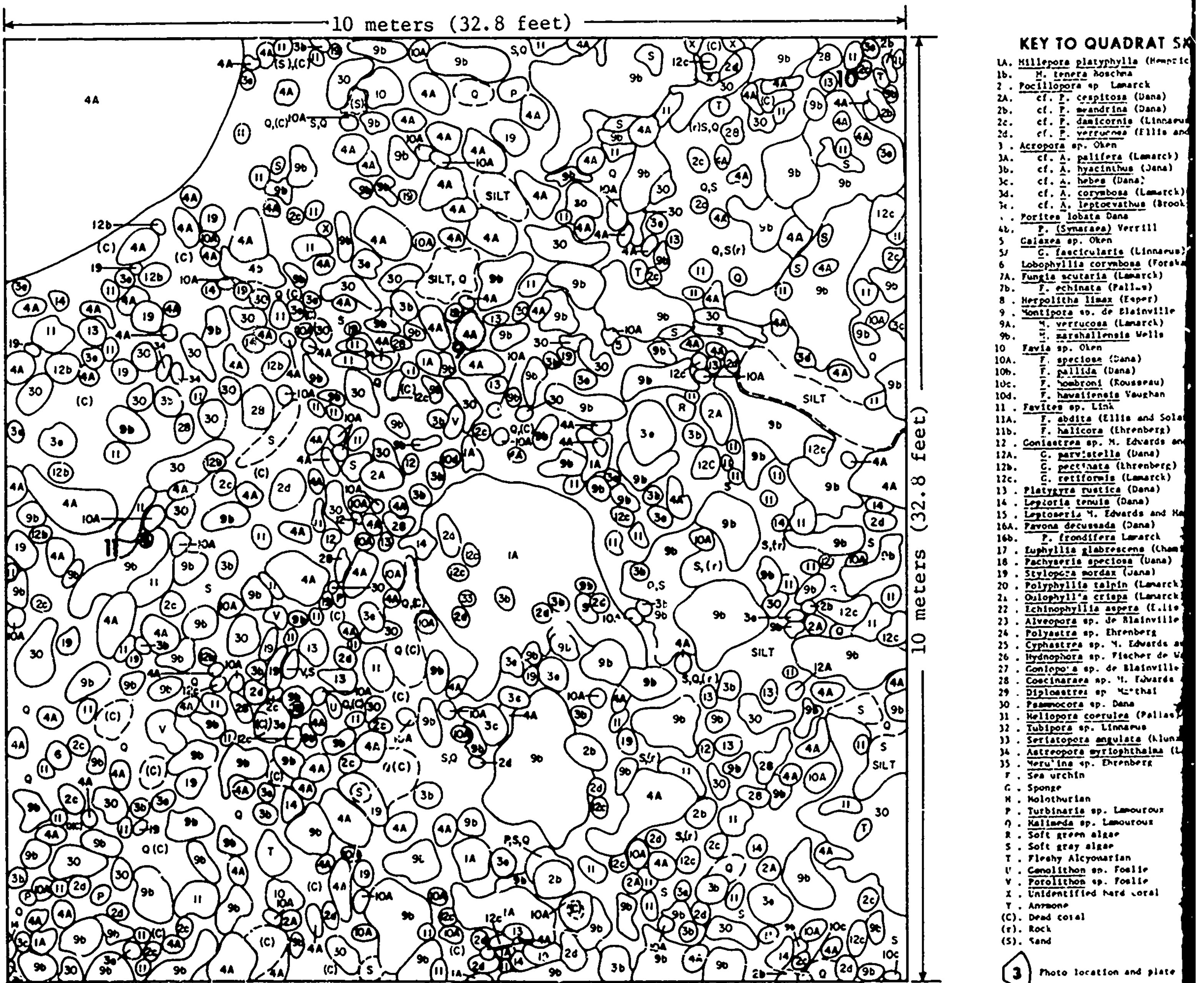
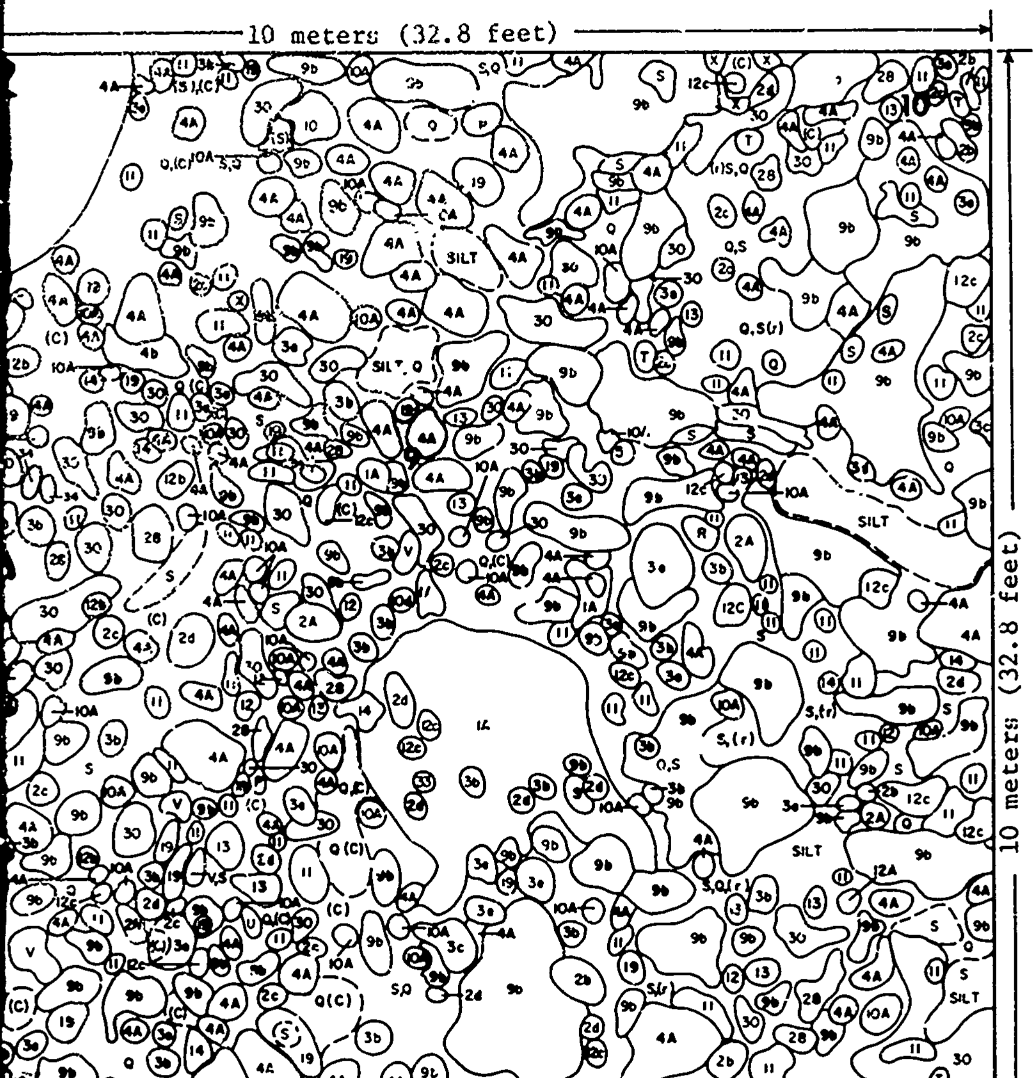


Figure 121. Species distribution chart, quadrat 3, Sella Bay.



KEY TO QUADRAT SKETCHES

1A. Millepora platyphylla (Hemprich and Ehrenberg)
1b. M. tenera Boschma
2 . Pocillopora sp. Lamarck
2A. cf. P. cespitosa (Dana)
2b. cf. P. meandrina (Dana)
2c. cf. P. damicornis (Linnaeus)
2d. cf. P. verrucosa (Ellis and Solander)
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3b. cf. A. hyacinthus (Dana)
3c. cf. A. hebes (Dana)
3d. cf. A. corymbosa (Lamarck)
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31 . Heliopora coerulea (Pallas)
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G . Sponge
H . Holothurian
P . Turbinaria sp. Lamouroux
Q . Halimeda sp. Lamouroux
R . Soft green algae
S . Soft gray algae
T . Fleshy Alcyonarian
U . Goniolithon sp. Foslie
V . Porolithon sp. Foslie
X . Unidentified hard coral
Y . Anemone
(C). Dead coral
(r). Rock
(S). Sand

Photo location and plate number

gure 121. Species distribution chart, quadrat 3, Sella Bay.

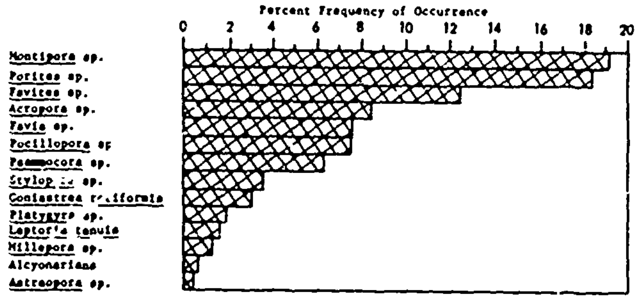

Figure 122. Frequency of occurrence of coral in quadrat 3, Sella Bay.

Plate 9. Photo 13-3 in Quadrat 3, Sella Bay - A species of *Porites* suffering from predation by fish.

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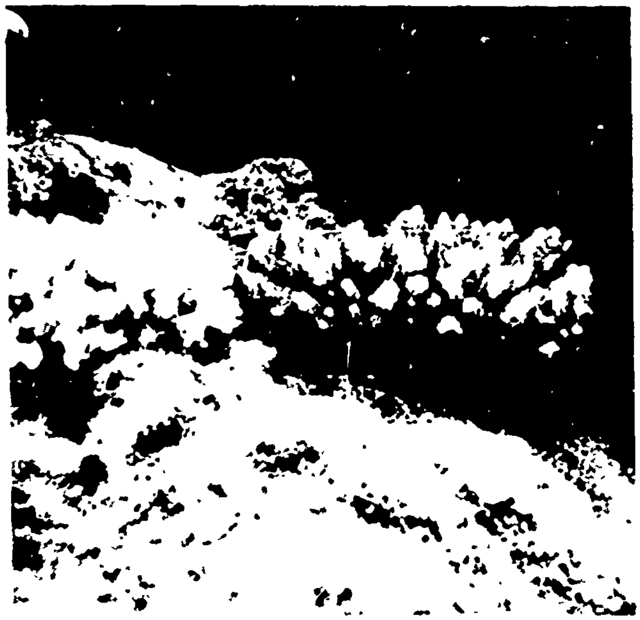


Plate 10. Photo 13-4 in Quadrat 3, Sella Bay - Species of Acropora and Pocillopora.

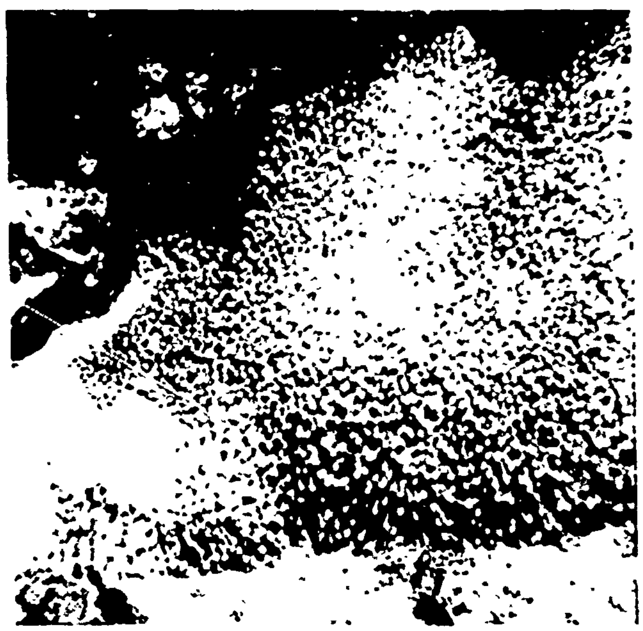


Plate 11. Photo 13-7 in Quadrat 3, Sella Bay - A species of Favites with polyps out thriving under a ledge in silt-laden hole.

Figure 123 shows the distribution of organisms within quadrat 4. The coral communities on this slope are among the most varied and luxurious in the leeward coastal waters, a condition attributed to plentiful nutrients and high water clarity. A count of the sessile population showed 1,726 organisms consisting of 48 species. Porites, Favia, Astreopora, Favites, and Montipora are the most prominent genera as shown in the frequency of occurrence histograms in figure 124. Plates 12, 13, 14, and 15 are representative photographs of some of the specimens which were selected in quadrat 4 for future monitoring of the environment.

3. Anae Island

The deep reef south of Anae Island was selected as a control quadrat location. Figure 125 presents a reef profile and chart of the area. It is neither polluted nor near a proposed ocean outfall. Monitoring this environment will help determine what reef changes are occurring naturally.

The reef flat, separated from the reef front by an elevated ridge, is heavily influenced by mud and silt from two small streams. The reef margin is a zone of high energy and luxurious coral growth. This zone of coral pinnacles, boulders, and caverns contains a dense population of Acropora, Porites, Montipora, Millepora, and calcareous algae. The reef front is a broad gradual slope dissected by sand-filled channels.

Quadrat 5 was installed on the reef front in 55 to 60 feet (16.8 to 18.3 meters) of water 100 yards (91.4 meters) south of Anae Island (fig. 125). The coral population of quadrat 5 (fig. 126) consists of 33 species and 542 organisms; fewer than in the other two deep reef fronts studied (quadrats 2 and 4). The reason for fewer corals in this quadrat is that a sand channel comprises a third of the quadrat area. The population in this quadrat is very similar to the population at quadrat 4 in Sella Bay; both have Porites, Favia, Astreopora, Favites, and Montipora as the most prominent genera. Quadrats 4 and 5 also are relatively similar in depth, water clarity, and proximity to a sand bottom. Figure 127 presents histograms of frequency occurrence of corals in quadrat 5. The other deep reef area studied (quadrat 2 at Bile Bay) has similarities to quadrat 5 also: Porites, Montipora, and Favia are common there; however, Lobophyllia and Porites (Synaraea), the most prominent genera at quadrat 2, which is heavily silted, are insignificant at quadrat 5.

Some of the individual organisms that were selected from this quadrat for photographic documentation are shown in plates 16, 17, 18, and 19. Some of the organisms selected are of the same genera as those selected from quadrats 2 and 4. This selection will enable a future comparison of modifications to the same genera from environments which may be affected by sewage effluent.

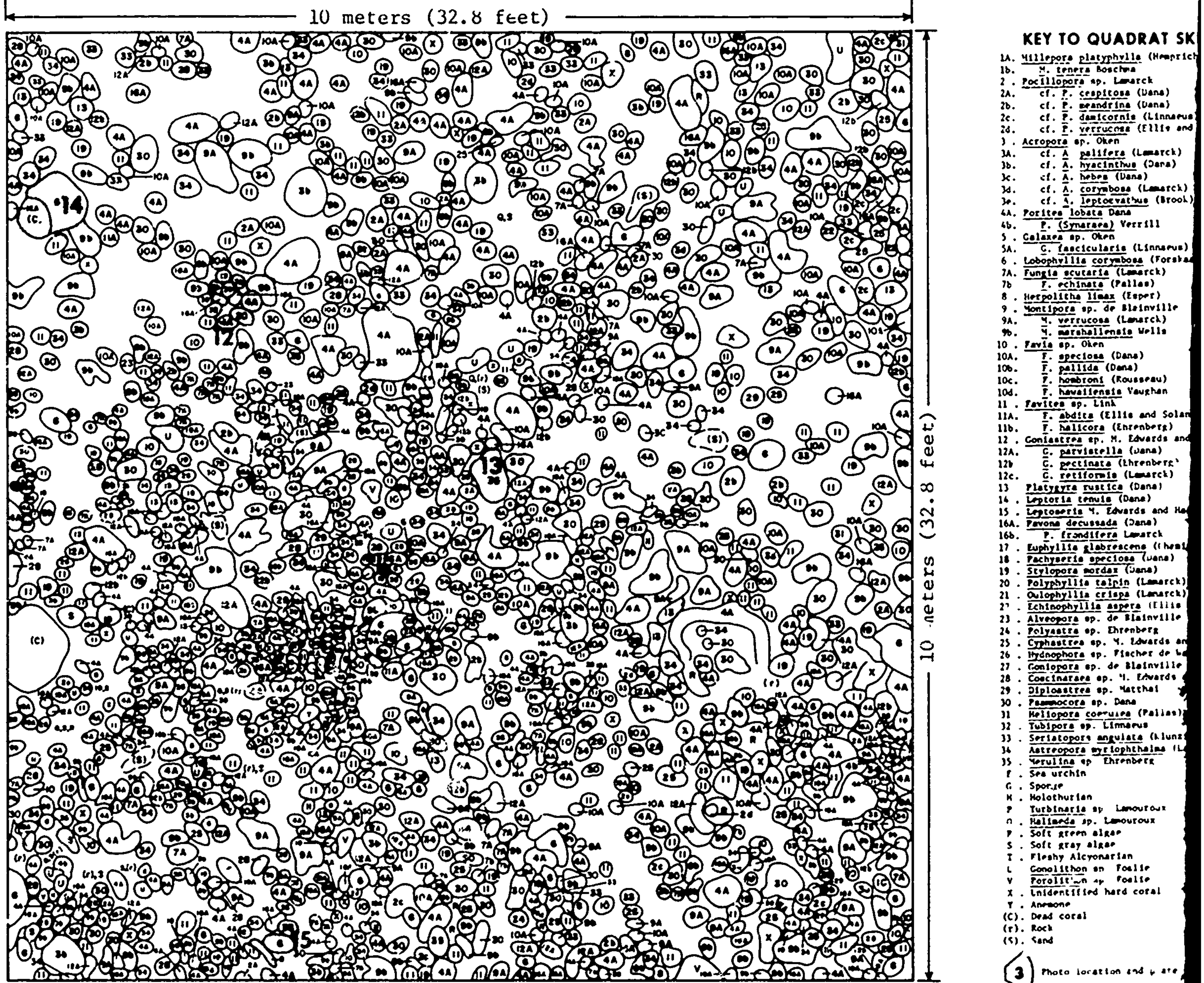
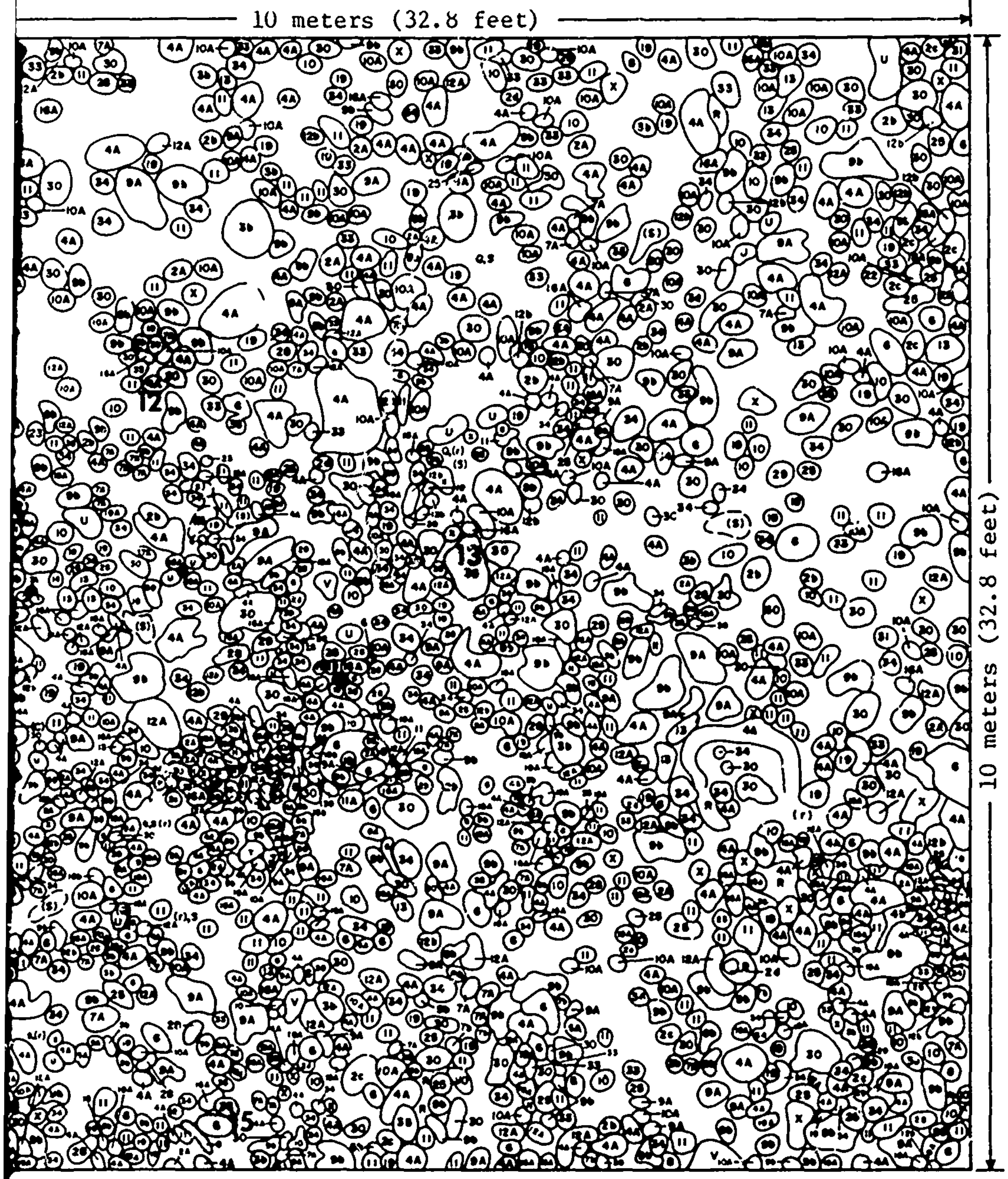


Figure 123. Species distribution chart, quadrat 4, Sella Bay.



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R . Soft green algae
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T . Fleshy Alcyonarian
U . Goniolithon sp. Foslie
V . Porolithon sp. Foslie
X . Unidentified hard coral
Y . Anemone
(C). Dead coral
(r). Rock
(S). Sand

(3) Photo location and plate number

Figure 123. Species distribution chart, quadrat 4, Sella Bay.

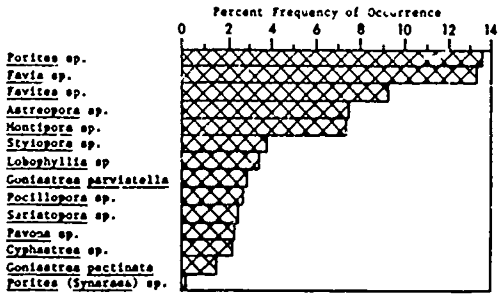

Figure 124. Frequency of occurrence of coral in quadrat 4, Sella Bay.

Plate 12. Photo 26-3 in Quadrat 4, Sella Bay - Porites growth in association with sponge, and Montipora and Favia in competition for space.

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Plate 13. Photo 26-13 in Quadrat 4, Sella Bay - An old head of Astreopora that has been damaged and encroached on by algae and Pocillopora.

Plate 14. Photo 26-19 in Quadrat 4, Sella Bay - An old head of Lobophyllia damaged extensively.

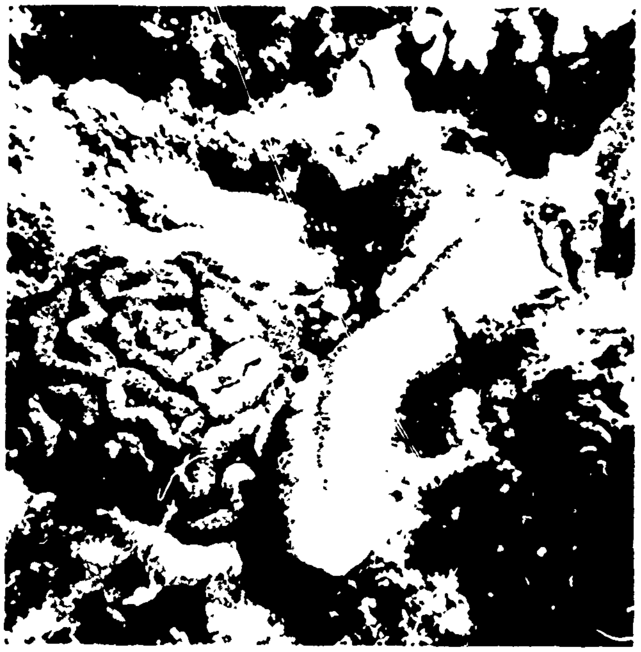
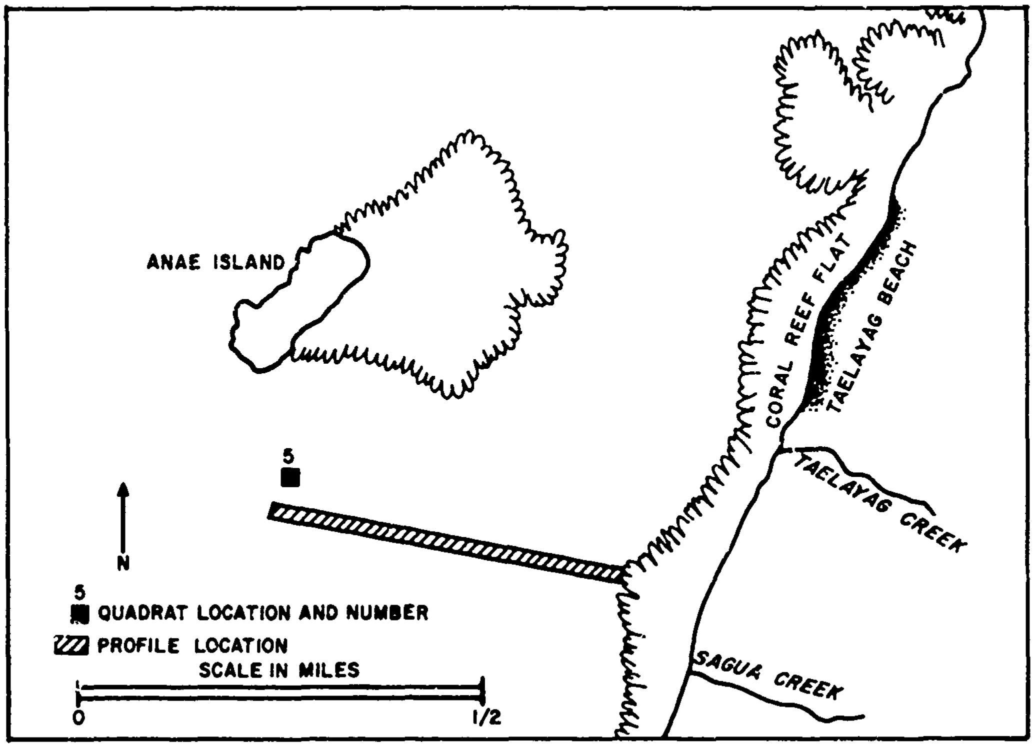


Plate 15. Photo 27-2 in Quadrat 4, Sella Bay - Herpolitha and new growth of Lobophyllia in a silt-laden depression.



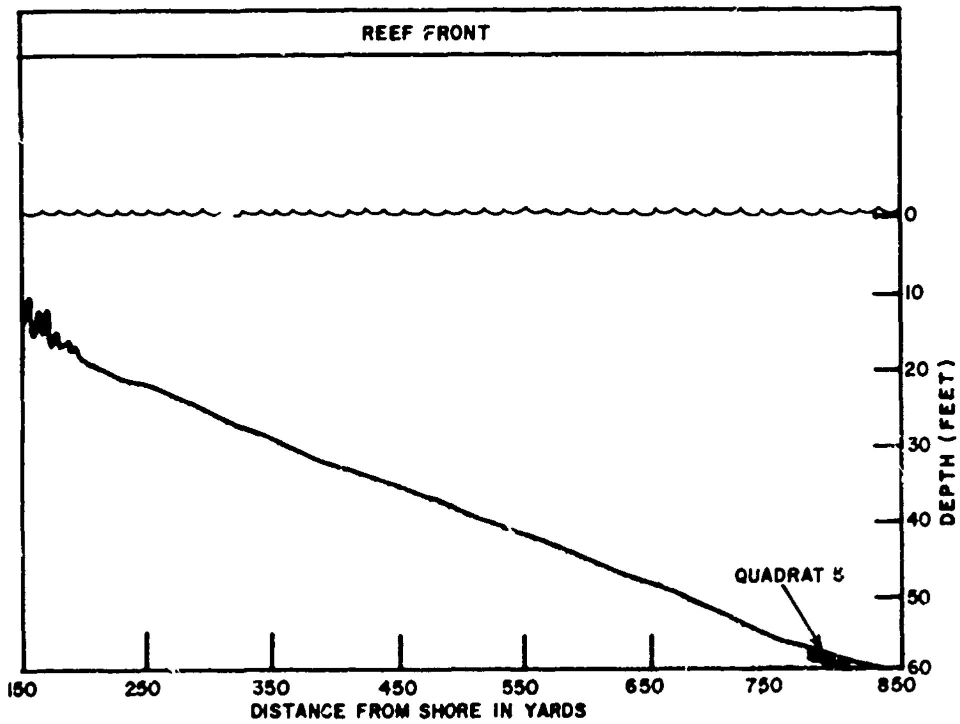


Figure 125. Area chart showing quadrat and reef profile of Anae Island.

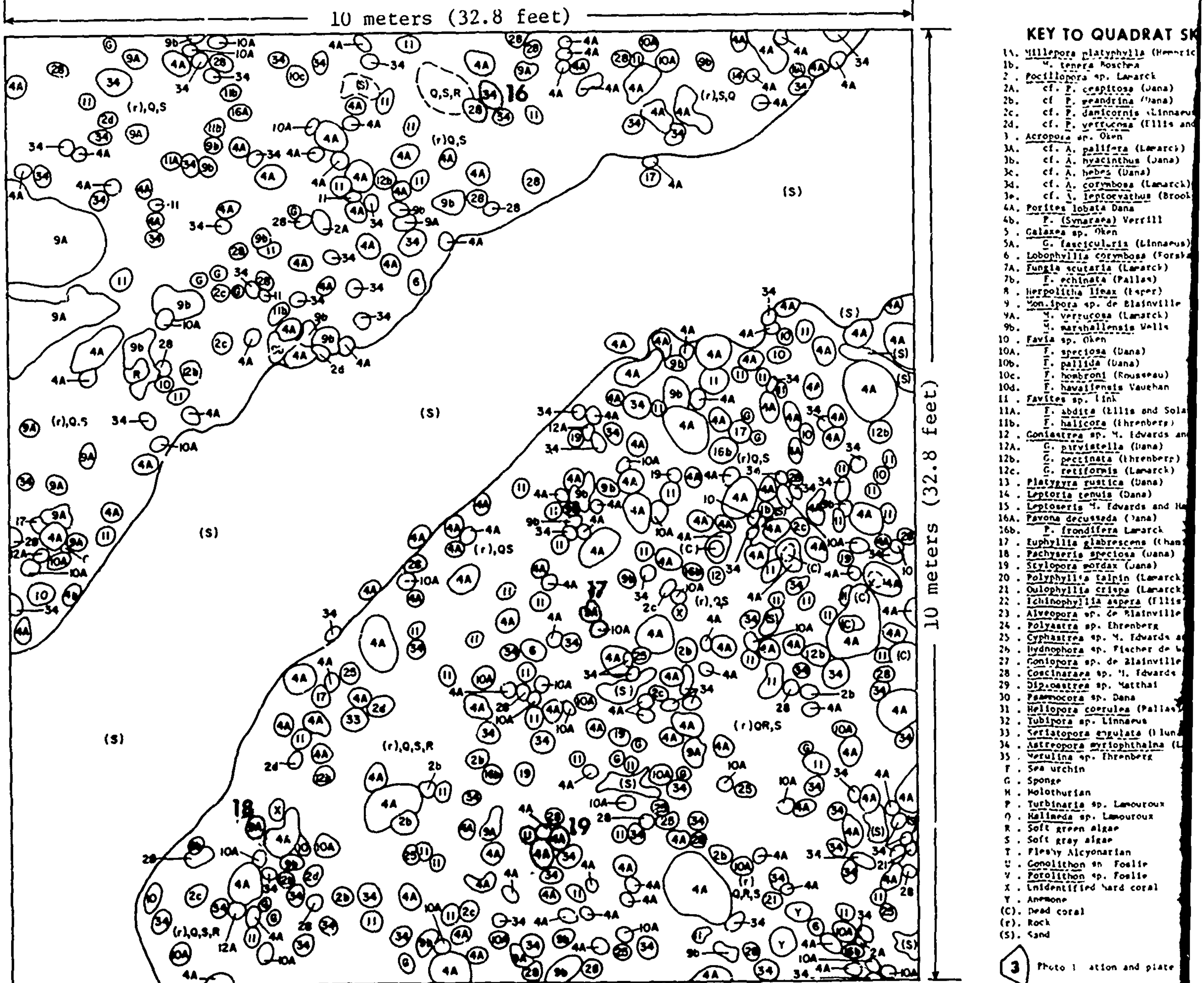


Figure 126. Species distribution chart, quadrat 5, Anae Island.

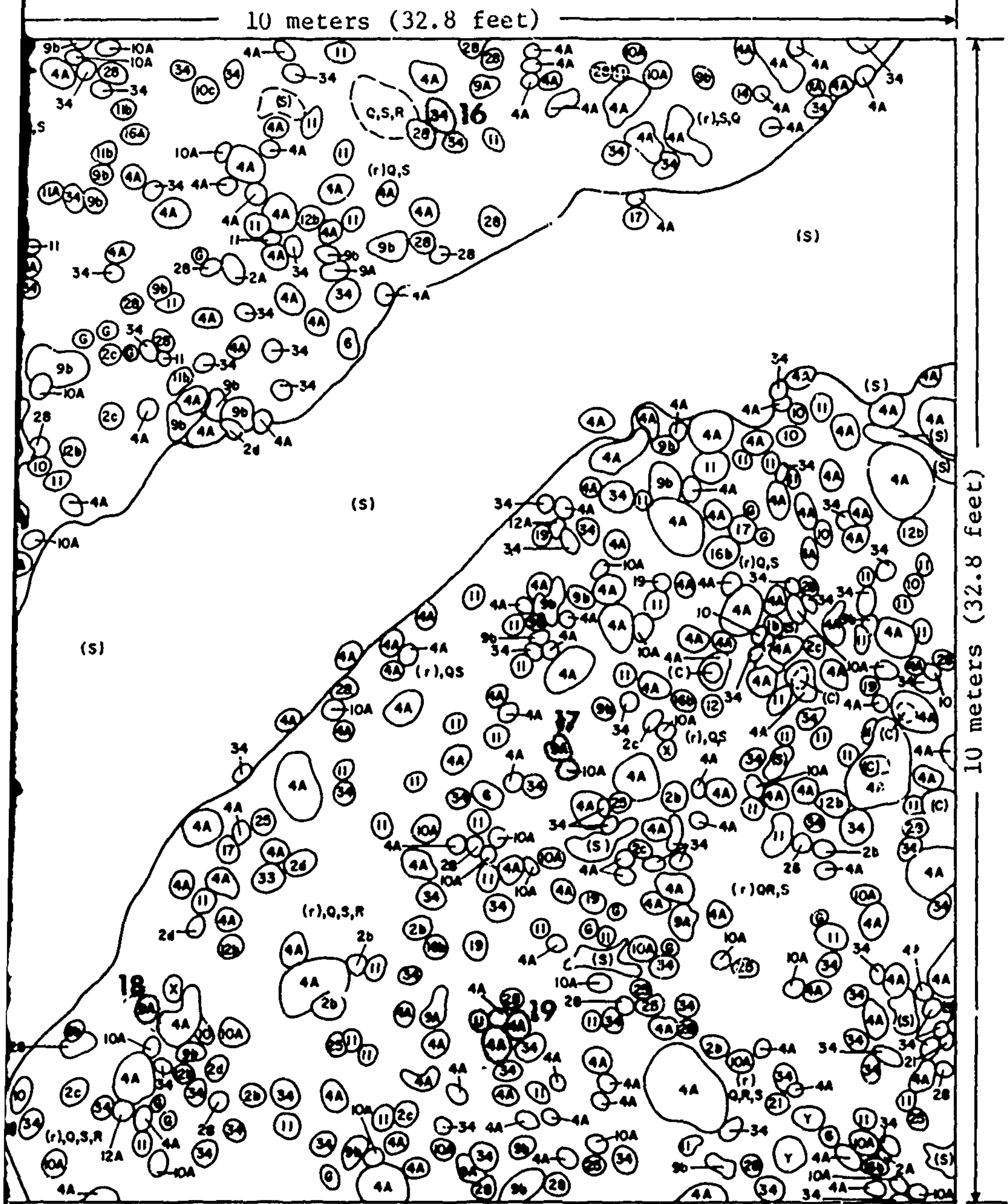


Figure 126. Species distribution chart, quadrat 5, Anae Island.

KEY TO QUADRAT SKETCHES

1A. Millepora platyphylla (Hemprich and Ehrenberg)
1b. M. tenera Boschma
2 . Pocillopora sp. Lamarck
2A. cf. P. cespitosa (Dana)
2b. cf. P. meandrina (Dana)
2c. cf. P. damicornis (Linnaeus)
2d. cf. P. verrucosa (Ellis and Solander)
3 . Acropora sp. Oken
3A. cf. A. palifera (Lamarck)
3b. cf. A. hyacinthus (Dana)
3c. cf. A. hebes (Dana)
3d. cf. A corymbosa (Lamarck)
3e. cf. A. leptocyathus (Brook)
4A. Porites lobata Dana
4b. P. (Synaraea) Verrill
5 . Galaxea sp. Oken
5A. G. fascicularis (Linnaeus)
6 . Lobophyllia corymbosa (Forskaal)
7A. Fungia scutaria (Lamarck)
7b. F. echinata (Pallas)
8 . Herpolitha limax (Esper)
9 . Montipora sp. de Blainville
9A. M. verrucosa (Lamarck)
9b. M. marshallensis Wells
10 . Favia sp. Oken
10A. F. speciosa (Dana)
10b. F. pallida (Dana)
10c. F. hombroni (Rousseau)
10d. F. hawaiiensis Vaughan
11 . Favites sp. Link
11A. F. abdita (Ellis and Solander)
11b. F. halicora (Ehrenberg)
12 . Goniastrea sp. M. Edwards and Haime
12A. G. parvistella (Dana)
12b. G. pectinata (Ehrenberg)
12c. G. retiformis (Lamarck)
13 . Platygyra rustica (Dana)
14 . Leptoria tenuis (Dana)
15 . Leptoseris M. Edwards and Haime
16A. Pavona decussada (Dana)
16b. P. frondifera Lamarck
17 . Euphyllia glabrescens (Chamisso and Eysenhardt)
18 . Pachyseris speciosa (Dana)
19 . Stylopora mordax (Dana)
20 . Polyphyllia talpin (Lamarck)
21 . Oulophyllia crispa (Lamarck)
22 . Echinophyllia aspera (Ellis and Solander)
23 . Alveopora sp. de Blainville
24 . Polyastra sp. Ehrenberg
25 . Cyphastrea sp. M. Edwards and Haime
26 . Hydnophora sp. Fischer de Waldheim
27 . Goniopora sp. de Blainville
28 . Coscinaraea sp. M. Edwards and Haime
29 . Diploastrea sp. Matthai
30 . Psammocora sp. Dana
31 . Heliopora coerulea (Pallas)
32 . Tubipora sp. Linnaeus
33 . Seriatopora angulata (Klunzinger)
34 . Astreopora myriophthalma (Lamarck)
35 . Merulina sp. Ehrenberg
F . Sea urchin
G . Sponge
H . Holothurian
P . Turbinaria sp. Lamouroux
Q . Halimeda sp. Lamouroux
R . Soft green algae
S . Soft gray algae
T . Fleshy Alcyonarian
U . Conolithon sp. Foslie
V . Porolithon sp. Foslie
X . Unidentified hard coral
Y . Anemone
(C). Dead coral
(r). Rock
(S). Sand

(3) Photo location and plate number

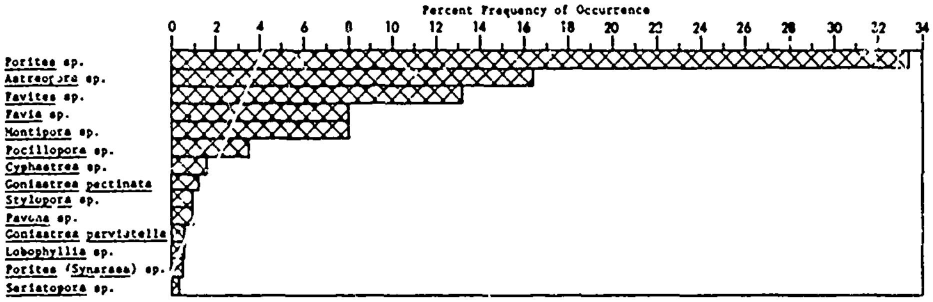


Figure 127. Frequency of occurrence of coral in quadrat 5, Anae Island area.

Plate 16. Photo 18-3 in Quadrat 5, Anae Island area - Species of Astreopora growing on a dead coral head and existing with algae.

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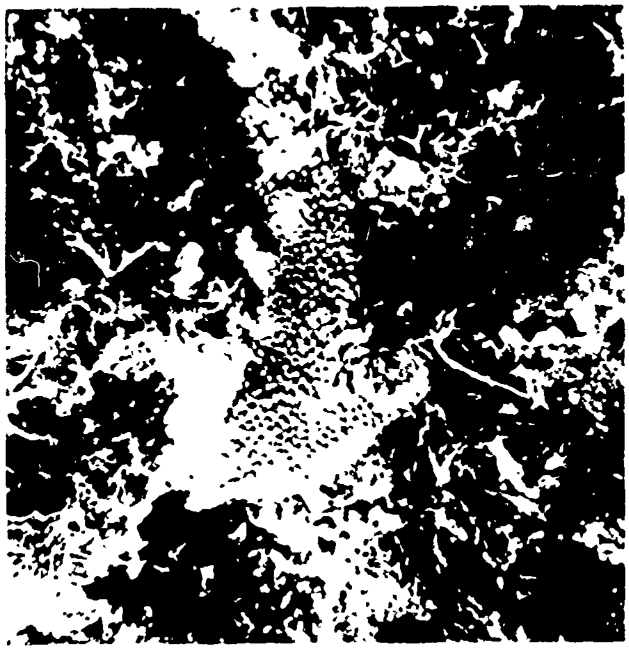


Plate 17. Photo 18-6 in Quadrat 5, Anae Island area - Species of Montipora partially dead in spots probably caused from feeding by the crown-of-thorns.

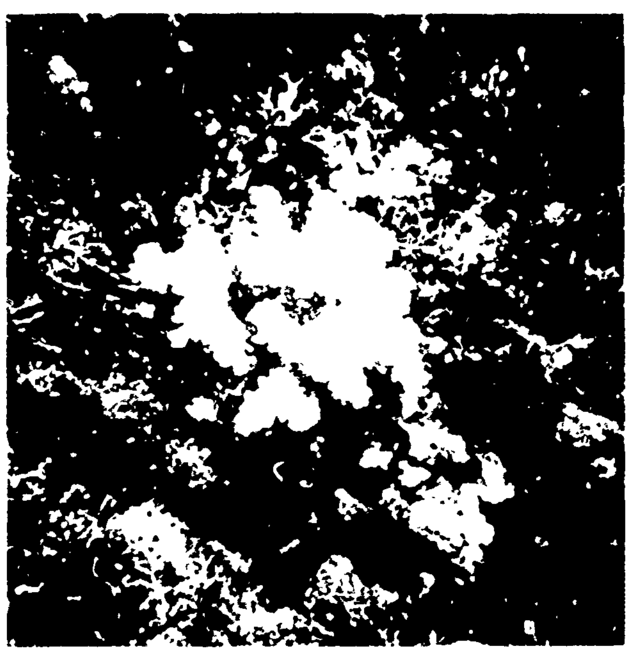


Plate 18. Photo 18-10 in Quadrat 5, Anae Island area - A small species of Pocillopora in an open, unprotected area.

Plate 19. Photo 18-11 in Quadrat 5, Anae Island area - Several species of Porites, some showing signs of fish grazing.

4. Bangi Island

This study area is a broad, shallow reef flat adjacent to Bangi Island. The flat extends 700 yards (640 meters) from a sand and mud shore to an algal ridge that is awash at low tide. A chart and profile of the area are shown in figure 128. This reef flat is characterized by the limiting factors of high sediment level, unstable bottom, and large temperature variations. The reef flat communities are zoned parallel to the shore, and most are dominated by the marine grass, *Zostera* sp. From the shoreline, these zones are: (1) barren, mud and sand; (2) *Zostera* and *Pocillopora*; (3) *Zostera*, *Pocillopora*, and *Pavona*; (4) *Zostera*, *Pavona*, and *Porites*; (5) *Zostera*, *Porites*, and *Acropora*; (6) *Turbinaria*; and (7) the algal ridge. Zonations of species in reef flat communities are common and have been described for similar areas by Mayor (1924) and Tracey et al. (1964). Generally, the communities of the reef flat are less populated than those on the reef front, a condition attributed to the limiting environmental factors of the reef flat.

Quadrat 6 (fig. 129) is located 500 yards (457 meters) from shore in a transition area between the *Pavona*/*Pocillopora* zone and the *Pavona*/*Porites* zone. The bottom coverage is equally divided between marine grass and coral and open holes with sand and gravel. Water depth over

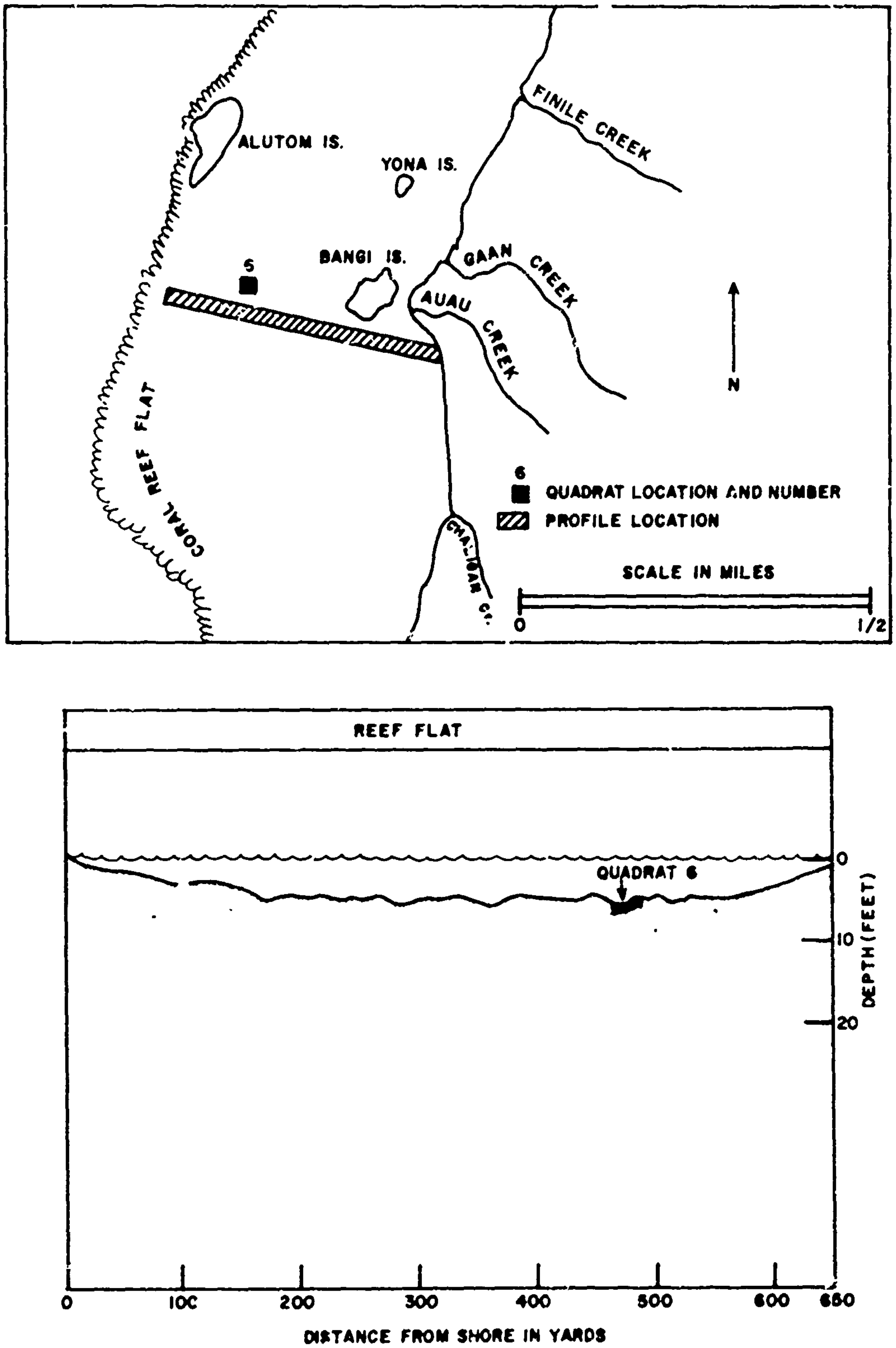


Figure 128. Area chart and reef profile for Bangi Island ecological study.

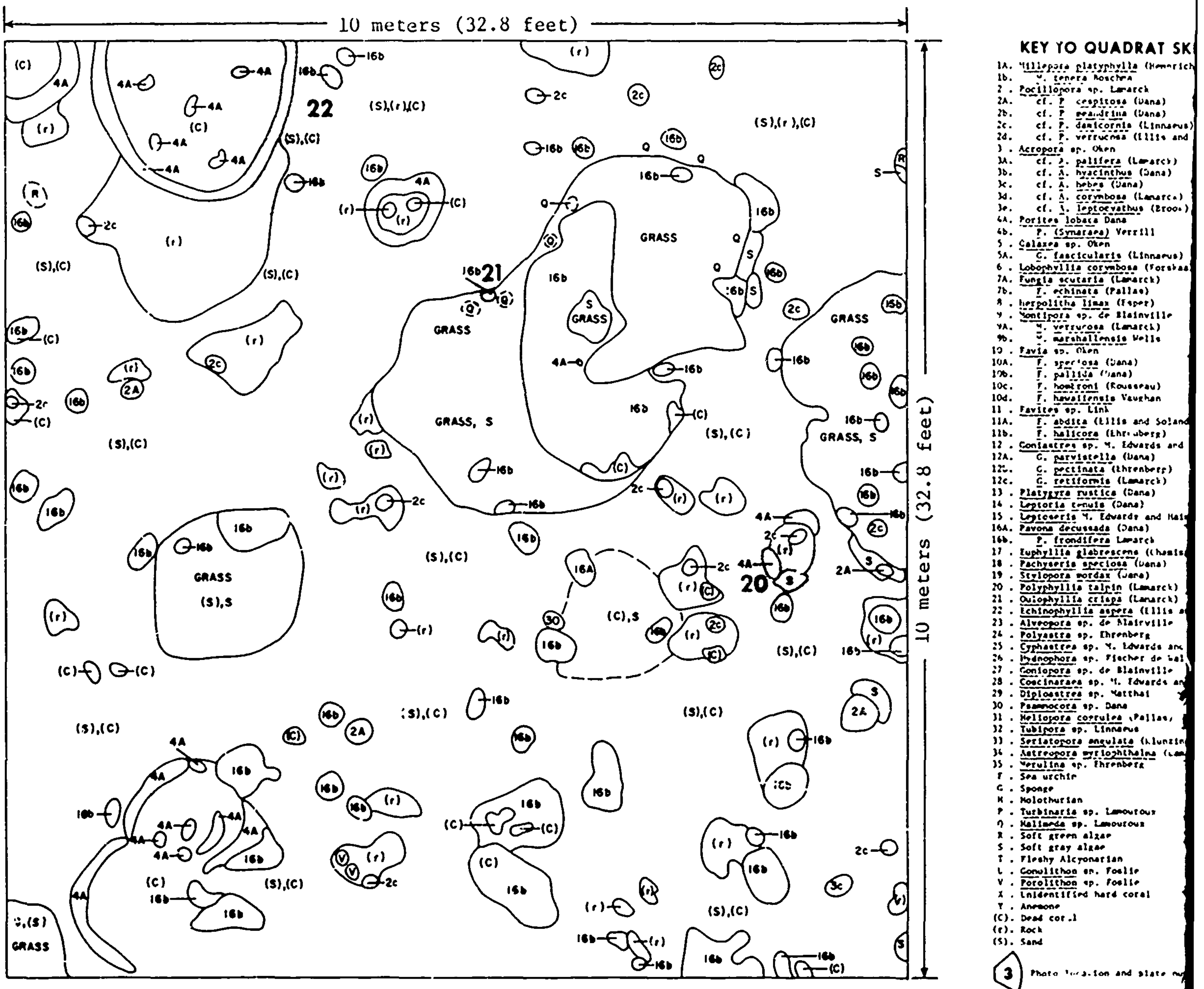
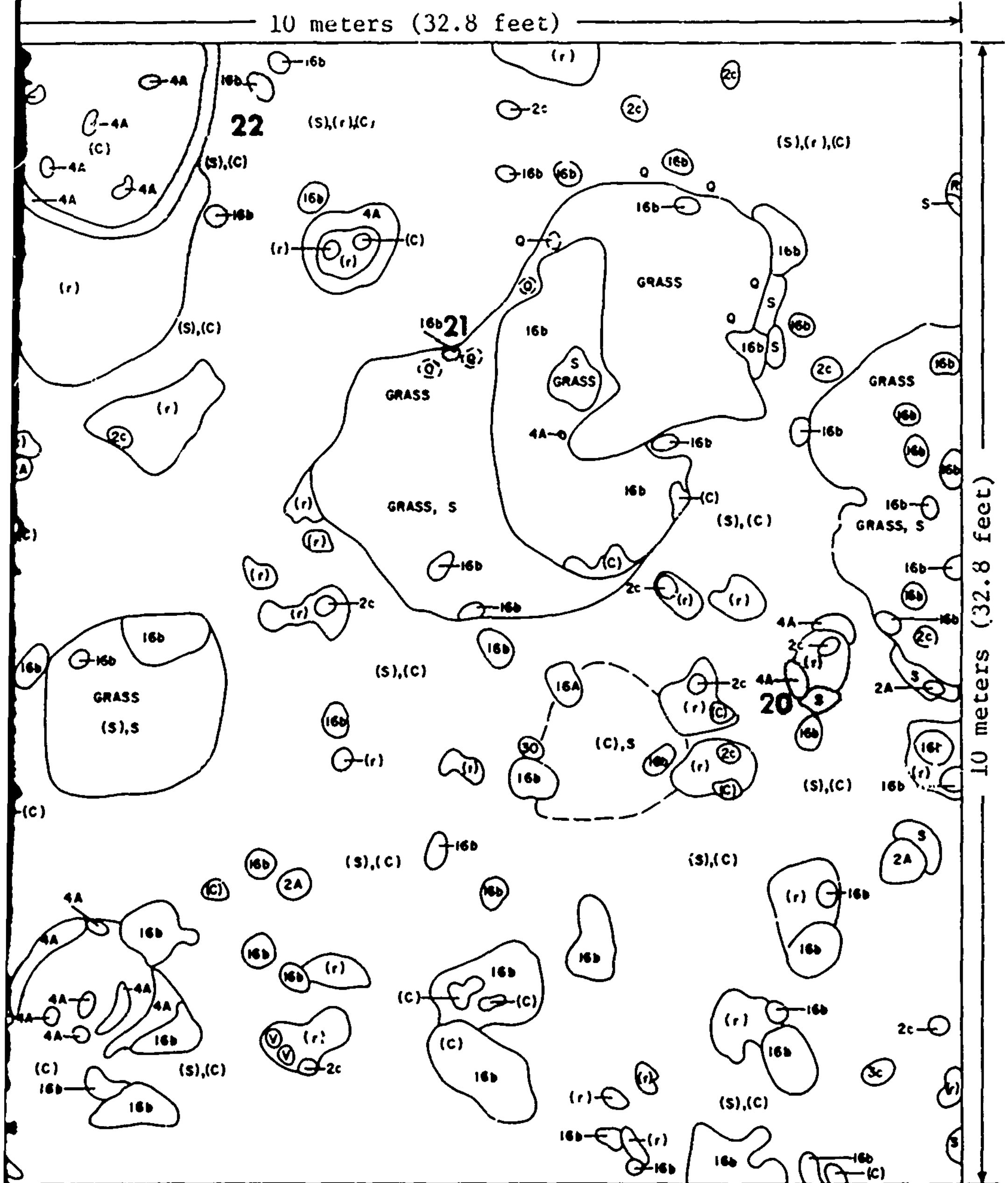


Figure 129. Species distribution chart, quadrat 6, Bangi Island.



ure 129. Species distribution chart, quadrat 6, Bangi Island.

KEY TO QUADRAT SKETCHES

1A. Millepora platyphylla (Hemprich and Ehrenberg)
1b. M. tenera Boschma
2 . Pocillopora sp. Lamarck
2A. cf P. cespitosa (Dana)
2b. cf. P. meandrina (Dana)
2c. cf. P. damicornis (Linnaeus)
2d cf. P verrucosa (Ellis and Solander)
3 . Acropora sp. Oken
3A. cf. A. palifera (Lamarck)
3b cf A. hyacinthus (Dana)
3c. cf. A. hebes (Dana)
3d. cf. A. corymbosa (Lamarck)
3e cf. A. leptocyathus (Brook)
4A. Porites lobata Dana
4b. P. (Synaraea) Verrill
5 . Galaxea sp. Oken
5A. G. fascicularis (Linnaeus)
6 . Lobophyllia corymbosa (Forskaal)
7A. Fungia scutaria (Lamarck)
7b. F. echinata (Pallas)
8 . Herpolitha limax (Esper)
9 . Montipora sp. de Blainville
9A. M. verrucosa (Lamarck)
9b. M. marshallensis Wells
10 Favia sp. Oken
10A. F speciosa (Dana)
10b. F. pallida (Dana)
10c. F. hombroni (Rousseau)
10d. F. hawaiiensis Vaughan
11 . Favites sp. Link
11A. F. abdita (Ellis and Solander)
11b. F. halicora (Ehrenberg)
12 . Goniastrea sp. M. Edwards and Haime
12A. G. parvistella (Dana)
12b. G. pectinata (Ehrenberg)
12c. G. retiformis (Lamarck)
13 . Platygyra rustica (Dana)
14 . Leptoria tenuis (Dana)
15 . Leptoseris M. Edwards and Haime
16A. Pavona decussata (Dana)
16b. P. frondifera Lamarck
17 . Euphyllia glabrescens (Chamisso and Eysenhardt)
18 . Pachyseris speciosa (Dana)
19 . Stylopora mordax (Dana)
20 . Polyphyllia talpin (Lamarck)
21 . Oulophyllia crispa (Lamarck)
22 . Echinophyllia aspera (Ellis and Solander)
23 . Alveopora sp. de Blainville
24 . Polyastra sp. Ehrenberg
25 . Cyphastrea sp. M. Edwards and Haime
26 . Hydnophora sp. Fischer de Waldheim
27 . Goniopora sp. de Blainville
28 . Coscinaraea sp. M. Edwards and Haime
29 . Diploastrea sp. Matthai
30 . Psammocora sp. Dana
31 . Heliopora coerulea (Pallas)
32 . Tubipora sp. Linnaeus
33 . Seriatopora angulata (Klunzinger)
34 . Astreopora myriophthalma (Lamarck)
35 . Merulina sp. Ehrenberg
F . Sea urchin
G . Sponge
H . Holothurian
P . Turbinaria sp. Lamouroux
Q . Halimeda sp. Lamouroux
R . Soft green algae
S . Soft gray algae
T . Fleshy Alcyonarian
U . Gonolithon sp. Foslie
V . Porolithon sp. Foslie
X . Unidentified hard coral
Y . Anemone
(C). Dead coral
(r). Rock
(S). Sand

(3) Photo location and plate number

the bottom of the holes is 3 to 4 feet (.9 to 1.2 meters) but only inches over the grass and large coral heads. The grass has stabilized the sand, but in the holes the sand is continually shifting, thus, inhibiting coral growth. The prominent organisms are *Pavona*, *Porites*, *Pocillopora*, and *Acropora* (fig. 130). The sessile population of the quadrat covers about 15 percent of the bottom and consists of 98 organisms of seven species. In most instances, coral growth in the quadrat is confined to areas stabilized by the grass (*Zostera*) and the higher rocky areas. Some coral growth, primarily *Pocillopora* and *Pavona*, occurs in the sand holes, but quite often these corals are partially dead because of the instability of the substrate.

Individual organisms were selected for documentation from both the grass areas and sand holes. The prominent genera for the transition zone are represented along with genera that characterize adjacent zones. Plates 20, 21, and 22 depict some of these specimens.

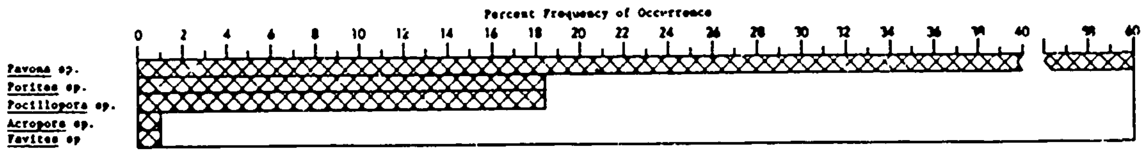


Figure 130. Frequency of occurrence of coral in quadrat 6, Bangi Island area.

Plate 20. Photo 14-9 in Quadrat 6, Bangi Island area - Species of *Pocillopora* (center) covered with algae attached to a rock in a sand hole. Underneath portions are dead. Dead *Acropora* and calcareous litter surround the area. *Porites* in bottom half of the photo.

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Plate 21. Photo 17-7 in Quadrat 6, Bangi Island area - A species of Pavona (center) in a Zostera/sand edge zone.

Plate 22. Photo 17-8 in Quadrat 6, Bangi Island area - Species of Porites in background showing characteristic round toadstool base and table top. Pavona and dead coral debris in foreground.

5. Piti Bay

Piti Bay (fig. 131) faces north-northwest, subjecting it to northerly winds and waves, which create strong currents in the outer section of the reef flat. Four distinct environments were observed on the reef flat: (1) a mud and grass flat extending from the shore; (2) a lagoon 10 feet (3.0 meters) deep with large deeper holes; (3) a shallower central zone (the quadrat area) dominated by Porites and Alcyonaria; and (4) an outer zone dominated by Acropora.

An outfall is located at Asan Point on the northern end of the bay, and sewage flows south into and across the reef flat. Additional pollutants are carried into the area by two streams which flow through populated areas. Little is known about the affect of sewage on a coral community. Sargent and Austin (1954) conducted a study at Bikini on the bioproduction of a coral reef washed by an unidirectional current, and they concluded that the community produced more organic matter than it consumed. A reef subjected to sewage pollution would not necessarily derive any benefit from the additional nutrients. Harmful effects of chemicals or increased turbidity would result if concentrations were extreme.

Quadrat 7 is located near the edge of the shallow lagoon about 1,050 yards (960 meters) from shore (fig. 131). A steady southerly current of 1 to 1.5 knots (.5 m/sec to .75 m/sec) flowed through the area during the installation and survey of the quadrat. The current was due to moderate surf, which carried water into the lagoon over the northern reef margin. This water exited through one of several channels in Piti Bay.

The area contains a sessile population, primarily soft corals (Alcyonaria) and Porites (fig. 132). The soft corals blanket about 20 percent of the bottom by attaching to the coral rock substrate, and are surrounded by sand 6 to 8 inches (15.24 to 20.32 centimeters) deep at the basal disks. The Porites heads are boulder-size structures that rise 2 to 3 feet (.6 to .9 meter) off the reef floor and provide attachment surfaces for other corals away from the sand. The population consists of 17 species totaling 202 organisms of which 46 percent are Porites and 33 percent are Alcyonaria (fig. 133). This area, with many soft corals, is unlike any of the other quadrats. Predominance of the soft corals is probably maintained through their tolerance of the shifting sand.

Predominant organisms in the sand (plates 23 and 24) and organisms on the boulders (plates 25 and 26) were selected for documentation.

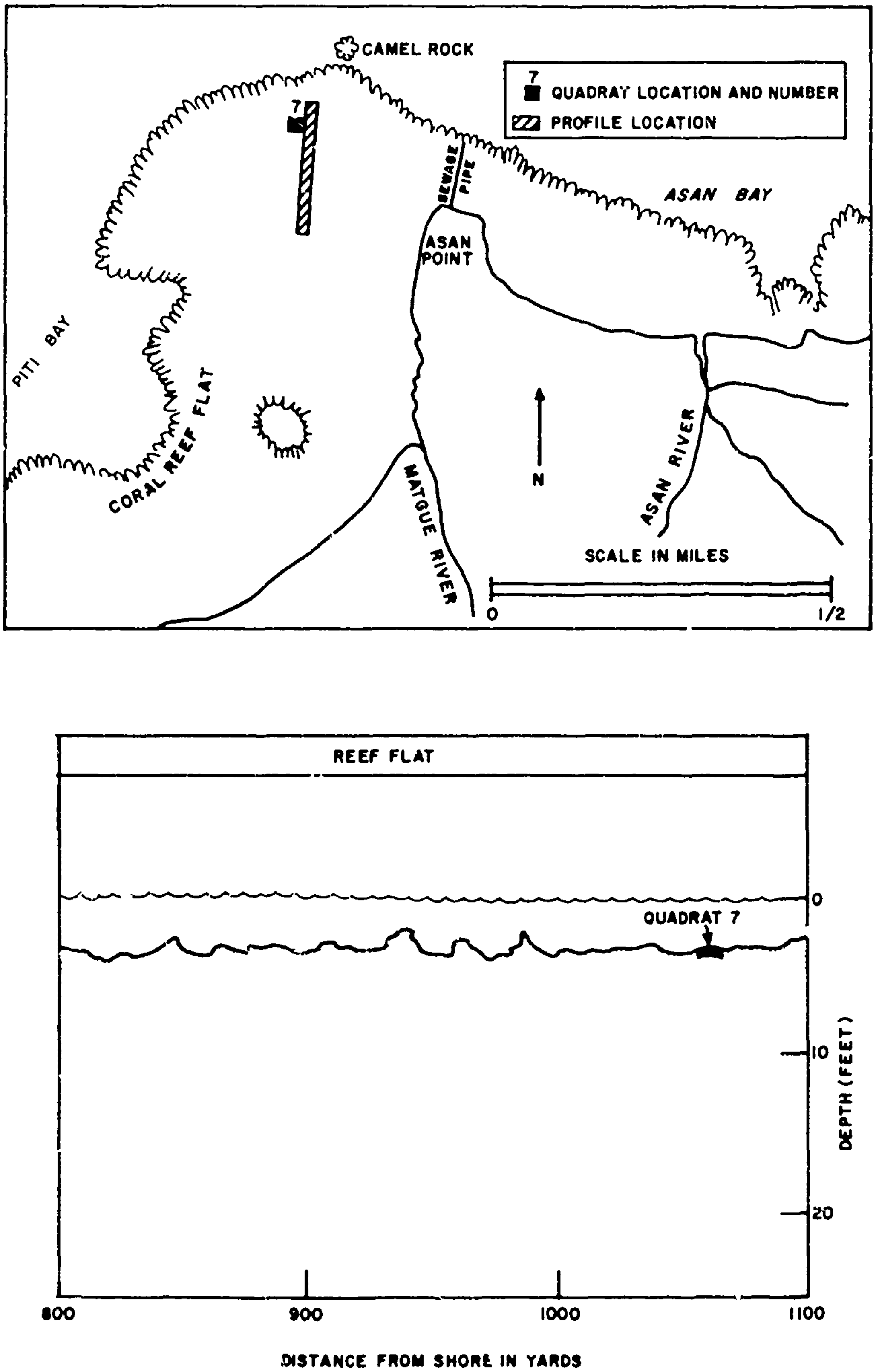


Figure 131. Area chart and reef profile for Piti Bay ecological study.

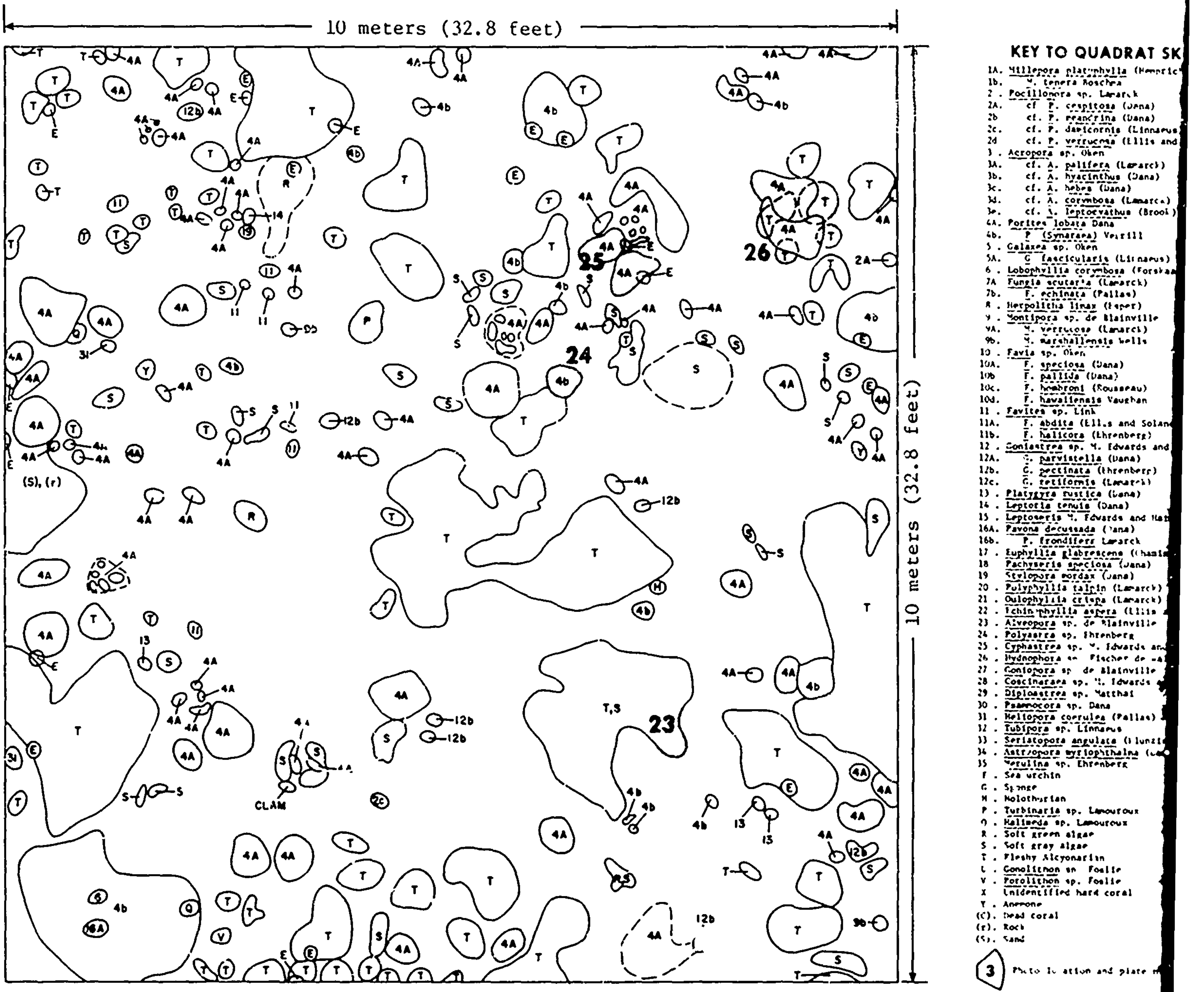
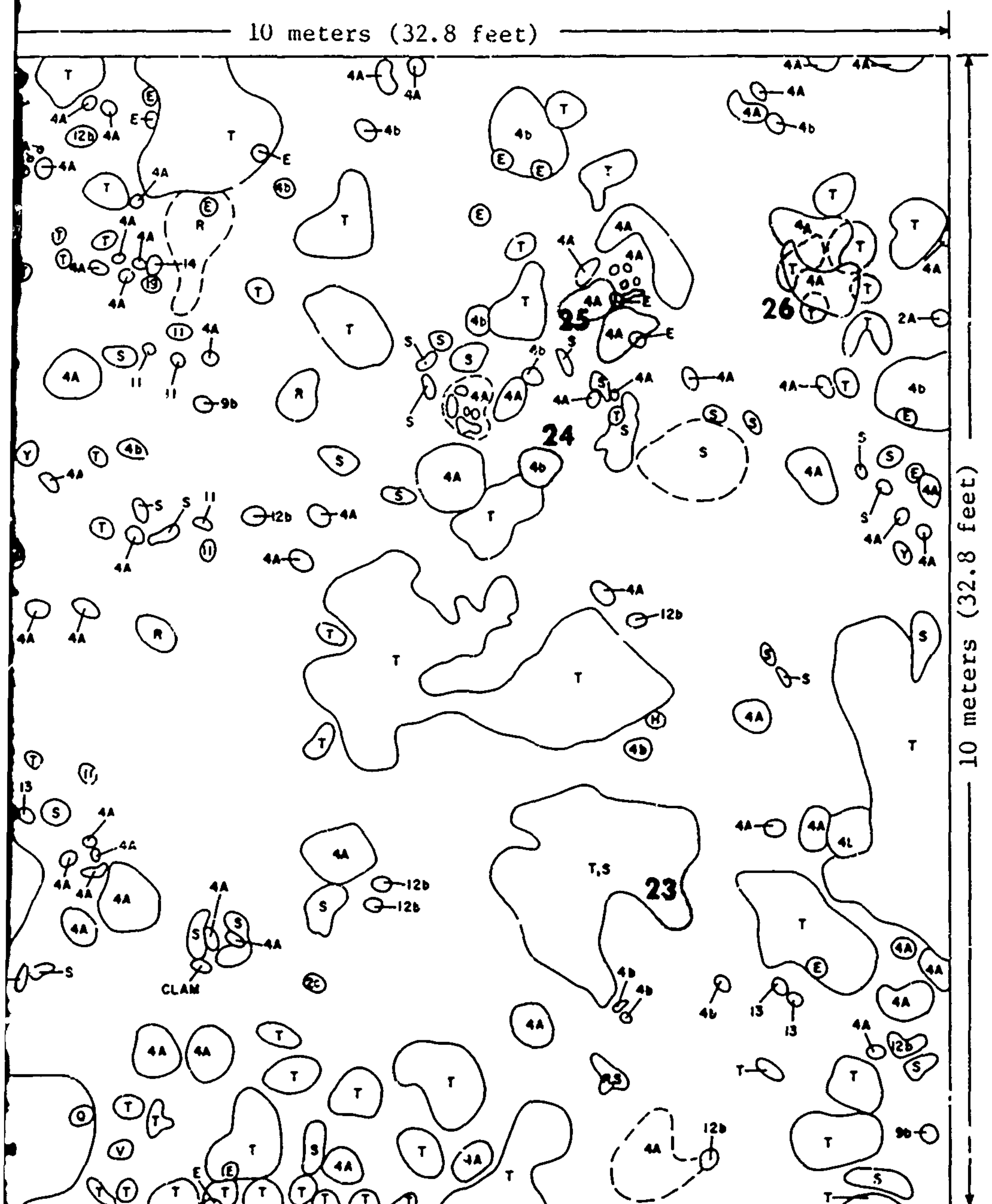


Figure 132. Species distribution chart, quadrat 7, Piti Bay.



KEY TO QUADRAT SKETCHES

1A. Millepora platyphylla (Hemprich and Ehrenberg)
1b. M. tenera Boschma
2 . Pocillopora sp. Lamarck
2A. cf P. caespitosa (Dana)
2b. cf P. meandrina (Dana)
2c. cf. P. damicornis (Linnaeus)
2d cf. P. verrucosa (Ellis and Solander)
3 . Acropora sp. Oken
3A. cf. A palifera (Lamarck)
3b. cf. A. hyacinthus (Dana)
3c. cf. A hebes (Dana)
3d. cf. A. corymbosa (Lamarck)
3e. cf A. leptocyathus (Brook)
4A Porites lobata Dana
4b. P. (Synaraea) Verrill
5 . Galaxea sp. Oken
5A. G. fascicularis (Linnaeus)
6 . Lobophyllia corymbosa (Forskaal)
7A. Fungia scutaria (Lamarck)
7b. F. echinata (Pallas)
8 . Herpolitha limax (Esper)
9 . Montipora sp. de Blainville
9A. M. verrucosa (Lamarck)
9b. M. marshallensis Wells
10 . Favia sp. Oken
10A. F. speciosa (Dana)
10b. F. pallida (Dana)
10c. F. hombroni (Rousseau)
10d. F. hawaiiensis Vaughan
11 . Favites sp. Link
11A. F abdita (Ellis and Solander)
11b. F. flexicora (Ehrenberg)
12 . Goniastrea sp. M. Edwards and Haime
12A. G. parvistella (Dana)
12b. G. pectinata (Ehrenberg)
12c. G. retiformis (Lamarck)
13 . Platygyra rustica (Dana)
14 . Leptoria tenuis (Dana)
15 . Leptoseris M. Edwards and Haime
16A Pavona decussada (Dana)
16b. P. frondifera Lamarck
17 . Euphyllia glabrescens (Chamisso and Eysenhardt)
18 . Pachyseris speciosa (Dana)
19 . Stylopora mordax (Dana)
20 . Polyphyllia talpin (Lamarck)
21 . Oulophyllia crispa (Lamarck)
22 . Echinophyllia aspera (Ellis and Solander)
23 . Alveopora sp. de Blainville
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30 . Psammocora sp. Dana
31 . Heliopora coerulea (Pallas)
32 . Tubipora sp. Linnaeus
33 . Seriatopora angulata (Klunzinger)
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E . Sea urchin
G . Sponge
H . Holothurian
P . Turbinaria sp. Lamouroux
Q . Halimeda sp. Lamouroux
R . Soft green algae
S . Soft gray algae
T Fleshy Alcyonarian
U Gonolithon sp. Foslie
V . Porolithon sp. Foslie
X . Unidentified hard coral
Y . Anemone
(C). Dead coral
(R). Rock
(S). Sand

(3) Photo location and plate number

Figure 132. Species distribution chart, quadrat 7, Piti Bay.

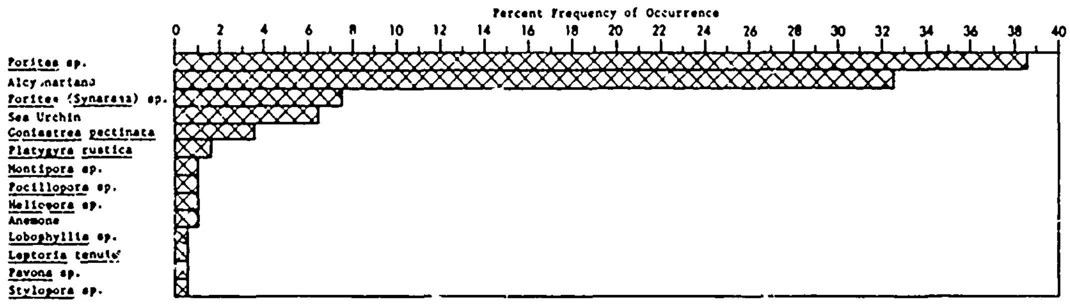

Figure 133. Frequency of occurrence of coral in quadrat 7, Piti Bay.

Plate 23. Photo 33-7 in Quadrat 7, Piti Bay - Alcyonarian attached to a rock substrate in a sand-layered bottom.

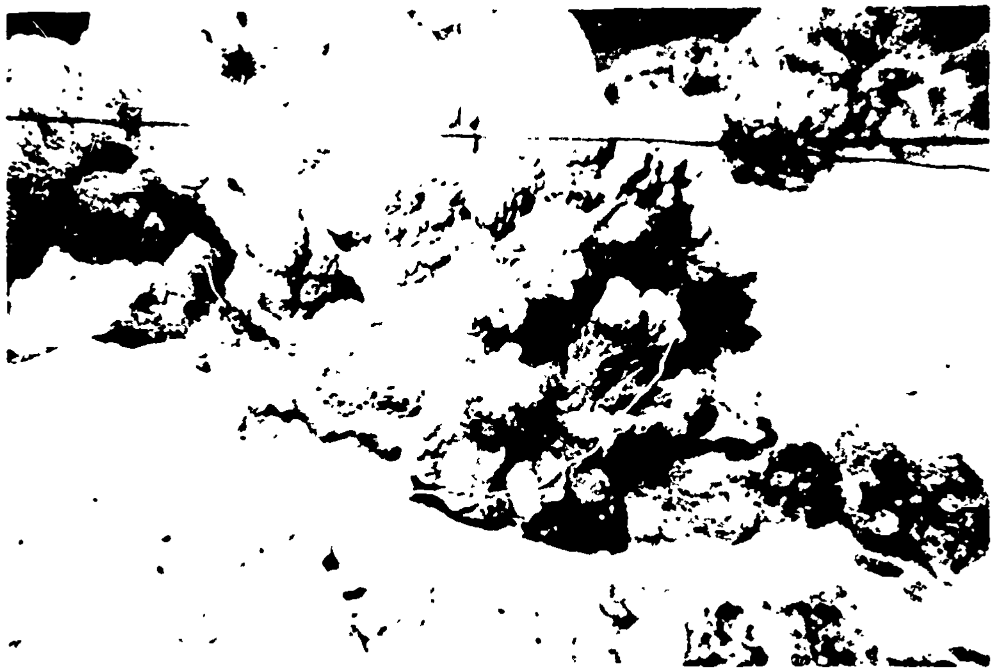

Plate 24. Photo 38-10 in Quadrat 7, Piti Bay - Porites (Synaraea) growth on rock surrounded by drifting sand.

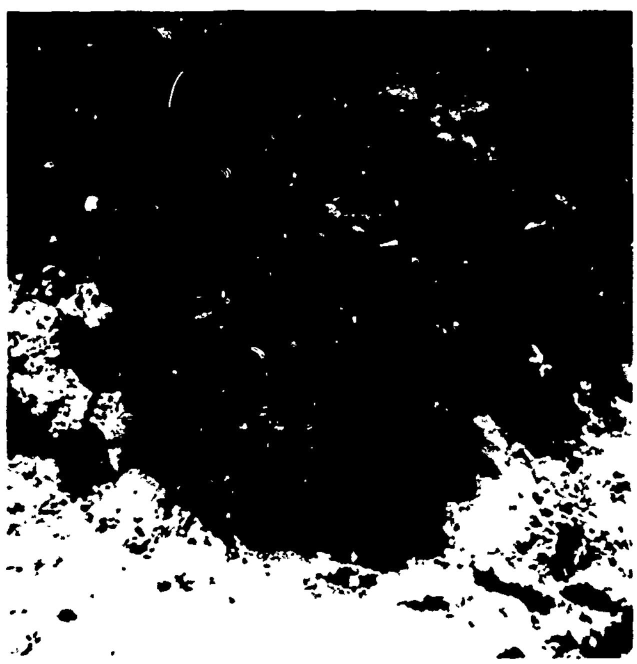

Plate 25. Photo 33-4 in Quadrat 7, Piti Bay - Porites growing on rock protruding from a sand-layered bottom.

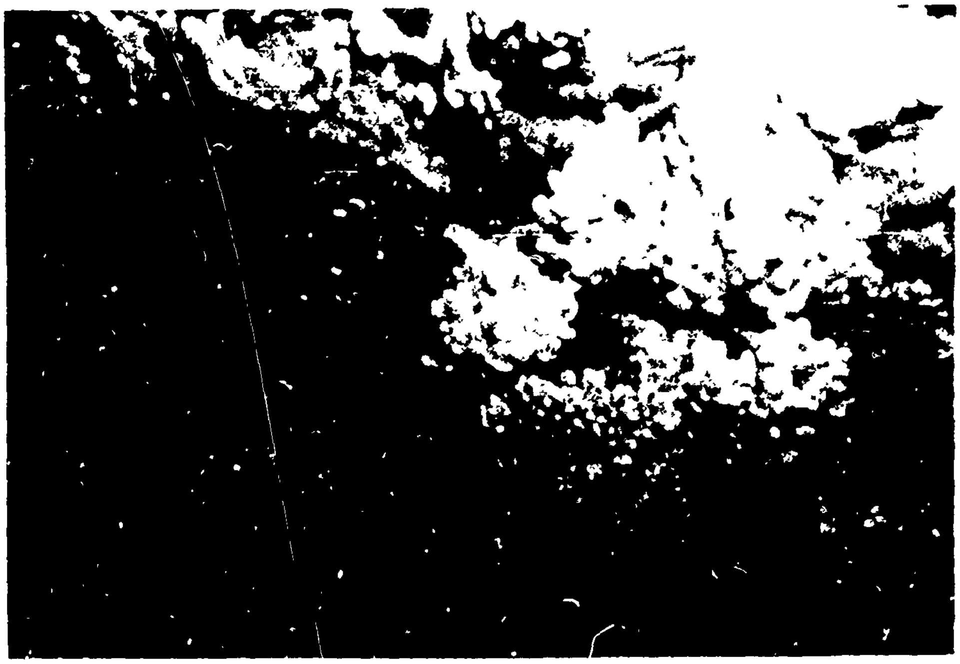

Plate 26. Photo 38-7 in Quadrat 7, Piti Bay - Alcyonarians and Porites growth on a rock protrusion. Organisms completely engulf the rock.

6. Tumon Bay

Its sandy beaches and wide, shallow lagoon make Tumon Bay one of the favorite tourist sites on the island. Several large hotels have been built along the shore and the Guam community uses the bay extensively for sunbathing, swimming, and fishing. Figure 134 is an area chart and reef profile of the bay.

Three days of observations were made of the fringing reef at Tumon. The reef front had been decimated by the starfish, Acanthaster (crown-of-thorns), and presented an ugly view of dead coral buttresses and pillars. This reef sector now appears to be in an early stage of redevelopment with sponges, algae, the coral Galaxea, and the hydrozoan Millepora being predominant. The reef flat extends 550 yards (503 meters) from the shore to the algal ridge and encompasses the following zones: (1) beach sand and marine grass (0-100 yards (0-91.4 meters)); (2) sand, and coral of the genera Goniastrea, Porites, and Acropora (100-350 yards (91.4-320 meters)); and (3) sand, rock, and coral of the genera Pocillopora, Acropora, and Porites (350-550 yards (320-503 meters)). A similar traverse was run by Tracey et al. (op. cit.) before the starfish infestation, and comparison of data indicates the reef flat did not suffer

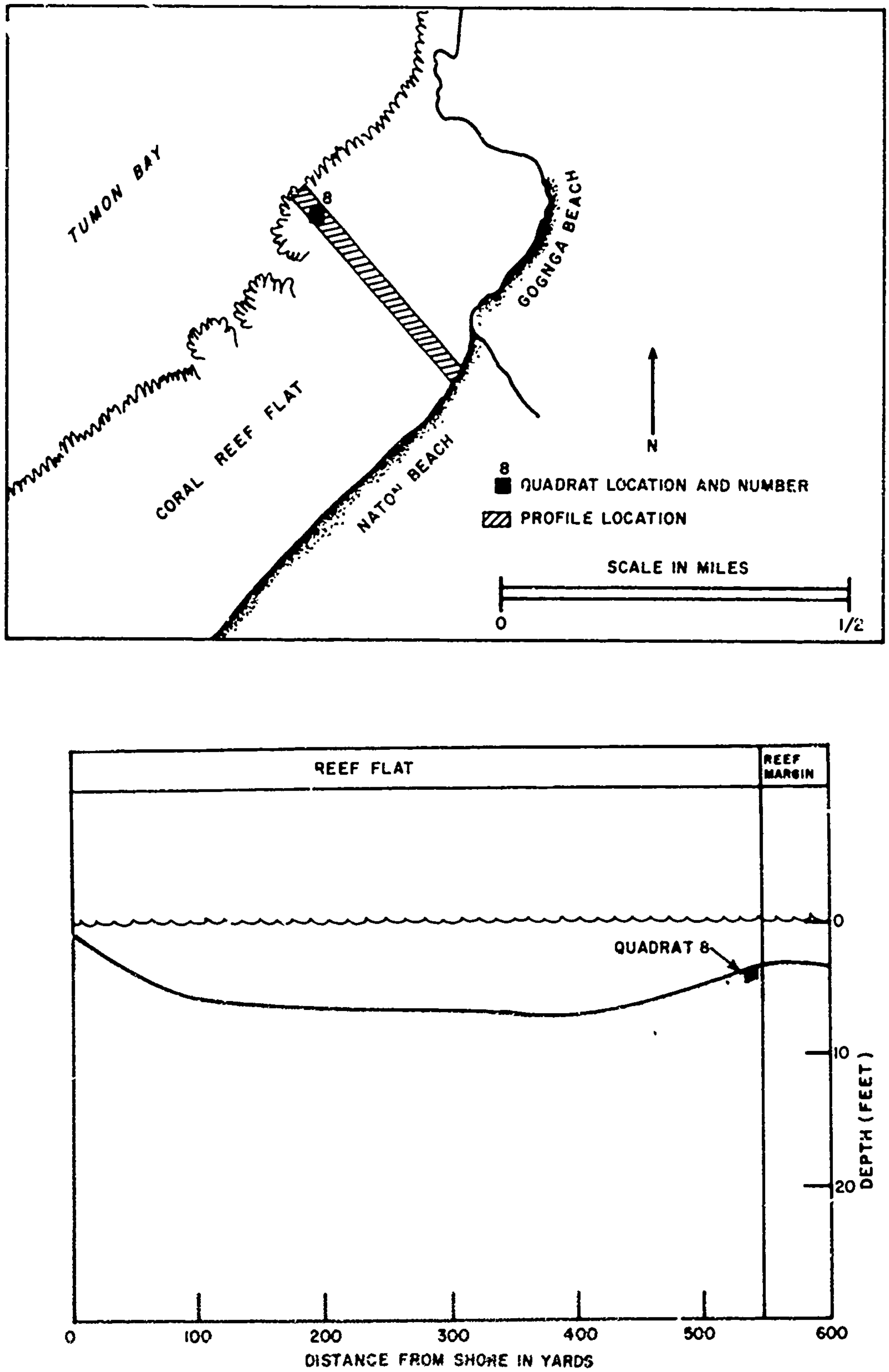

Figure 134. Area chart and reef profile for Tumon Bay ecological study.

from the crown-of-thorns invasion, nor has it been significantly damaged by heavy recreational use.

Quadrat 8, located in the Pocillopora, Acropora, and Porites zone, is covered by 6 inches to 2 feet (15.24 centimeters to .6 meter) of water depending on the tide. Much of the bottom is covered by sand and loose coral, especially around the Acropora thickets. Figure 135 presents the species distribution in the quadrat. The population consisted of 226 sessile organisms of nine genera with Pocillopora, Acropora, Porites, and Pavona occurring most frequently (fig. 136).

As in quadrat 6 at Alutom Island, the Pocillopora clumps occurring in the sand were partly dead and covered by algae. Although Pocillopora occurred with the greatest frequency, Acropora and the hydrozoan Palythoa actually covered the largest area. Another distinctive organism in the quadrat was a cone-shaped dark green sponge. The occurrence of Acropora and Pocillopora on the sand substrate indicates a high-energy environment, because these corals do not exist with sand or silt unless moving water is present to clean them. A strong current was moving south across the flat through a break in the reef margin. Plates 27, 28, and 29 are representative photographs taken to document the existing population.

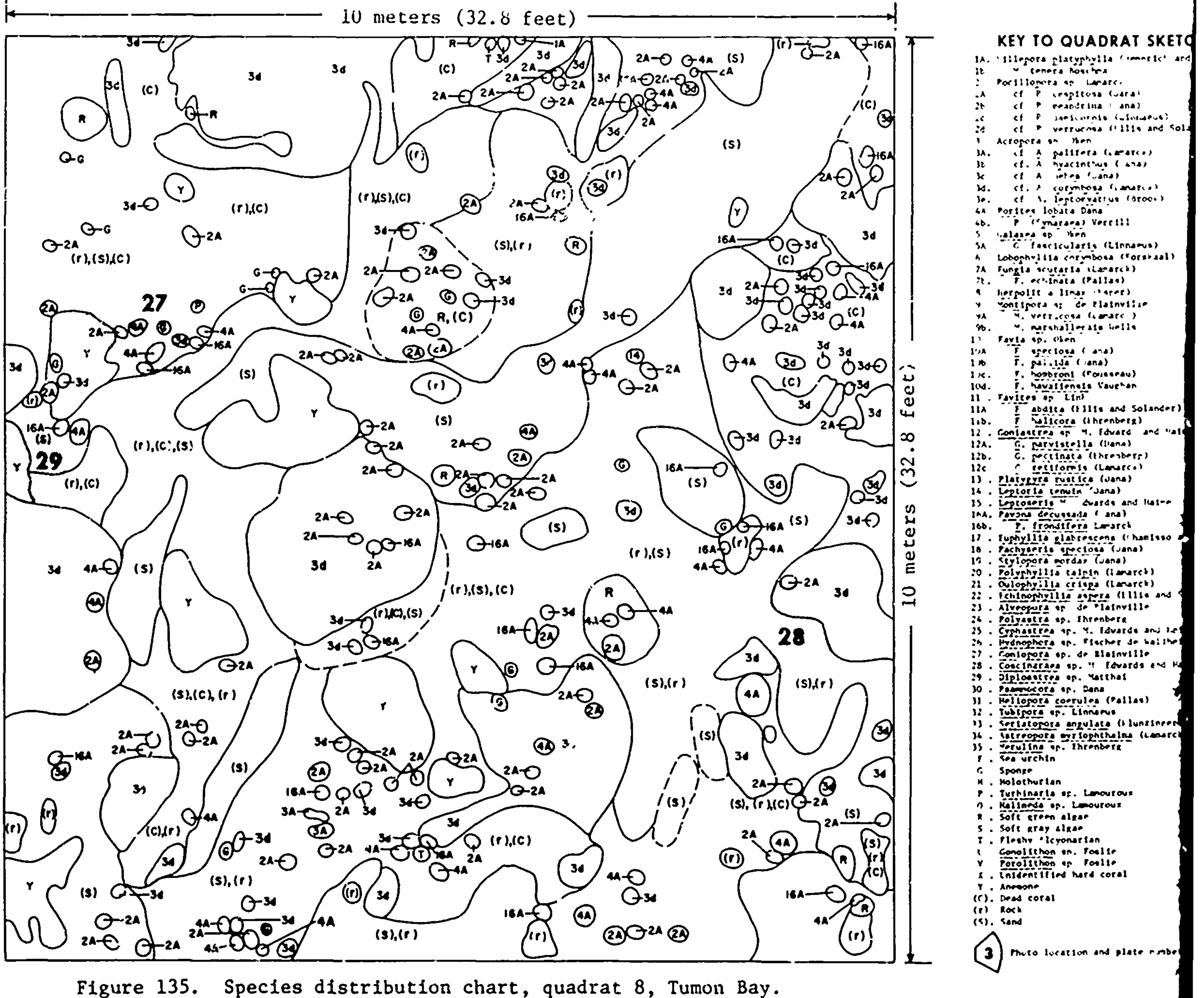

Figure 135. Species distribution chart, quadrat 8, Tumon Bay.

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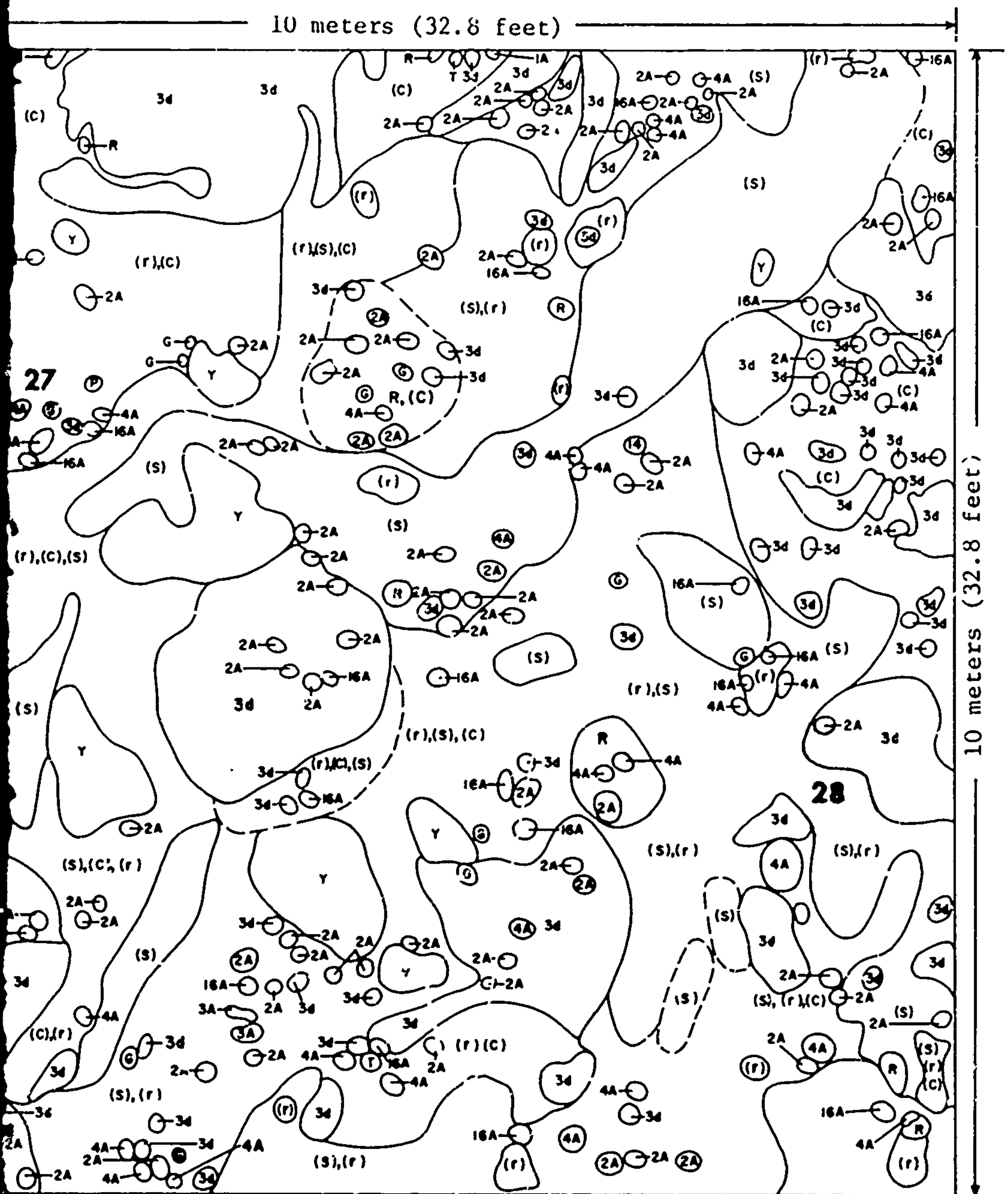

KEY TO QUADRAT SKETCHES

1A Millepora platyphylla (Hemprich and Ehrenberg)
1b. M. tenera Boschma
2 . Pocillopora sp. Lamarck
2A cf. P. cespitosa (Dana)
2b cf. P. meandrina (Dana)
2c cf. P. damicornis (Linnaeus)
2d. cf. P. verrucosa (Ellis and Solander)
3 . Acropora sp. Oken
3A. cf. A. palifera (Lamarck)
3b cf. A. hyacinthus (Dana)
3c cf. A. nobilis (Dana)
3d cf. A. corymbosa (Lamarck)
3e. cf. A. leptocyathus (Brook)
4A. Porites lobata Dana
4b. P. (Synaraea) Verrill
5 . Galaxea sp. Oken
5A. G. fascicularis (Linnaeus)
6 . Lobophyllia corymbosa (Forskaal)
7A. Fungia scutaria (Lamarck)
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8 . Herpolitha limax (Esper)
9 . Montipora sp. de Blainville
9A. M. verrucosa (Lamarck)
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10 Favia sp. Oken
10A. F. speciosa (Dana)
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19 . Stylopora mordax (Dana)
20 . Polyphyllia talpin (Lamarck)
21 . Oulophyllia crispa (Lamarck)
22 . Echinophyllia aspera (Ellis and Solander)
23 . Alveopora sp. de Blainville
24 . Polyastra sp. Ehrenberg
25 . Cyphastrea sp. M. Edwards and Haime
26 Hydnophora sp. Fischer de Waldheim
27 . Goniopora sp. de Blainville
28 . Coscinaraea sp. M. Edwards and Haime
29 . Diploastrea sp. Matthai
30 . Psammocora sp. Dana
31 . Heliopora coerulea (Pallas)
32 . Tubipora sp. Linnaeus
33 . Seriatopora angulata (Klunzinger)
34 . Astreopora myriophthalma (Lamarck)
35 . Merulina sp. Ehrenberg
F . Sea urchin
G . Sponge
H . Holothurian
P . Turbinaria sp. Lamouroux
Q . Halimeda sp. Lamouroux
R . Soft green algae
S . Soft gray algae
T . Fleshy Alcyonarian
U . Gonolithon sp. Foslie
V . Porolithon sp. Foslie
X . Unidentified hard coral
Y . Anemone
(C). Dead coral
(r). Rock
(S). Sand

(3) Photo location and plate number

re 135. Species distribution chart, quadrat 8, Tumon Bay.

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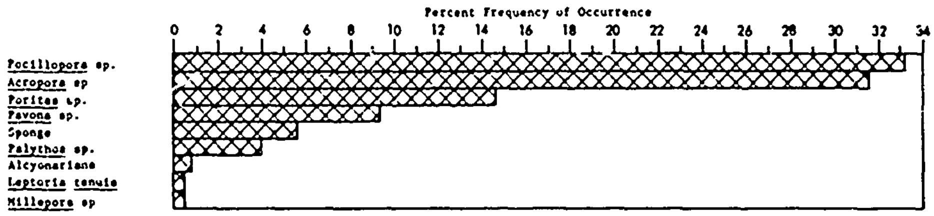

Figure 136. Frequency of occurrence of coral in quadrat 8, Tumon Bay.

Plate 27. Photo 34-2 in Quadrat 8, Tumon Bay - Small growths of Porites on rocks protruding from sand and rubble.

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Plate 28. Photo 34-18 in Quadrat 8, Tumon Bay - Large thickets of <u>Acropora</u> on sand-covered bottom. The sand also supports a community of green algae.

Plate 29. Photo 36-11 in Quadrat 8, Tumon Bay - A community of <u>Palythoa</u>, holothurian, and <u>Acropora</u>. <u>Porites</u> and <u>Pocillopora</u> are growing in the clumps of <u>Acropora</u>.

IV. CONCLUSIONS AND RECOMMENDATIONS

Bile Bay appears to be a relatively poor location for a sewer outfall. Sewage discharged into the bay will be caught by slowly eddying currents and will remain in coastal waters for long periods of time. The most favorable locations within this section would appear to be at Facpi Point and off the extreme southwestern end of Cocos Island. It is recommended that Mamatgun Point and Fouha Point be investigated as possible alternatives for an outfall in the Bile Bay area.

The current data collected in the Agat section give another example of the general unsuitability of bays and other semienclosed waters for sewage disposal. The slow eddying of surface waters within Agat Bay is in marked contrast to the stronger, more consistent flow off Facpi Point, Orote Peninsula, and Tantapalo Point. Sewage released at the Agat outfall pollutes a large area of Agat Bay. The outfall at Tantapalo Point appears to be in a more favorable location. Here, the prevailing currents tend to carry the effluent west along the rugged, unpopulated coast of Orote Peninsula where it is eventually dispersed by the strong currents off the tip of the peninsula.

The Agana outfall location has the advantage of proximity to the sewage producing areas and resulting lower cost in pipeline construction. However, this outfall places the effluent close to areas of high recreational use. Contributing to the eddying nature of the circulation in Agana Bay is the presence of a wide reef flat. After the outfall reaches design capacity (approximately six times the present flow) a reevaluation should be made of the suitability of Agana Bay as an outfall location, or sewage treatment should be upgraded to prevent contamination of recreational areas. The possibility of placing an outfall at Cabras Island to serve the entire central portion of Guam and to eventually replace the Agana outfall should be investigated.

North of the NCS Beach, a relatively wide reef flat is located between Amantes Point and Hilaan Point. Water is supplied to this shallow reef flat primarily by the action of waves carrying water across the reef margin. Wave action creates a longshore current which travels along the reef flat until a break in the reef is encountered. Sewage carried onto the reef flat would be likely to travel a considerable distance along the beach before being carried out to sea. Dye studies reveal that north of Oceanview currents are more likely to carry pollutants in the desired direction. The ideal location for an outfall appears to be Ague Point which is located at some distance from the broad reef flat south of Hilaan Point. Dye at this location consistently moved either northerly or directly out to sea.

Surface currents north of Ritidian Point flowed against the prevailing winds and opposite to the North Equatorial Current. Additional data covering longer periods of time will be necessary to resolve this apparent contradiction. Although the near-bottom currents are of interest, they have little application in sewage pollution problems due to the tendency of sewage effluent to rise rapidly to the surface.

Eight ecological quadrats have been installed in bay areas along the western coast of Guam. Species distribution charts of each quadrat and photographs of individual specimens have been made to monitor natural changes in the reef population and to detect changes caused by pollution. These quadrats should be monitored periodically to detect the effects of continued military and civilian construction on the island. Additionally, more ecological investigations should be made and quadrats installed to include the locations of proposed outfalls and future construction.

V. CONVERSION TABLES - METRIC AND ENGLISH UNITS

—VELOCITY CONVERSION—KNOTS TO METERS PER SECOND

Knots	0	1	2	3	4	5	6	7	8	9
00	00.0	00.5	01.0	01.5	02.1	02.6	03.1	03.6	04.1	04.6
10	05.2	05.7	06.2	06.7	07.2	07.7	08.2	08.8	09.3	09.8
20	10.3	10.8	11.3	11.8	12.4	12.9	13.4	13.9	14.4	14.9
30	15.4	16.0	16.5	17.0	17.5	18.0	18.5	19.1	19.6	20.1
40	20.6	21.1	21.6	22.1	22.7	23.2	23.7	24.2	24.7	25.2
50	25.7	26.3	26.8	27.3	27.8	28.3	28.8	29.3	29.9	30.4
60	30.9	31.4	31.9	32.4	33.0	33.5	34.0	34.5	35.0	35.5
70	36.0	36.6	37.1	37.6	38.1	38.6	39.1	39.6	40.2	40.7
80	41.2	41.7	42.2	42.7	43.2	43.8	44.3	44.8	45.3	45.9
90	46.3	46.9	47.4	47.9	48.4	48.9	49.4	49.9	50.5	51.0

—DISTANCE CONVERSION—NAUTICAL MILES TO KILOMETERS

Nautical miles	0	1	2	3	4	5	6	7	8	9
0	0.0	1.8	3.7	5.6	7.4	9.3	11.1	13.0	14.8	16.7
10	18.5	20.4	22.2	24.1	25.9	27.8	29.7	31.5	33.4	35.2
20	37.1	38.9	40.8	42.6	44.5	46.3	48.2	50.0	51.9	53.7
30	55.6	57.5	59.3	61.2	63.0	64.9	66.7	68.6	70.4	72.3
40	74.1	76.0	77.8	79.7	81.5	83.4	85.2	87.1	89.0	90.8
50	92.7	94.5	96.4	98.2	100.1	101.9	103.8	105.6	107.5	109.3
60	111.2	113.0	114.9	116.8	118.6	120.5	122.3	124.2	126.0	127.9
70	129.7	131.6	133.4	135.3	137.1	139.0	140.8	142.7	144.6	146.4
80	148.3	150.1	152.0	153.8	155.7	157.5	159.4	161.2	163.1	164.9
90	166.8	168.6	170.5	172.4	174.2	176.1	177.9	179.8	181.6	183.5

DEPTH CONVERSION—FEET TO METERS

Feet	0	1	2	3	4	5	6	7	8	9
0	0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7
10	3.0	3.4	3.7	4.0	4.3	4.6	4.9	5.2	5.5	5.8
20	6.1	6.4	6.7	7.0	7.3	7.6	7.9	8.2	8.5	8.8
30	9.1	9.4	9.8	10.1	10.4	10.7	11.0	11.3	11.6	11.9
40	12.2	12.5	12.8	13.1	13.4	13.7	14.0	14.3	14.6	14.9
50	15.2	15.5	15.8	16.1	16.5	16.8	17.1	17.4	17.7	18.0
60	18.3	18.6	18.9	19.2	19.5	19.8	20.1	20.4	20.7	21.0
70	21.3	21.6	21.9	22.3	22.6	22.9	23.2	23.5	23.8	24.1
80	24.4	24.7	25.0	25.3	25.6	25.9	26.2	26.5	26.8	27.1
90	27.4	27.7	28.0	28.3	28.7	29.0	29.3	29.6	29.9	30.2
100	30.5	30.8	31.1	31.4	31.7	32.0	32.3	32.6	32.9	33.2
110	33.5	33.8	34.1	34.4	34.7	35.1	35.4	35.7	36.0	36.3
120	36.6	36.9	37.2	37.5	37.8	38.1	38.4	38.7	39.0	39.3
130	39.6	39.9	40.2	40.5	40.8	41.1	41.5	41.8	42.1	42.4
140	42.7	43.0	43.3	43.6	43.9	44.2	44.5	44.8	45.1	45.4
150	45.7	46.0	46.3	46.6	46.9	47.2	47.5	47.9	48.2	48.5
160	48.8	49.1	49.4	49.7	50.0	50.3	50.6	50.9	51.2	51.5
170	51.8	52.1	52.4	52.7	53.0	53.3	53.6	53.9	54.3	54.6
180	54.9	55.2	55.5	55.8	56.1	56.4	56.7	57.0	57.3	57.6
190	57.9	58.2	58.5	58.8	59.1	59.4	59.7	60.0	60.4	60.7
200	61.0	61.3	61.6	61.9	62.2	62.5	62.8	63.1	63.4	63.7
210	64.0	64.3	64.6	64.9	65.2	65.5	65.8	66.1	66.4	66.8
220	67.1	67.4	67.7	68.0	68.3	68.6	68.9	69.2	69.5	69.8
230	70.1	70.4	70.7	71.0	71.3	71.6	71.9	72.2	72.5	72.8
240	73.2	73.5	73.8	74.1	74.4	74.7	75.0	75.3	75.6	75.9
250	76.2	76.5	76.8	77.1	77.4	77.7	78.0	78.3	78.6	78.9
260	79.2	79.6	79.9	80.2	80.5	80.8	81.1	81.4	81.7	82.0
270	82.3	82.6	82.9	83.2	83.5	83.8	84.1	84.4	84.7	85.0
280	85.3	85.6	86.0	86.3	86.6	86.9	87.2	87.5	87.8	88.1
290	88.4	88.7	89.0	89.3	89.6	89.9	90.2	90.5	90.8	91.1

Feet	00	10	20	30	40	50	60	70	80	90
300	91.4	94.5	97.5	100.6	103.6	106.7	109.7	112.8	115.8	118.9
400	121.9	125.0	128.0	131.1	134.1	137.2	140.2	143.3	146.3	149.4
500	152.4	155.4	158.5	161.5	164.6	167.6	170.7	173.7	176.8	179.8
600	182.9	185.9	189.0	192.0	195.1	198.1	201.2	204.2	207.3	210.3
700	213.4	216.4	219.5	222.5	225.6	228.6	231.6	234.7	237.7	240.8
800	243.8	246.9	249.9	253.0	256.0	259.1	262.1	265.2	268.2	271.3
900	274.3	277.4	280.4	283.5	286.5	289.6	292.6	295.7	298.7	301.8

Feet	000	100	200	300	400	500	600	700	800	900
1,000	305	335	366	396	427	457	488	518	549	579
2,000	610	640	671	701	732	762	792	823	853	884
3,000	914	945	975	1,006	1,036	1,067	1,097	1,128	1,158	1,189
4,000	1,219	1,250	1,280	1,311	1,341	1,372	1,402	1,433	1,463	1,494
5,000	1,524	1,554	1,585	1,615	1,646	1,676	1,707	1,737	1,768	1,798
6,000	1,829	1,859	1,890	1,920	1,951	1,981	2,012	2,042	2,073	2,103
7,000	2,134	2,164	2,195	2,225	2,256	2,286	2,316	2,347	2,377	2,408
8,000	2,438	2,469	2,499	2,530	2,560	2,591	2,621	2,652	2,682	2,713
9,000	2,743	2,774	2,804	2,835	2,865	2,896	2,926	2,957	2,987	3,018

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