CHAPTER IV

RESULTS

The results are separated into two sessions, the image analysis explains the remote sensing studies on coral reef ecosystem. Another session is data integration which reveals the combination of remotely sensed data and the checking of remotely sensed data with the ground truthing data.

4.1 Image Analysis

The image analysis results of Samui and its surrounding islands were separated into 3 processes; spectral band corresponded with the reef substrate, image enhancement, and reef and water movement classification. The ground truthing data was used for identifying and checking these results. Using plastic sheet as the ground control point it could be located by the high infrared reflectance value in that pixel which was different from other pixels. The transect lines were laid in four dimensions recording the substrate size and water depth. However, this method also depended on the sky condition with free of cloud. Two plastic sheets were laid in different time, only the point on 25 March 1989 could be detected. Another laid on 18 July 1989 had the cloud disturbing the data.

4.1.1 Spectral Band Corresponded with the Reef Substrate

By the new transect program (mTRAN) four sampling lines in the remotely sensed image were selected. These lines had to overlap with the ground survey line. The results are the reflectance from pixels along the line in different bands. Comparing the reflectance with the substrate area that correlations could be used to further explain the imageries. Based on these results, they can give an idea to use different reflectance bands for classifying the reef zone.

In the exposed area or terrestrial condition, such as shore line, the infrared spectral can give a good indication of the

location of different substrate zones. A sandy beach and rocky shore reflect the different values which can easy be separated from each other. A comparison with a ground survey of the shore revealed that the high values of infrared band corresponded with fine sandy area while the coarse sand had the lower value. Although an infrared spectral can get through the water for only 20-30 centimeters in depth, the shallow reef flat can give the different reflectance values depending on the main substrate in that area. The results suggest that an infrared band can be selected to separate the high vegetation biomass in a wide area from other reef flat zones. However in the low dense zone the infrared values are low and closely similar to the surrounding sandy area, so the image representation only in infrared band can highlight the seagrass in patches.

Although the reflectance values of TM band 1 highly correlate to the depth, the shallow reef flat has a small depth range. The result from band 1 gives the low effective for separating the depth zone. The high intensity reflected from the substrate especially sand may be disturbed the received data. The results suggest that band 1 is not suitable to class the depth and substrate zones. However, in the areas such as the sand patch at Tae Nai Island, the reef profile is flat. The reflectance values from band 1 show the higher values in a shallow sand patch and lower in the reef flat area. Band 1 can be used for separating the reef profile only in the steeply area such as reef flat and reef slope.

According to the isolated seagrass bed, Nai Wog Bay is the ideal study site for this study. The result from mTRAN demonstrates that it is possible to separate the seagrass bed from other substrates (Figure 18). The reflectance values from band 1 show the lowest value on the seagrass bed among the reef flat substrate. The value from Band 2 and band 3 are also lower than other substrates. These results suggest that seagrass reflects the light similar to the land vegetation. Compared with a ground data, the result suggests that in the inner reef flat area the high reflectance values may come from a sandy substrate. While the outer reef flat consist of the dead coral reflecting light more than the seagrass. Comparing with these two bands, the values in band 2 show the similar value in the seagrass area while the values in band 3 are different. The result suggested that band 3 is an ideal band for classifying the seagrass beds in its component.

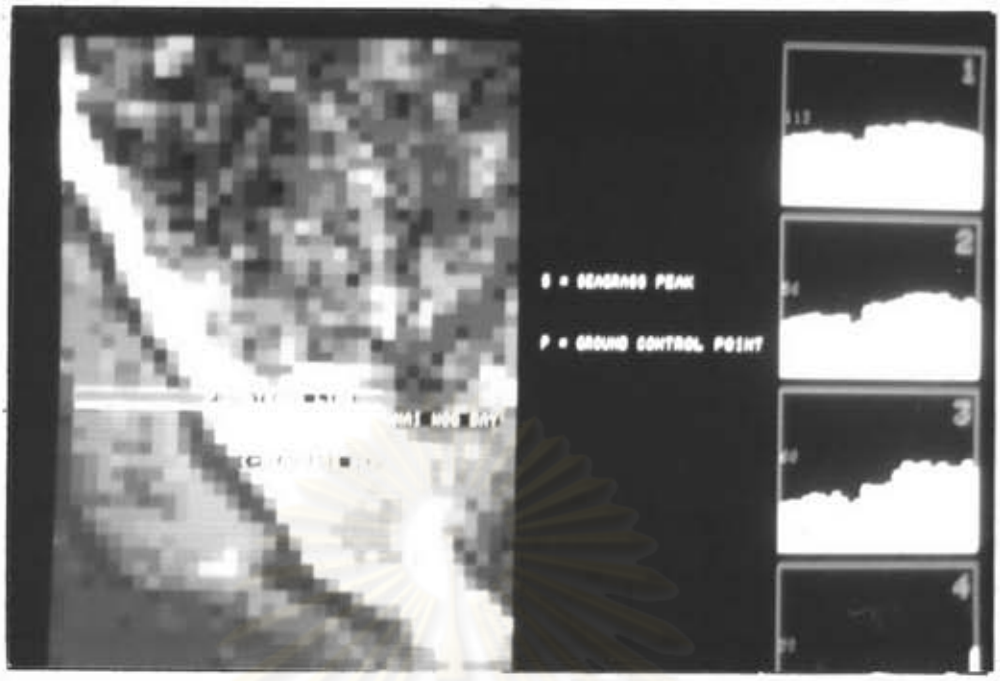


Figure 18. The mTRAN Line of Nai Wog Bay and The Reflectance Graph in Landsat TM Band 1,2 and 3.

From the reflectance values in infrared band, the seagrass pixels have higher values than other areas except the area with the white sandy substrate in the inner reef flat. The reflectance values show in three peaks are based on the ground data. The first peak is the seagrass while the other peaks are the algae on the dead coral.

The macro brown algae, Sargassum, at Tae Nai Island has the same feature as the seagrass at Nai Wog Bay. The ground survey using photograph cannot separate the algae area from seagrass bed. The reflectance values from both substrates have been observed, the result proves that seagrass bed can be separated from the macroalgae by the lower reflectance values in band 1, 2 and 3.

In Mat Lang Island the values in band 3 and 4 rise up at the submerged reef edge. The results suggest that the reflectance values in band 3 vary in the zone of the dead coral area, so this band can be used to identify the dead coral density. The reflectance value from band 4 also suggests that the submerged reef edge reflect light more strongly than the submerged sandy area.

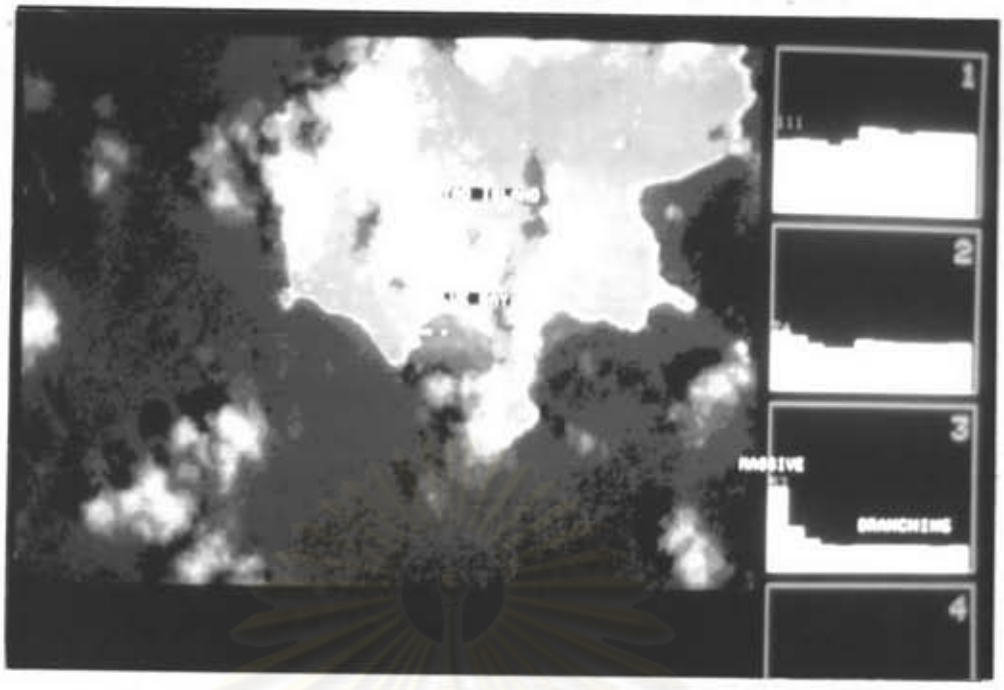


Figure 19. The Spectral Band 3 Corresponded with The Massive and Branching Corals at Luk Bay, Tao Island.

The results from this sessions recommend that studying of spectral band corresponded with the reef substrate using mTRAN program can give us the ideal data to select the band in post-studying.

4.1.2 Image Enhancement

4.1.2.1 Histogram Enhancement

The results in this session are the colour composite imagery of the islands. The true colour image (band 1, 2 and 3) is identified as being suitable for reef covered with water. However, the problems are land which may be hardly separated from water, cloud shadow and the reef flat area that all display in the same colour. In some areas the image displays the blue-hole close to the reef. This blue-hole is very difficult to be separated from reef slope because of similar colour. Kuchler et al. (1986) advised that blue-hole is the deeper area which is different than the others. To solve that problem, the false colour image is selected from the results of spectral band corresponding with the reef substrate (Figure 20). The false colour image is displayed in band 1, 2, 4 which clarify land and reef area.

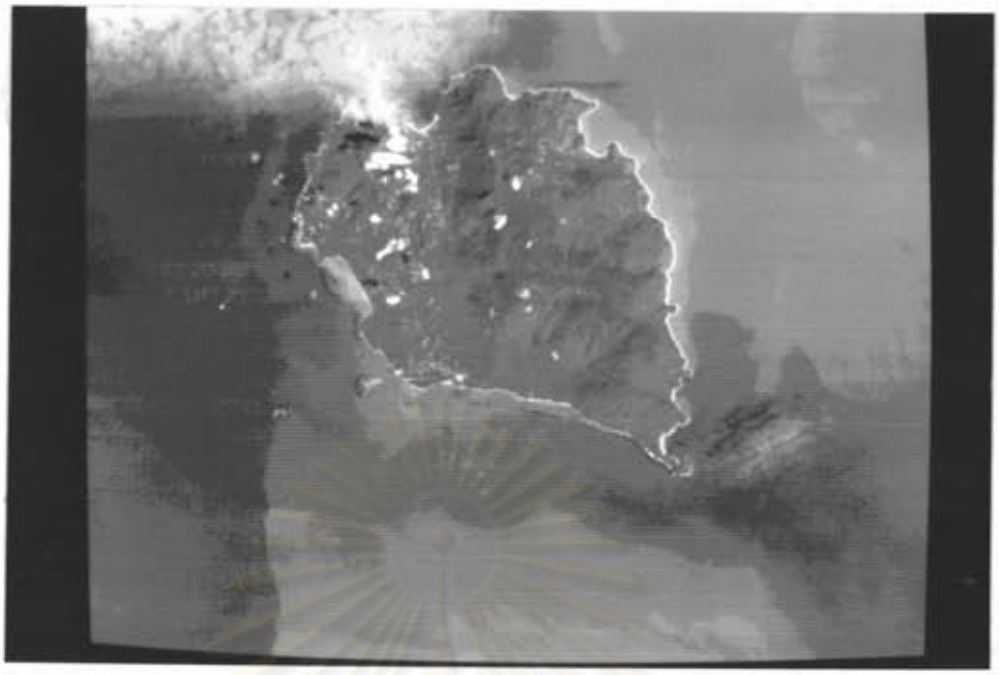


Figure 20. The False Colour Image of Pha-ngan Island Display in Band 1, 2 and 4.

The false colour composite displaying band 1, 4 and 3 as blue green and red colour can show the reef area in purple which is the different shade in reef flat. Land can be observed by the bright green colour while the cloud shadow is in black. The blue-hole can be easy to detect with the dark blue colour while reef slope has light blue. The problem of this colour composite is that the shallow water area and the high sediment water mass have the same purple color as the reef. However, the patterns of those areas are different from the reef. Based on the reef knowledge, the area can be separated from the others. Although these colour composite images give the ideal data for whole reef imagery, some important zone, such as seagrass, can still be hardly observed in the image.

4.1.2.2 Band Ratio

The band ratio is used to modify the reef image. The results from band 1, 2 and 2/5 display Nai Wog reef which can be clearly separated in three parts, inner reef flat, seagrass bed and outer reef flat (Figure 21). The divided band gives high reflectance values in shallow and exposed seagrass bed on the reef flat. While band 1 gives the high values in the reef flat area which quickly

drop in the seagrass bed. The land and sea can be separated in band 2 which display the land area in green colour.

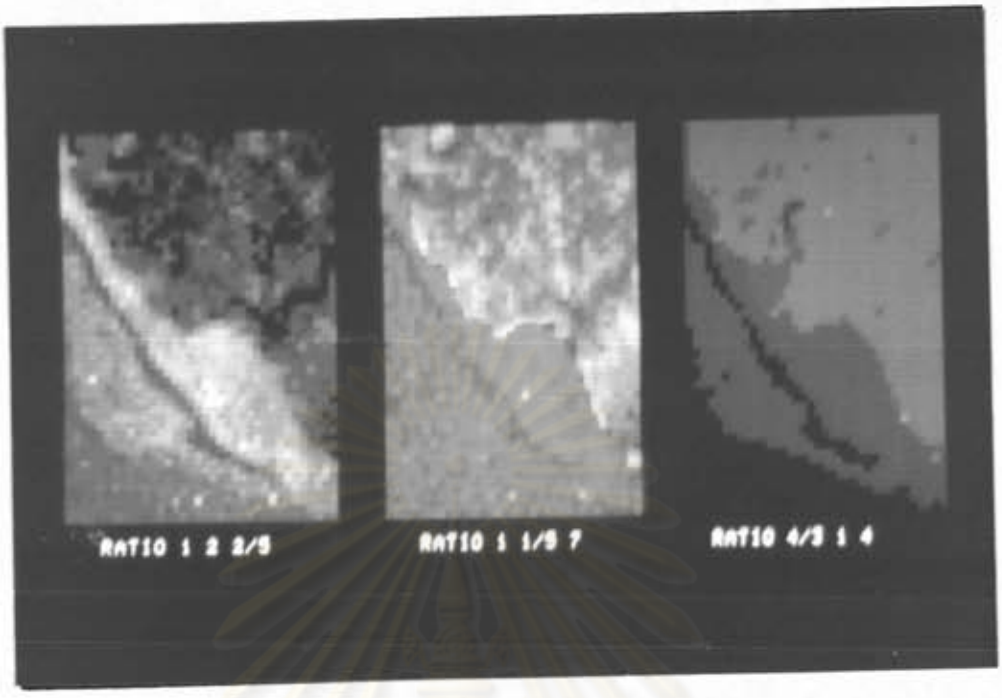


Figure 21. The Band Ratio Results of Nai Wog Bay Show Different Image Highlight on The Seagrass Bed.

Although the 1, 2, 2/5 band ratio image suits the whole reef area, the seagrass bed is still needed to be detected in this ratio. The ratio image result using band 4/3, 1 and 4 is displayed to locate the seagrass bed (Figure 21). The result shows the land area in red brown colour with high values in band 4/3 and 4. The water is cut out in band 1 and the seagrass bed is displayed in black pixels. This image uses the low reflectance value of band 1 to highlight the seagrass bed area while band 4/3 helps to make the other area brighter than the seagrass bed.

4.1.2.3 Principle Component Analysis

In the mixed reef area, which has two reef substrate components distributed together, the band ratio may help in identifying the reef substrate, but it may not be able to give the classification. In this case the principle component analysis (PCA) is used for giving the easier data for the reef component classification. The study site at Nai Wog Bay which has the big seagrass bed is used as the example. The reef classification which was done emphasized on the seagrass bed in the reef flat area,

however, the thematic reef image could not give the clear seagrass zone. The band ratio was used but the result still had the mixing class of seagrass and dead coral with algae. The new technique was developed by using the principle component analysis to show the reef area, then the values are observed in the histogram (Figure 22).

Figure 22. The PCA Image Result in Band 1, 2 and 3

The PCA image displays in percent canopy band 1, 2 and 3, and it has the clear seagrass area with other separated component zones (Figure 22). This result is better than other unclassified results. However, this image cannot separate the macroalgae in the outer reef flat. The PCA in band 1 gives the low values in seagrass pixels but high values in macroalgae zone, so this band is displayed in reverse value (0, -1, 0) the result now shows the green pixels in the seagrass area. The seagrass area can be selected easily and classification is focused on the different seagrass density.

4.1.2.4 Multi Combined Image

Although the image enhancement technique which was described earlier is good for highlighting the reef with seagrass bed, in the other zones, such as land area, the image may not be displayed clearly. The multi combined imagery results which would produce products to show better of the whole reef and its surrounding areas

better. The land area, reef area and water movement had already been divided from the others. Enhancing the land image with band 4 and 5 gave the clear vegetation and urban development area. The water mass was enhanced by band 3 and produces smoothly image by mSMOOO. The reef area was enhanced by histogram enhancement or band ratio or principle component analysis. The final product of image enhancement was the whole image which each area enhanced by the most suitable band value and combined for the end product together. The result is fit for any useful data for studying the reef ecosystem.

4.1.3 Reef and Water Mass Classification

4.1.3.1 SPOT Data Analysis

Although the landsat image enhancement gives the ideal results to study the reef area covered with water, the SPOT XS imagery data with its high resolution (20 meters) can display the detail in some small reefs. Based on three spectral bands, the image displays in false colour map band 1, 2 and 3. The SPOT imagery data at Tao and Phaluai Islands was tested (Figure 23), the result demonstrated that the high resolution data gives more detail in the shore and reef flat. However, small detail can be received from the reef slope because the spectral are absorbed by water.

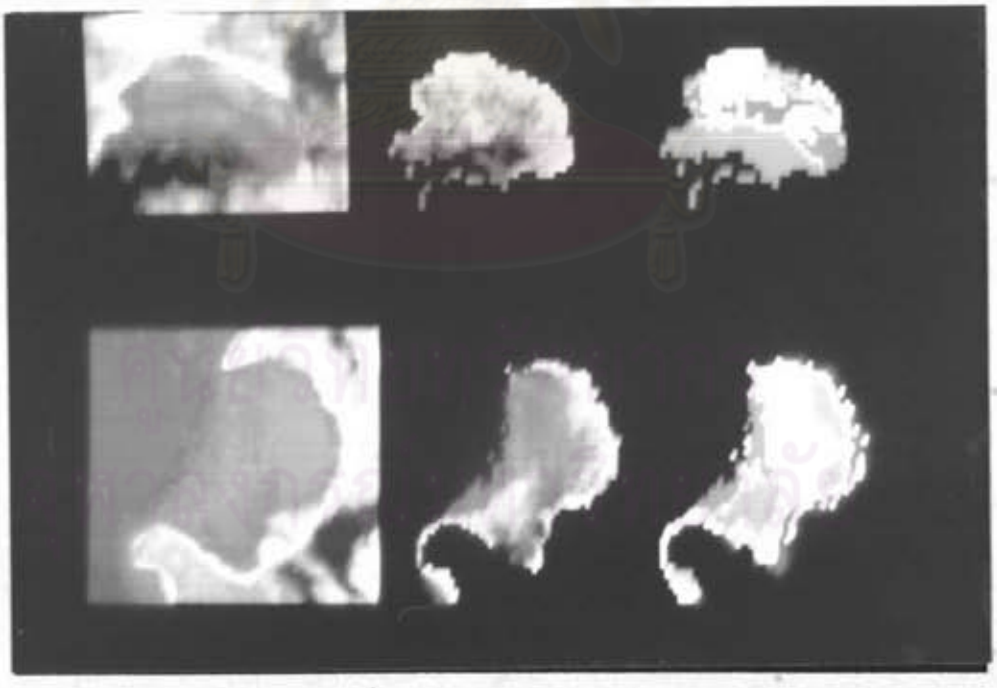


Figure 23. The SPOT XS Imagery Data Analysis of Tao Island (Above) and Phaluai Island (Below).

4.1.3.2 Landsat Data Analysis

Samui and its surrounding islands imagery acquired on 28 October 1988 is the ideal for coral reef classification because the satellite image was at low tide (0.5 meters above chart datum). However, this image did not cover Ban Don Delta so the water movement pattern may be discontinuous. The second image acquired on 17 march 1989 covers Ban Don Delta (Figure 24), however, this image was taken in the high tide (1.7 meters above chart datum) so the remotely sensed data of coral reef had a large effect from the water depth. Although those two images have some problems, from 1985 - 1990 only these images could be considered as the best for studying in term of being free of clouds and suitable for the sediment zone effecting the reef.

To solve this problem, the results in this session are separated in two parts, the reef thematic image and the sediment density slicing. The image acquired on 28 October 1988 was selected and processed for the reef thematic image while the Landsat TM image acquired on 17 March 1989 was processed for sediment density slicing. After all, the results were combined for explaining the reef and the sediment effects on the reef.

i Reef Thematic Image

For the reef thematic map at Samui and its surrounding island, the processing results were 163 small classes. These were grouped to 14 classes which should not have less than 70 percent of dissimilar to each other. Ground data revealed that some groups could be gathered because the substrate components were not so interesting to separate them, and the less number of group would be easier to reach conclusion. The end products were the thematic maps of reefs along Samui and its surrounding islands which had 11 classes. Some classes had the percent of dissimilarity less than 70 percent. The problem of these thematic maps was the shadow of cloud cover in some reef area. This shadow disturbed the reflectance data and caused error in classification process especially in the middle part of Bang Kao Bay, the reef at Thong Krut Bay and the reef in front of Na Thon Beach.

Along Samui reefs, sand and coral rubble are the dominant components in the reef flat area. Using ground truthing, the

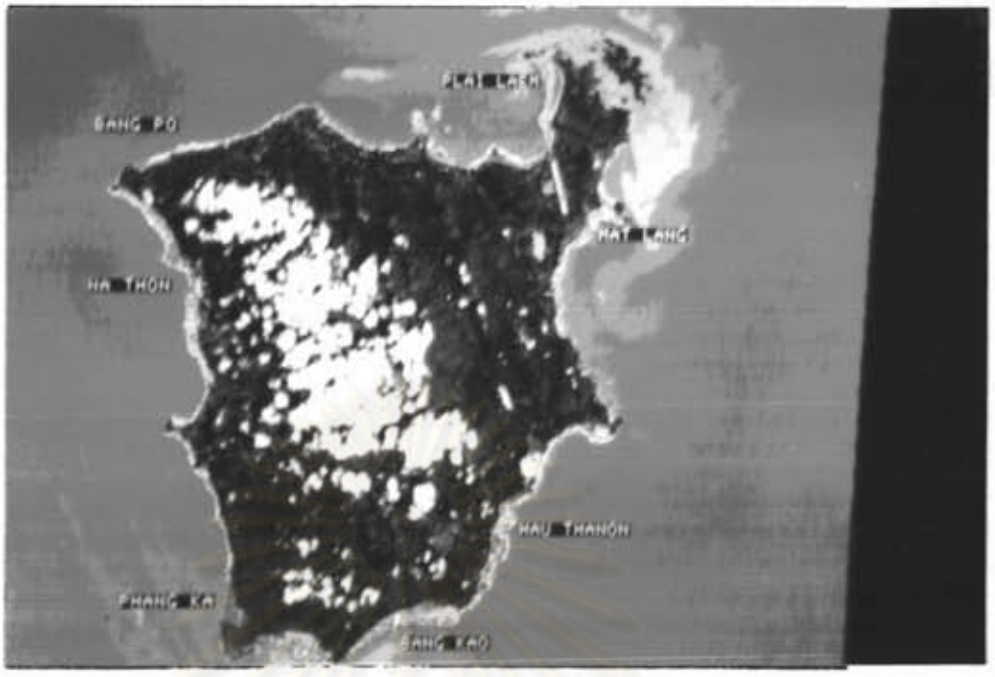


Figure 24. The Reef Thematic Image of Samui Island.

Figure 25. Coarse Sand Area at Plai Laem Cape.

dominant substrates are identified as coarse sand (light blue) and coral rubble (pink). The coarse sand is the sand composed of some scattered shells, in some areas turf and other small algae can be found on this substrate but in low density (Figure 25). This class is produced by combining three small classes at 72 percent of dissimilar to other classes, and Chi-square is 4.1 which is the highest in this processing. Although this class varies in its reflectance values, the components are different only in the algae and the sand component density.

The coral rubble areas are identified as the sandy zone which has many small coral rubble covered with some sediment and turf algae. Comparing with the coarse sand group, the percent of dissimilarity between the coarse sand and coral rubble is 81 percent. The Chi-square in this class is 1.71 so this group has the unique component. The dominant reef component demonstrates that reef flat in Samui Island can be separated into four types. The first type has the coral rubble as the dominant reef flat component. These reefs can be found at the northern reef of Na Thon Beach and Phang Ka Bay (Figure 26).

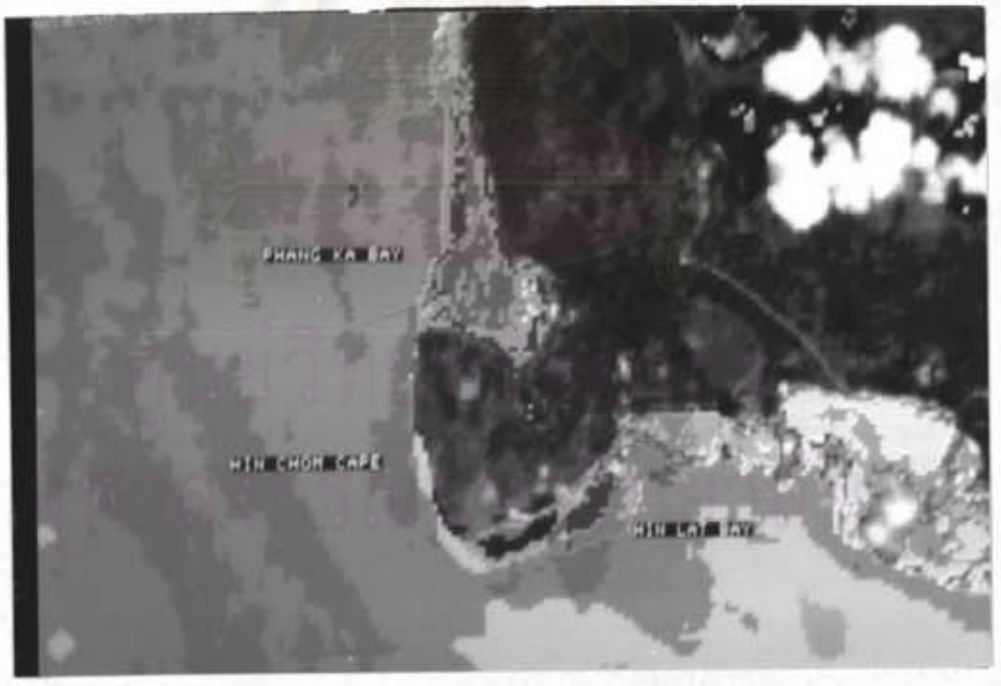


Figure 26. The Reef Thematic Image of Phang Ka Bay Clearly Display The Coral Rubble (Pink) as The Dominant Component in The Reef Flat.

The second reef type has the coarse sand as the dominant reef flat component, the reef slope is very narrow and rapidly drops to the sea floor. This reef pattern can be found in the southern part of Na Thon Beach, on the east site of Tan Island and the northern reef of Rapp Island (Figure 27).

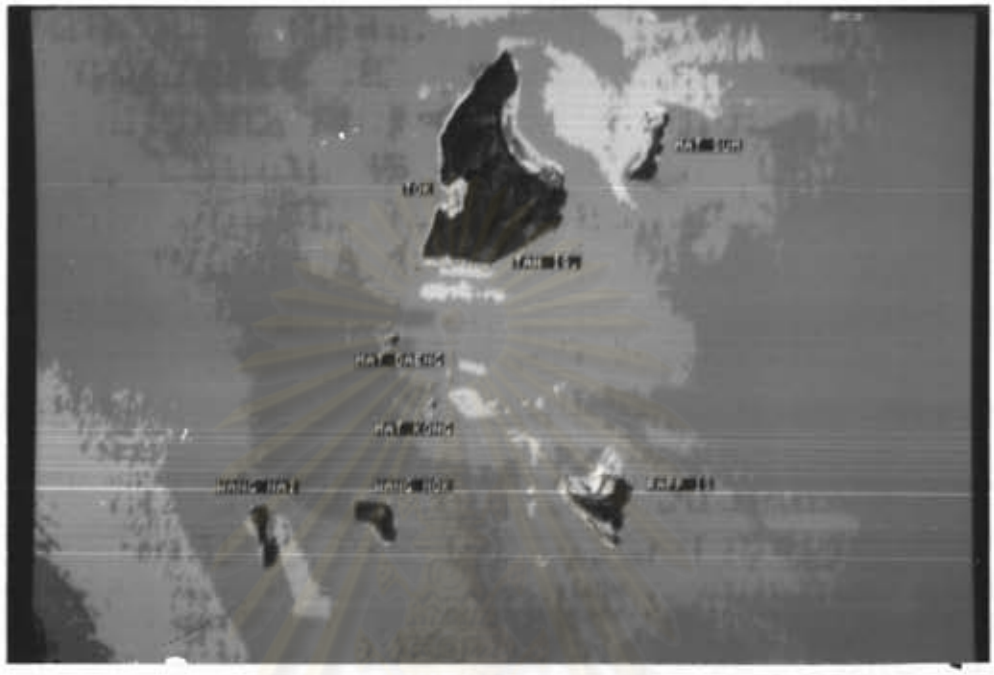


Figure 27. The Reef Thematic Image of Tan Islands, Grey Pixels Cover All Reef Flat Area at Rapp Island.

The third type has the coral rubble and coarse sand mixed together on the reef flat. However, the area is separated from each other. Usually the reef flat has the coarse sand spitted into two areas, close to the beach and near the outer reef flat, with the coral rubble being located in the middle. This reef type is located on Yai Cape, Chon Khram Cape, Plai Laem Bay, Bang Kao Bay, the northern part of Mat Sum Island and the southern part of Rapp Island (Figure 28).

On the other hand, the reef which has the coral rubble in the outer reef flat area can be found in some parts of Samui reefs. The reefs at Thong Krut and Tok Bay, Tan Island clearly show this pattern (Figure 29). In the southern part of Samui, the reefs have indefinite pattern with coarse sand and coral rubber stay in few small groups on the reef flat. This indefinite pattern is the

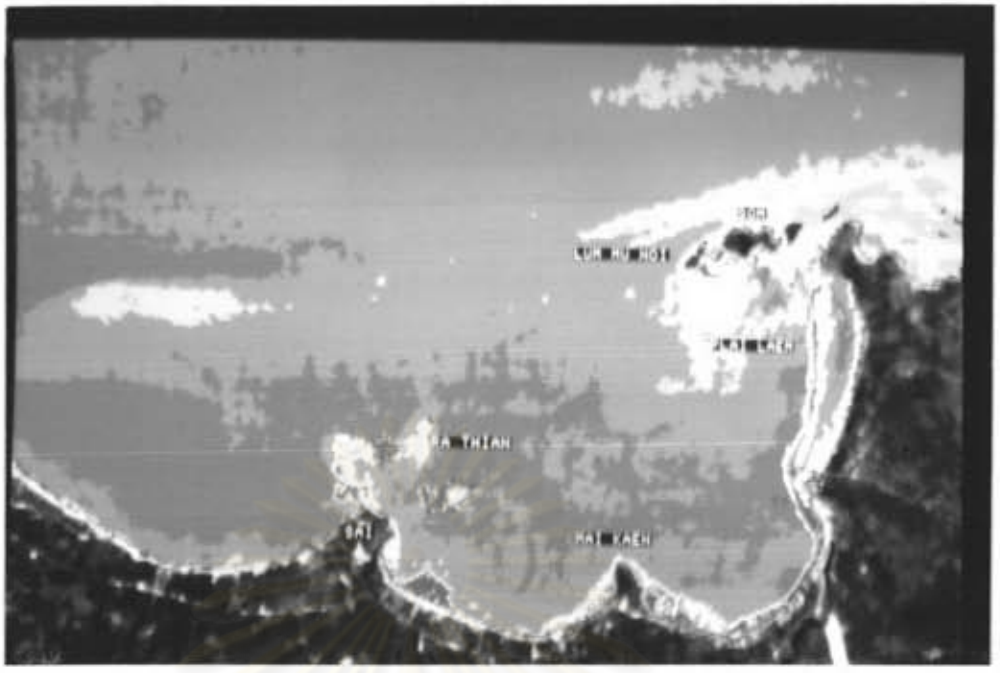


Figure 28. The Reef Thematic Image of Plai Laem Cape Displays The Coral Rubble as Pink on The Middle Part of The Reef.

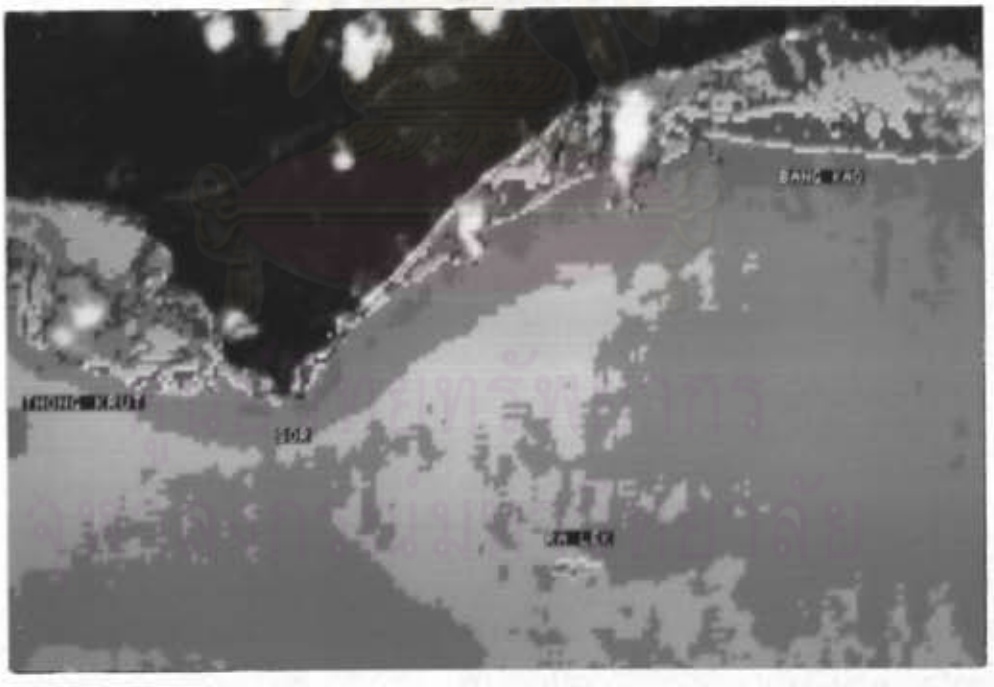


Figure 29. The Reef Thematic Image of Bang Kao and Thong Krut Cape Shows The Predominant Component on The Reef Flat.

predominant reef flat component, so the reef flat zone can not be clearly located. The reefs from Mat Lang Island to Sor Cape belong to this pattern.

The last type is the reef without reef flat, from the shoreline reefs have the narrow indefinite pattern before the reef edge and reef slope area. This reef type will be explained in the coral area classification.

There are other seven components which can be found in the reef flat area, composed of fine sand (blue), bare sand (dark blue), pack of dead coral (grey), group of dead coral (purple), seagrass (light green) and macro algae (dark green).

The fine sand is not commonly found as the coarse sand. Only in some protected areas this substrate can be observed. This class is unique, isolated from the others, the percent of dissimilarity is 87 percent which is the highest. Chi-square is 1.02 which is low compared with other classes except the pack of dead coral. The Chi-square may be higher than the real value because of the error from cloud shadow which cannot be cut out from this class. These blue pixels were observed around the clouds over the reefs at Thong Krut and Bang Kao Bay. The exactly fine sand site is located at Phang Ka Bay, Mat lang Island and the area between the beach and inner reef flat of the large size reefs. The ground truthing suggests that this area is the white fine sand without other components. Usually they are formed in small patches isolated from other areas nearby.

The bare sand is very similar to coarse sand with 77 percent of dissimilarity. This area has sand as the dominant substrate, the bare sand does not have any organisms or sediment cover on its surface. Usually this area can be found close to the shore or in the lagoon. The ground truthing was done in Mat Lang middle reef lagoon and it suggested that this sand were cleaned by the tidal current which runs pass this area. The water move through the small rocky channel smoothly so the bottom sediments do not blow up and cover the sandy area.

The pack of dead corals can be found only on the middle part of reef flat at Yai Cape. In this area, dead corals are packed in pile, it is the dead coral patches. The results show that the reflectance values in this area have 80 percent of dissimilarity to

other classes, and the Chi-square in this group is 0.88 which is the lowest in all classes. The result suggests that the substrate in this group is very similar to each other and they are isolated from other classes.

The dead coral areas are located on the reef flat area, usually found in the middle part of coral rubble zone. In some reefs such as Phang Ka Bay, the dead coral area is on the outer reef flat. Ground data suggested that this area was composed of massive dead coral and coral rubble grouped together but did not pack together. These dead corals are covered with thick sediment, and reef organisms are not found in this area. The reflectance values are closed to the coral rubble, with 85 percent of dissimilarity. The Chi-square in this group is 1.57 which is not so high. This class can be separated easily from other classes along the process.

The reflectance values of seagrass and macroalgae live on the dead corals can be hardly separated from each other. The first processing results shows that there is only 61 percent of dissimilarity between seagrass and macroalgae which hardly separate the seagrass and macroalgae. The second process was run with more ground truthing data emphasizing on this group, the result reveals that they can be classed at 68 percent of dissimilarity. However, in the areas which have the small seagrass patches, the process is classed as the macro algae class. Based on this result, the seagrass bed is found only in the reef flat close to Mat Lang Island. Enhalus acoroides is a tall seagrass live on the coarse sandy substrate. The ground truthing reveals that there are other seagrass patches in the other areas which cannot be grouped in this class. The process was re-run again but this time the seagrass and macro algae were selected from other components using the theme from the first process, then the training area in seagrass and macro algae were selected and processed.

The result can separate the seagrass patches from macro algae at 76 percent of dissimilarity. However, the area which has low density of seagrass and macro algae is hardly be separated from the area which has the low density of pure seagrass. The processing result combined these areas together and grouped them in the seagrass group. The result suggests that the TM remotely sensed data has not enough resolution to identify the seagrass by its density especially in the mixing area as Mat Lang Island.

To search further in this hypothesis, the seagrass bed at Nai Wog (Figure 30) Bay which is the biggest bed in Samui Islands was selected. Comparing with the seagrass at Mat Lang, Nai Wog bed is bigger and formed in a wide band parallel to the shore. The patch of seagrass does not distribute in this area, the imagery data is disturbed by the patch of macroalgae live on the dead coral head in the outer reef flat area. The principle component analysis is used for digitizing other areas out of the image (the process describe in session 4.1.2.3) then the classification is precessed. The results demonstrate that the high dense of seagrass area can be separated from the low dense area and the seagrass bed distributes in the middle reef flat area between the sandy inner reef flat and the dead and living coral in the outer reef flat. Results on seagrass classes demonstrates that the seagrass on a reef flat can be classified by remotely sensed data (Figure 31). However, the process may carefully select a seagrass area from other components. One thing should be recommended from the result is the seasonal changing of the seagrass. So the ground truthing and the satellite image time should be close to each other.

These coral classes are separated from others reef component at 75 percent of dissimilarity. Based on the ground data, seven coral classes are reclassified into three classes. The dead and living coral class (red colour) is separated at 68 percent dissimilarity. While the coral and rock class (dark yellow) is separated from living coral class (yellow) at 51 percent dissimilarity. The reason why the rock and living coral are more closely similar than the living coral and dead coral may come from the coralline algae which look similar to the coral and usually grow on the rock more than dead coral. However, this hypothesis should be further searched.

The dead and living coral area are located in front of the outer reef flat around Samui Islands. The ground truthing revealed that the area composed of massive dead coral and the small living coral are usually Porites lutea. This area has the small lagoon with the sandy substrate between those corals and there are some marine organisms in this area. Sponge and algae are the common organisms. The benthic life form method done in this area for two lines demonstrates that the percent coverage of living coral in this area is less than 30 percent. The ground survey recorded the height of dead and living coral for 25 heads, the height average was 31.42

Figure 30. The Overall Reef Photographed at Nai Wog Bay.

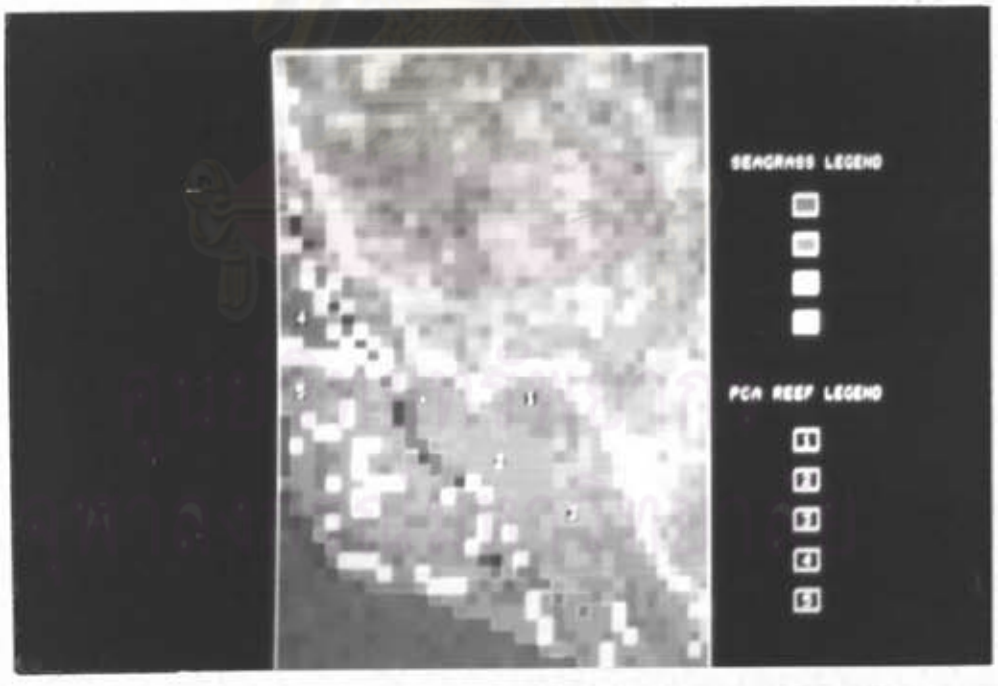


Figure 31. The Reef Thematic Image of Nai Wog Bay Shows Four Seagrass Zones and Four Other Components Zones.

centimeters. The processing image was recorded at the depth at 0.43 meters (calculate with the chart-datum already) so this area was submerged when the satellite was passed. The shallow water may affect the reflectance values of infrared band but the values in band 1, 2 and 3 is low disturbance, so the classification process which emphasizes on these three bands is correct.

The coral and rock zone is the area which is close to the cliff shore. It usually does not form the reef flat. The result reveals that this area locates at the east end of Bang Po Reef. In this area the massive coral is distributed along a big rock. The life form found by benthic area indicates that massive coral is the dominant coral in this area while the encrusting coral can be found in this area. A ground data records that these coral and rock were submerged when the satellite passed. The average depth was 1.67 meters below that sea level.

The yellow band of living coral zone was observed in the reef edge and reef slope. The imagery result most reefs in Samui Islands have the yellow band connecting with the water. A ground data reveals that this area is composed of high density of living corals which are the mixing coral zone. The massive coral, Porites lutea, and the branching coral, Acropora spp., are the predominant corals along Samui Reefs. This variety of coral types make the classification process unable to separate the unique coral type area.

ii Reef Area Measurement

The results from thematic reef map also consisted of area measurements which is calculated the overall reef area and the living coral area. In Mat Lang Island the seagrass area was measured but in Nai Wog Bay the seagrass could not be calculated because the area of this bed was distributed in a band and patch from Wog Tom to Yow Beach and the ground truthing did not observe enough to calculate this area. Based on the ground data the living coral area is the area which has the living coral more than 30 percent coverage. The overall reef area is calculated from the beach to the reef slope. In Pha-ngan and Angthong Islands the only overall reef areas were calculated because the thematic reef map in this area was done for the reef area, it did not run for the living coral coverage. The data are presented in Table 3 to Table 7.

Location	Reef Feature (Square Meter) (Rai)	Overall (Square Meter) (Rai)	Reef Region
Yai	Lc:232,200 145.13	1,485,900 928.69	B-2
Chon Krum	Lc:256,500 160.31	672,300 420.19	B-2
Hin Khom	Lc:244,800 153.00	836,100 522.56	B-2
Tong Tanod	Lc:432,900 270.56	1,322,340 826.46	C-2
Na Tian	Lc:317,700 198.56	1,527,490 954.68	B-4
Hau Thanon	Lc:367,200 229.50	1,393,200 870.75	B-4
Nan	Lc:109,800 68.63	543,600 339.75	B-3
Mat Lang	Lc:289,800 181.13 Sg:44,100 27.56	818,100 511.31	B-4
Fan	Lc:40,500 25.31	89,100 55.69	C-1
Plai Laem	Lc:129,600 81.00	975,600 609.75	C-2
Som	Lc:36,900 23.06	149,400 93.38	C-2
Mai Kaen	Lc:204,300 127.69	388,800 243.00	B-2
Sai	Lc:207,900 129.94	370,800 231.75	B-2
Bang Po	Lc:866,700 541.69	950,363 593.98	B-1
Total	**Lc:3,736,800** 2,335.50	11,523,093 7,201.93	

Remark: Lc: Living Coral Area
Sg: Seagrass Area

Table 3. The Area Measurement of Samui Islands and The Reef Region.

Location	Overall Reef Area (Square Meter) (Rai)	Reef Region
Ta Pan Noi	39,600 24.75	C-1
Chalok Lam	186,300 116.44	B-1
Mae Hat	40,500 25.31	B-1
Hat Lat	120,600 75.38	B-2
Hat Yao	189,900 118.69	B-2
Nai Wok	1,475,100 921.94	B-2
Talat Mai	1,555,200 972.00	B-2
Tae Nai	107,100 66.94	B-4
Tae Nok	36,000 22.50	B-2
Total	3,750,300 2,343.94	

Table 4. The Area Measurement of Pha-ngan Islands and The Reef Region.

Location	Overall Reef Area (Square Meter) (Rai)	Reef Region
Tai Plau	50,400 31.50	A-1
Hin Dup	56,700 35.44	B-2
Mae Ko	68,400 42.75	B-2
Wau Ta Lup	170,100 106.31	B-2
Pha-Luai	922,500 576.56	C-2
Total	1,268,100 792.56	

Table 5. The Area Measurement of Angthong Islands and The Reef Region.

Location	Reef Feature (Square Meter) (Rai)	Overall (Square Meter) (Rai)	Reef Region
Luk	110,700 69.19	134,000 83.75	A-1
Sai Lee (N)	50,400 31.5	85,900 53.69	A-2
Sai Lee (S)	108,900 68.1	128,700 80.44	A-1
Nang Yuan	48,600 30.38	63,000 39.38	A-2
Total	318,600 199.13	411,600 257.25	

Table 6. The Area Measurement of Tao Islands and The Reef Region.

Location	Living Coral (Square Meter) (Rai)	Overall (Square Meter) (Rai)	Reef Region
East Tan	132,300 82.69	546,300 341.44	B-2
South Tan	65,700 41.06	99,900 62.44	B-1
West Tan	178,200 111.38	400,500 250.31	B-2
Hin Ang Wang	50,400 31.50	60,300 37.69	B-4
Hin Mat Kong	37,800 23.63	39,600 24.75	B-2
Wang Nai	900 1800	6,300 3.94	C-1
Wang Nok	135,000 84.38	157,500 98.44	C-1
Rapp	75,600 47.25	471,600 294.75	B-3
Mat Sum	33,300 20.81	205,200 128.25	C-2
Total	708,300 442.69	1,987,200 1,242.00	

Table 7. The Area Measurement of Tan Islands and The Reef Region.

iii Sediment Density Slicing

The TM imagery acquired on 17 March 1989 was processed to show the water pattern in Ban Don Bay. Based on the continuity of the water mass the classification could not be used. The sediment density was processed by cutting the reflectance values in band 3 into 7 classes and identified from turbid to clear water area.

The colours representing the water areas were dark brown to dark blue. The result demonstrates that the big load of sediment in Ban Don Bay came from two major sources, Tapi-Phum Daung river and long shore drift along the coastal area of Khanom and Don Suk. The high turbidity areas in the image were located on Tapi-Phum Daung delta, the area between Don Suk to Nok Taphoa Island and the coastal zone of Khanom. The high sediment in Tapi-Phum Daung comes from the sediment along the river while the sediment at Khanom comes from the long shore drift from two water current from Tapi and Khanom meeting each other. This area may has the highly turbid water from the Don Suk canal, however this is only the recommendation.

The shallow and exposed areas might disturb the result, so the process was corrected by infrared band to find out the exposed areas. The result shows the expose areas near Sui Cape. For the shallow water area, the error was corrected by checking the result with the navigation map in 1983. Based on the ground truthing the depth penetration of band 3 in the turbid water was approximate 0.74 meters. This result was done at two points in front of Tapi-Phum Daung delta on 21 March 1989, four days after the satellite data so they might have a little bite error. The result suggests that only the sea floor close to Tapi-Phum Daung delta which is shallower than 0.5 meters effects the band 3 reflectance values.

The water pattern in Ban Don Bay clearly displayed two water channels. Pha-ngan channel locate between Samui and Pha-ngan Islands, the clear water mass come from the inner bay through this channel and ran out to the open sea. The source of this water mass might come from Tapi-Phum Daung River through Samui channel. There is the small channel call Tan channel which is located between Samui and Tan Islands (Figure 32). Although the bottom of this channel is very deep, the imagery result showed that the water mass is very turbid.

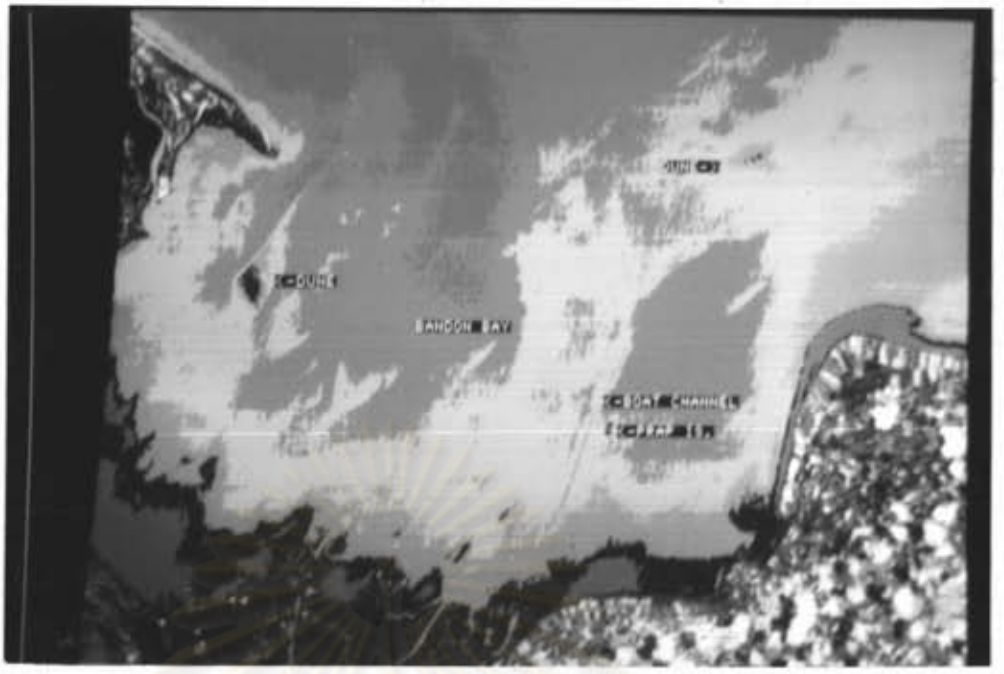


Figure 32. The Sediment Density Slicing of Ban Don Bay Display Some Mud Dunes near Sui Cape.

From the imagery result, four turbid water areas were located close to the shore and only the reefs around Phaluai and Wang Nai Islands are in this area. The result from over all reef thematic map suggests that from Ban Don Delta, Phaluai Island is the first reef location, while Wang Nai Island which is the nearest island close to the mainland shore has the small reef. The small islands near Don Suk such as Nok Taphoa, Chuak and Som do not have any reef.

Samui and its surrounding islands are located on the clear water area. However, the image displays three turbid areas at Tan Islands, the northeastern part of Samui and the northeastern part of Pha-ngan. The result from over all reef thematic map suggests that there are the big reefs at the first two sites while the northeastern part of Pha-ngan does not have a reef. The high sediment at Tan Islands may come from the long shore drift along Khanom coastline meeting the islands and the southern part of Samui. The high sediment and the northeastern part of Samui may come from the interaction between the currents along the eastern part of Samui and the current along Pha-ngan channel (Figure 33). This interaction blows up the bottom sediment at Plai Laem Bay which has the shallow sea floor (3.8 meters). The aerial survey gives a good response with this conclusion of patch of high sediment in this

area. The high sediment at the northeastern part of Pha-ngan may come from the high water action from the wave in the open sea. However, this result is only explained by the image, more ground truthing data are required to support this hypothesis. The ground data from seschi disk recorded from many sites during the field trip are shown in Figure 34.

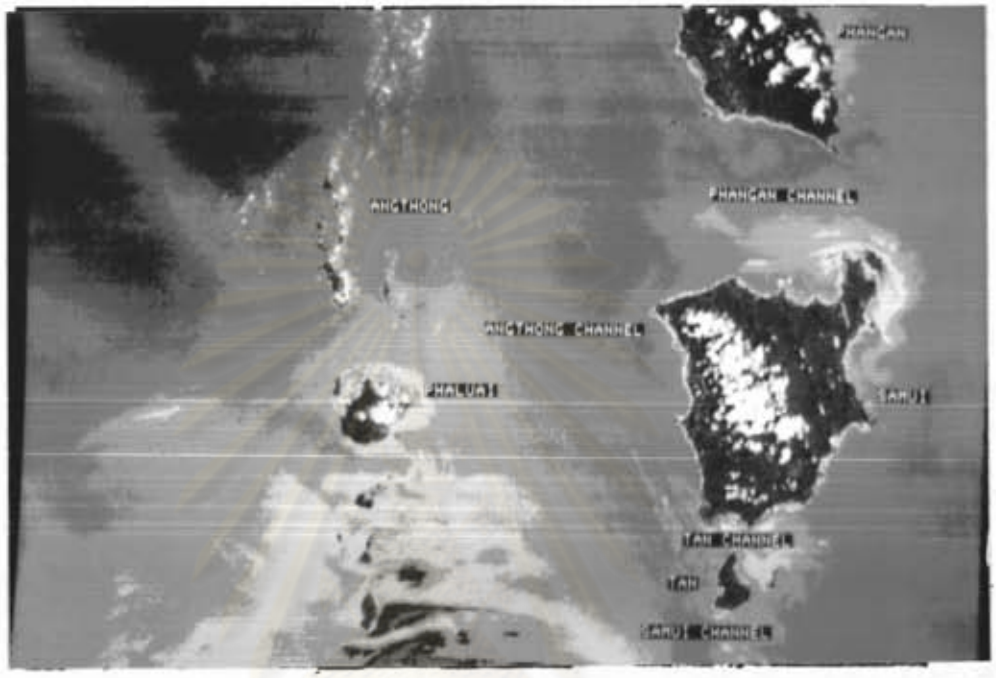


Figure 33. The Sediment Density Slicing of Samui Islands Presents The Channel Locations.

From the image the reefs at the northern part of Angthong Islands and the southwestern part of Pha-ngan Islands are located in the clear water. There is the islands group called "Wao" located in the clearest water in the northern part of Ban Don Bay. Unfortunately in this area there is no reef.

4.2 Data Integration

This session is to clarify the multi-resolution maps of SPOT Panchromatic and Landsat TM. The result emphasizes on the reef along the eastern part of Samui Island. Another product is the topographic map of Tan Island using Landsat TM data as vector data to combine with depth data as raster data presenting in Army map scale 1:50,000 and Navigation map scale 1:250,000.

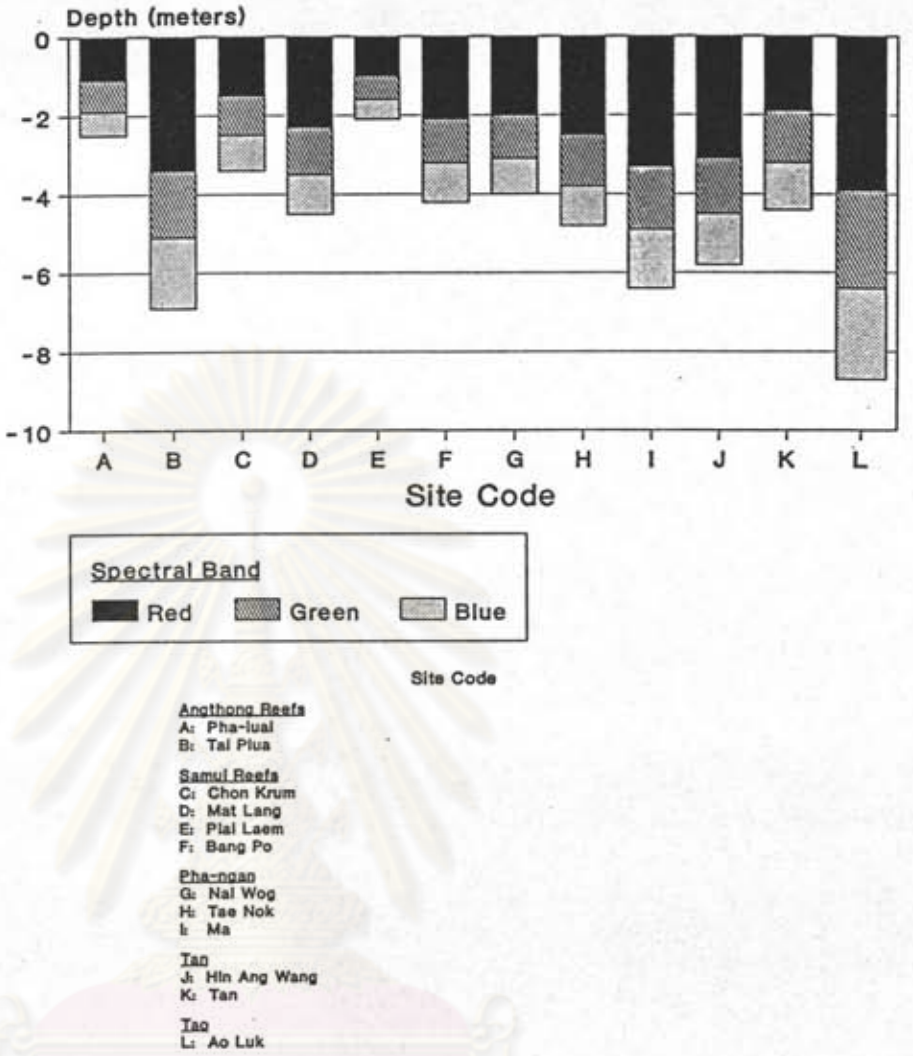


Figure 34. Seschi Disk Recorded from Samui Islands.

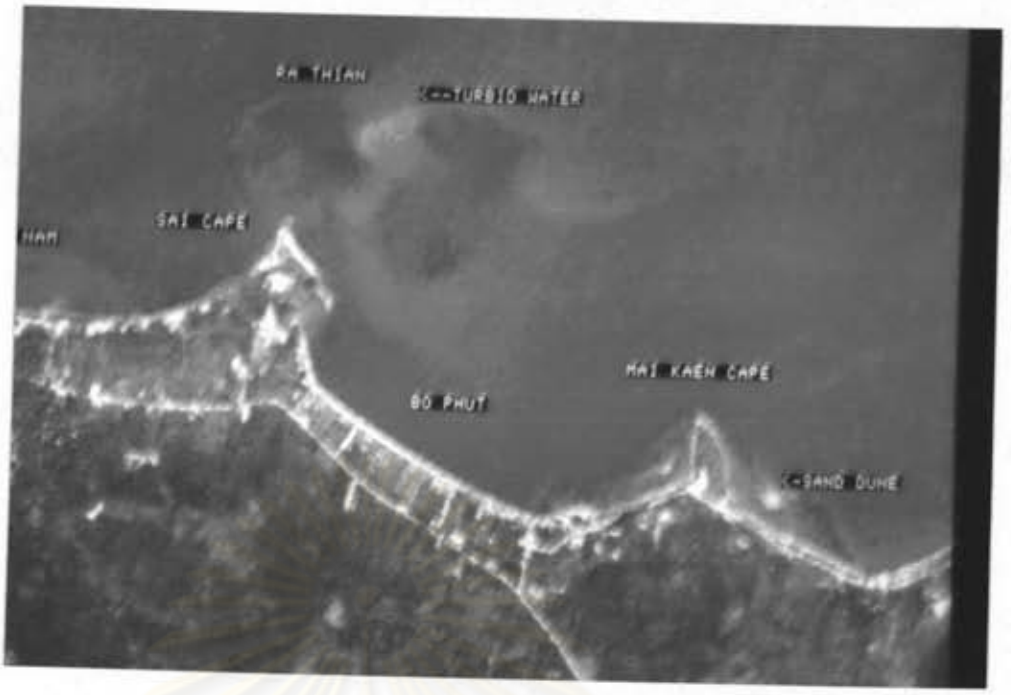
4.2.1 Multi-Resolution Map

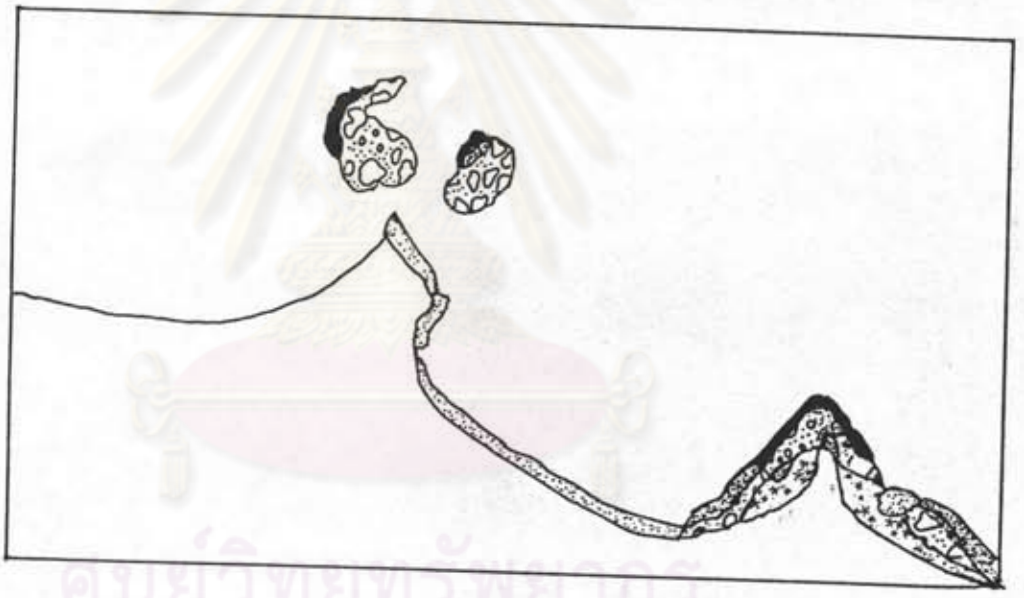
The work has been carried out covering the western part of Samui Island. The achievement involves developing a method to rectify the SPOT Panchromatic data with topographic map. The landsat TM data was transformed to the panchromatic data. The result demonstrated that a merged remotely sensed map can explains reef and urban settlements along the shore.

The processing problem resulted from the topographic map which was made in 1976. At that time the area did not have the new road and urban development. The ground control points were selected for 35 points from SPOT. However only 18 point fit with the topographic map. The result has a prediction error for 9.8 miters in X axis and 7.8 meters in Y axis which are quit good compared with the prediction error from Global Positioning System (GPS) equipment which is 15 meters. This technique and equipment could be used in merging maps in the future.

The Landsat TM data was transformed with SPOT Panchromatic data by 15 new ground control points. The process was quite easy because the road in those images usually correlated to each other. The prediction error is 8.1 meters in X axis and 5.1 meters in Y axis. The over all map is presented in 1:25,000 which is the formal scale. The rectification result was tested using map scales 1:50,000 overlap on topographic map, and the results showed that they can fit each other so this result suggests that the rectification process is correct.

The reefs along the eastern coasts of Samui can be separated into 7 sites. The first reef, located at Sai Cape, between Mae Nam Bay and Bo Phut Bay, is the small reef (Figure 35). The western reef of that is another smaller reef. The areas of coral in both sides are narrow displayed by the brown and green pixel in small groups. The dark green pixels are identified as a group of small type of living coral while the brown pixels are massive corals. The ground data give a good correlation with the imagery identification. On the reef flat area, it usually cannot be separated to inner and outer reef flat. The bright blue pixels in the eastern reef flat are identified as the sandy area. The coral area has the green and blue pixels which are identified as the massive coral and dead coral in a patch form.





Living Coral

Dead Coral

Sand

Sand and Coral Rubble

Dead Coral
and Small Living Coral

Figure 35. The Multi-Resolution Map of Mai Kaen and Sai Cape.

On the eastern side of this cape there is a long beach (200 meters) with the big sand dune at the cape end. About 50 meters from this sand dune there are two patch reefs in front of this cape. The result shows a few bright green pixels at the western patch reef which are identified as the areas covered with dead coral. The dark green and brown pixels in a band are identified as the massive coral. The clump of light blue pixels displayed over some part of eastern reef suggests that the water has high sediment.

The reef morphology at Mai Kaen Cape is similar to Sai reef but the reef is wider and continue from west to east (Figure 35). The brown and green pixels packed together as a band suggests that this reef has more living coral area than Sai reef. The reef can be separated into two parts by the sand dunes which are displayed in the white patch at both sides. The dark green pixels identified as the massive coral can be observed along the northern reef, while the bright green pixel located only in the western part of the reef could be identified as a dead coral area.

In the south eastern part of this cape there is a sand dune covering about 600 square meters. The band of living coral stops at this point. Near the sand dune the colour classification on the map shows the light brown pixels as a patch. A ground truthing revealed that the substrate is very old dead massive coral which was displayed in light green. A few dark green pixels located near by are the small living massive coral. This living coral area is smaller than that at the coral area at the northern part of the reef.

The biggest reef in the northeastern part of Samui is the Plai Laem Reef (Figure 36). The reef starts south of Fan Island covering wide area towards the north end of the cape. This reef clearly shows its zonation composed of inner reef flat, the outer reef flat and the reef slope. The bright blue colour in the inner reef flat suggests that this zone is composed of the shallow sandy bottom. A few pixels shown in blue spot are the small lagoon. The outer reef flat near Fan Island shown in light green is identified as the small dead coral area. The reef edge has dark brown pixels, a comparison with ground survey reveals that this area is composed of some massive corals packed in a band. The narrow band of dark green pixels suggests that the reef slope of this reef is narrow and the shore rapidly drops to the fore reef area.

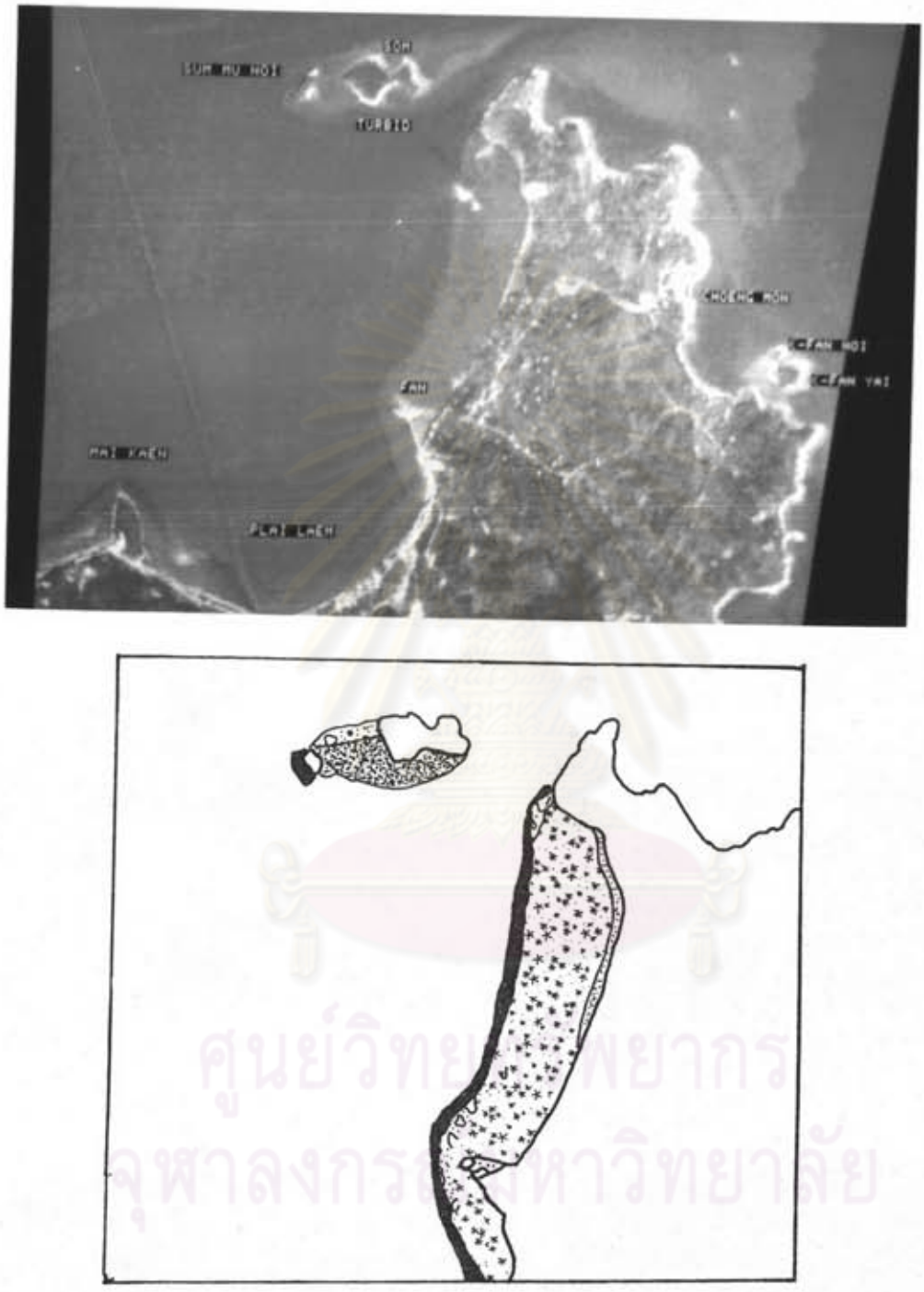


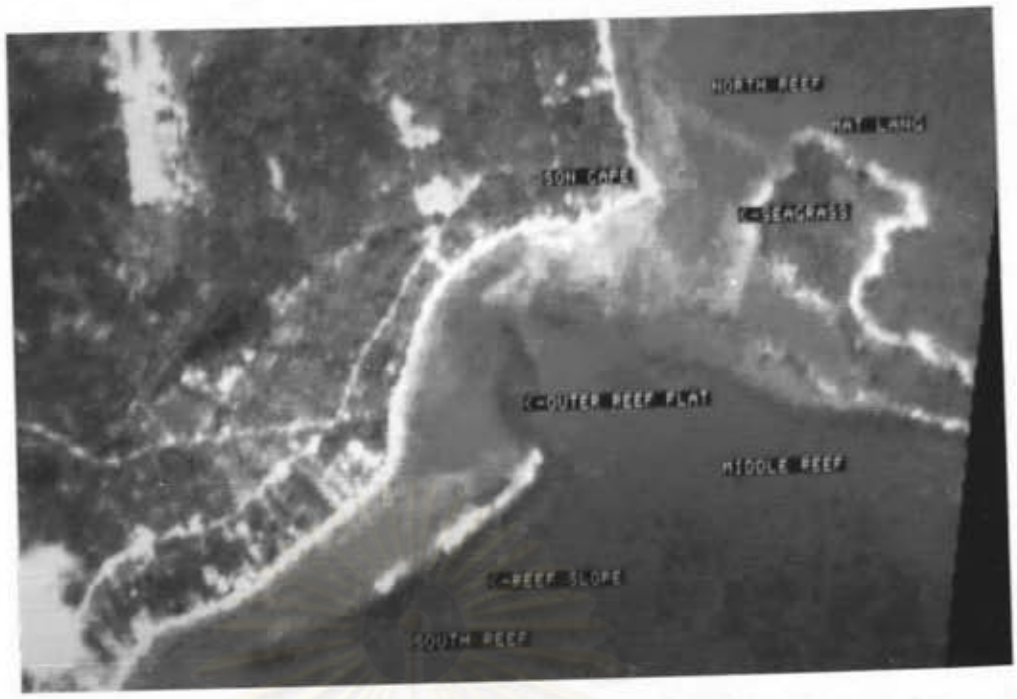
Figure 36. The Multi-Resolution Map of Plai Laem Cape.

There is a small reef located on Som and Lum Mu Noi Islands (Figure 36). In the northwestern part of Lum Mu Noi a few brown pixels are displayed. This area may have some massive corals distributed in the form of coral head close to a rocky shore. Between both islands there is a dune which is displayed in light purple and light brown pixels. This dune may have dead coral as a dominant component but the bright pink pixels close to the beach are some error from the process. In the southern part the image presents unclear reef. Ground truthing data show that there is a reef in this area but in a poor condition. The high turbid water inhabited the remotely sensed survey. However the reef in the high turbid water has low percent coverage of living coral which is not so interesting.

Fan Island (different island from that near Plai Laem Cape) is located in the northeastern part of Samui Island (Figure 36). The water is rather turbid and the flow pattern in this area shows that the water flows from the northern part of Samui through this area. In the western part of Fan Yai Island there are some light purple pixelswhich which are the small dead coral area and the ground truth data corresponded with the imagery data.

The most important reef in the eastern coast is Mat Lang reef (Figure 37). It is the famous tourist place. In the area of this reef flat there is also a big seagrass bed. This study would concentrate on this site due to all this combination and its healthy condition. Five lines were laid in this site for ground truthing and the horizontal photograph was made. The imagery classification resulted has a good correspondence with the ground data and could identify the reefs in many zones.

Using the multi-resolution map scale 1:25,000 at Mat Lang Reef to identify the small component area of this reef, the result demonstrated that the morphology of this reef is very complicated. The reef edge composed of dead coral can be clearly seen in three areas. The northern reef edge displayed in red brown band is submerged during high tide. The middle and southern reef edge displayed in white band are exposed all the time. In comparison with ground survey the reef edge can be separated through their characteristics into 2 types. The northern reef edge is composed with big dead coral heads and rocks covered with turf algae while the middle and southern reef edges are composed of unique patch of



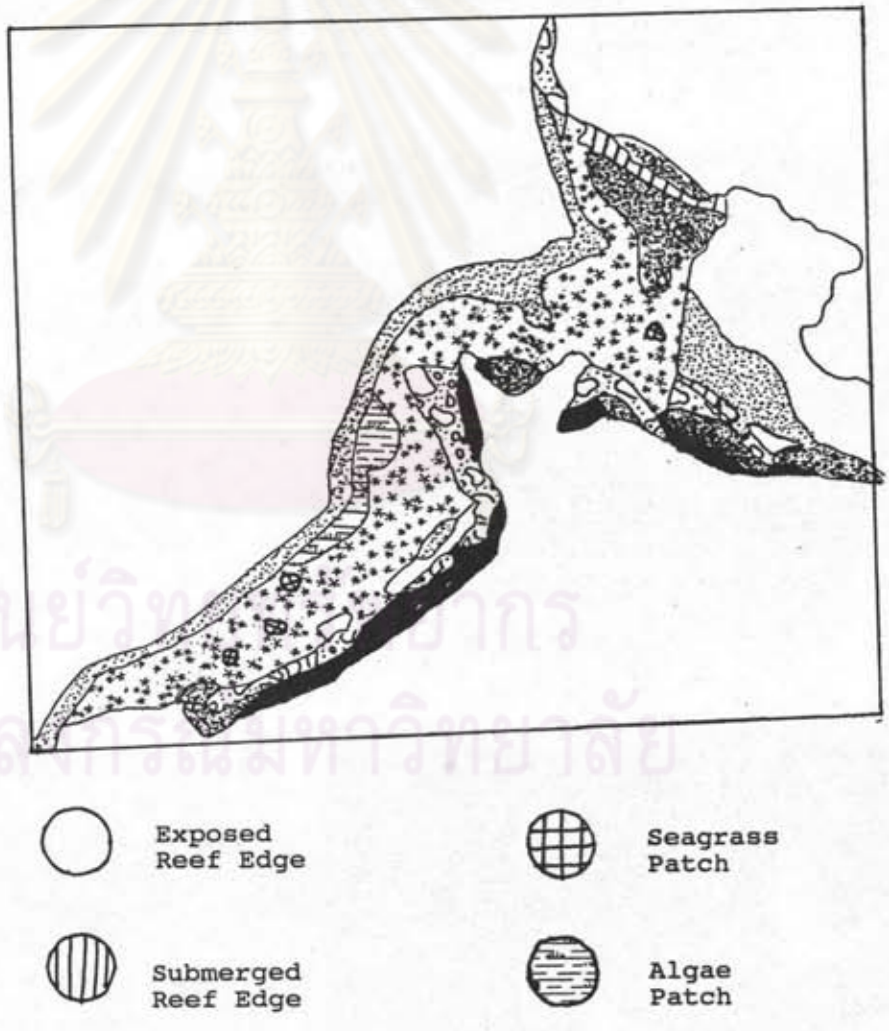


Figure 37. The Multi-Resolution Map of Mat Lang Island.

mangrove, Lumnitzera racemosa and these areas will develop into a cay soon (more detail in discussion session).

From the observation the water moves from outside into the reef flat through the channel between the middle and southern reef edges, which has sandy bottom. The water passes at the edge of sand patch and moves out through the small channel at the west end of the northern reef. The sides of the channel are sandy substrate which represented in white pixels, while the sides of the channel across the reef edge has some dead corals which are displayed in dark pixels.

The high resolution of merged map shows the living coral area in green and brown pixels which help to identify its zone. The living coral area can be separated into three parts according to the morphology. The northern reef has the submerged low coral coverage area with a group of coral heads which can be observed in a few brown pixels, while the middle reef has the reef edge (show in bright colour) before the narrow reef slope. The reef edge which displays in light blue and green colours is identified as the small submassive corals on the sandy substrate. The reef slope appears a patch of dark green pixels is the small submassive or branching coral.

The southern reef has the widest reef slope in this area, brown and dark green pixels can be seen in a band. This is one of the wide reef slope in Samui Island. It is separated into 2 zones, the dark pixels are the massive coral. The green pixels are the branching and submassive corals.

There is another coral area in the middle reef channel, this area can be called the outer reef flat. The brown band in this area is identified as the massive coral on the reef edge and the shore line rapidly drops to the sea floor.

The inner reef flat is identified from the horizontal photograph. It can be separated into two types of substrate, dead coral and sand. Two dead coral areas are located behind the northern reef and at the outer reef flat. The area near northern reef shows bright purple which can be identified as the dead corals scatter around. The area near the outer reef flat shows more brown green colour pixels which represents the high concentration of dead

coral. The ground data reveal that this area is composed of the small dead coral with the sediment on top.

The white colour zone on the reef flat is identified as sand patch while the small patches of seagrass bed can clearly be seen in few grey pixels on the western part of Mat Lang Island. The seagrass beds can be separated into three sites. The first site is near a small beach of Mat Lang Island. This site is rather small covering the area of about 7,000 square meters. The second seagrass bed is located parallel to the shore on the eastern side of the first bed, this is the biggest bed which covers about 17,000 square meters. The last bed, the smallest, is on the western side of the others, and covers the area of 5,000 square meters so this bed show a small group pattern. Other small seagrass patches are located on a southern reef flat. A few grey pixels are scattered around in this area. However, base on a ground data seagrass in this area is distributed in small patches, each group covering the area not more than 1,000 square meters, and the total small seagrass patches cover the area of about 12,000 square meters (Figure 38).

Figure 38. The Seagrass Patch at Mat Lang Island.

The inner reef flat of Mat Lang Reef is mostly composed of sandy substrate. The sand patch which can be seen in white pixel is located in the southern part close to the tip of Laem Son Cape.

Other interesting pixels are observed in the light green colour close to Chaweng beach at the middle part of the figure, when checking with the ground truthing suggest that it is the area composed of very dense calcareous algae, Halimeda. The bright pink line along the beach is an error from the process which may be caused by the disturbance of sand which is blown up by wave action.

The reef morphology at Nan Cape has a similar structure as Plai Laem Reef but the reef zones are different (Figure 39). Nan reefs are composed of the dead corals and sandy areas. A band of red brown pixels is located near the point of the cape are the submerged reef edge. This reef edge is similar to that of northern Mat Lang reef but it is smaller. The group of green pixels on the outer reef flat are dead coral. The inner reef flat is composed of sandy bottom as the major substrate. A blue spot in this area is a small lagoon which can be easily observed during the low tide.

The blue canal in the multi-resolution map is the channel. This channel is small in the inner reef flat which may be made by local people for boat channel. In the outer reef the channel is larger and run pass the reef edge with a white spot as the sand patch in the middle. This part of the channel is in the natural condition.

The coral area here can be separated into three zones, the first zone is located close to the reef edge shown as brown and green pixels in wide band. These pixels are identified as the massive and submassive corals. The middle zone, is separated from the first zone by a channel. In this zone, it shows the same pixel colour but they are formed in small groups. The last zone close to Lamai Beach shows light green pixels which are identified as the small dead corals. There are few brown pixels of massive coral in this area also.

The last reef on the eastern coast is Hau Thanon reef, this reef starts from Lamai Cape pass Hua Thanon, Set Cape, Bang Kao Bay to Sor Cape (Figure 40). The reef at Hau Thanon has two exposed reef edges parallel to the shore. There are two channels, the first of which is between Lamai Cape and the northern reef edge. This channel is smaller than the another one which is located between the two reef edges. The bottom of these channels is sand which is displayed in blue pixel. Along both sides of these channels are the

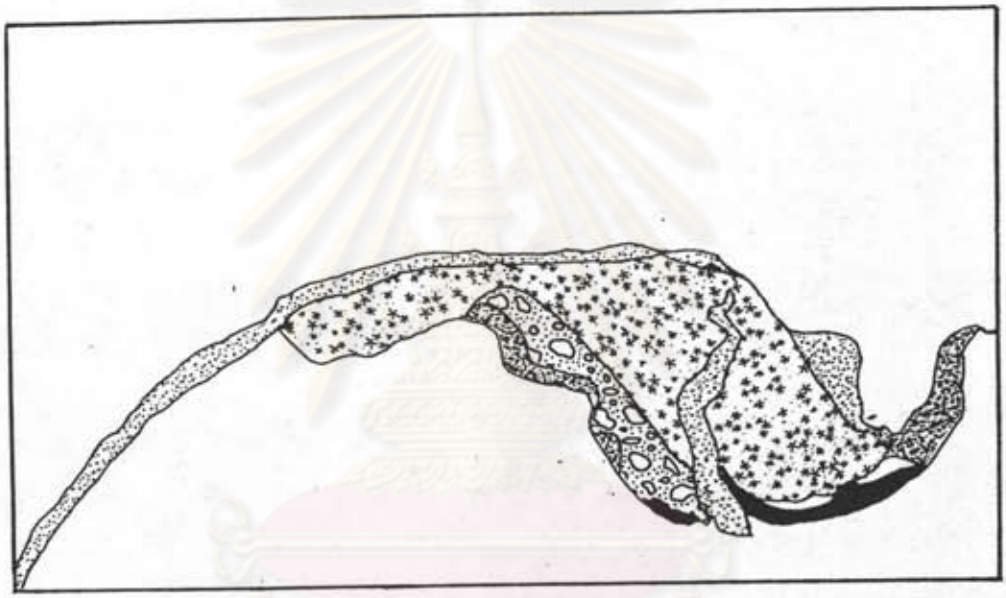


Figure 39. The Multi-Resolution Map at Nan Cape.

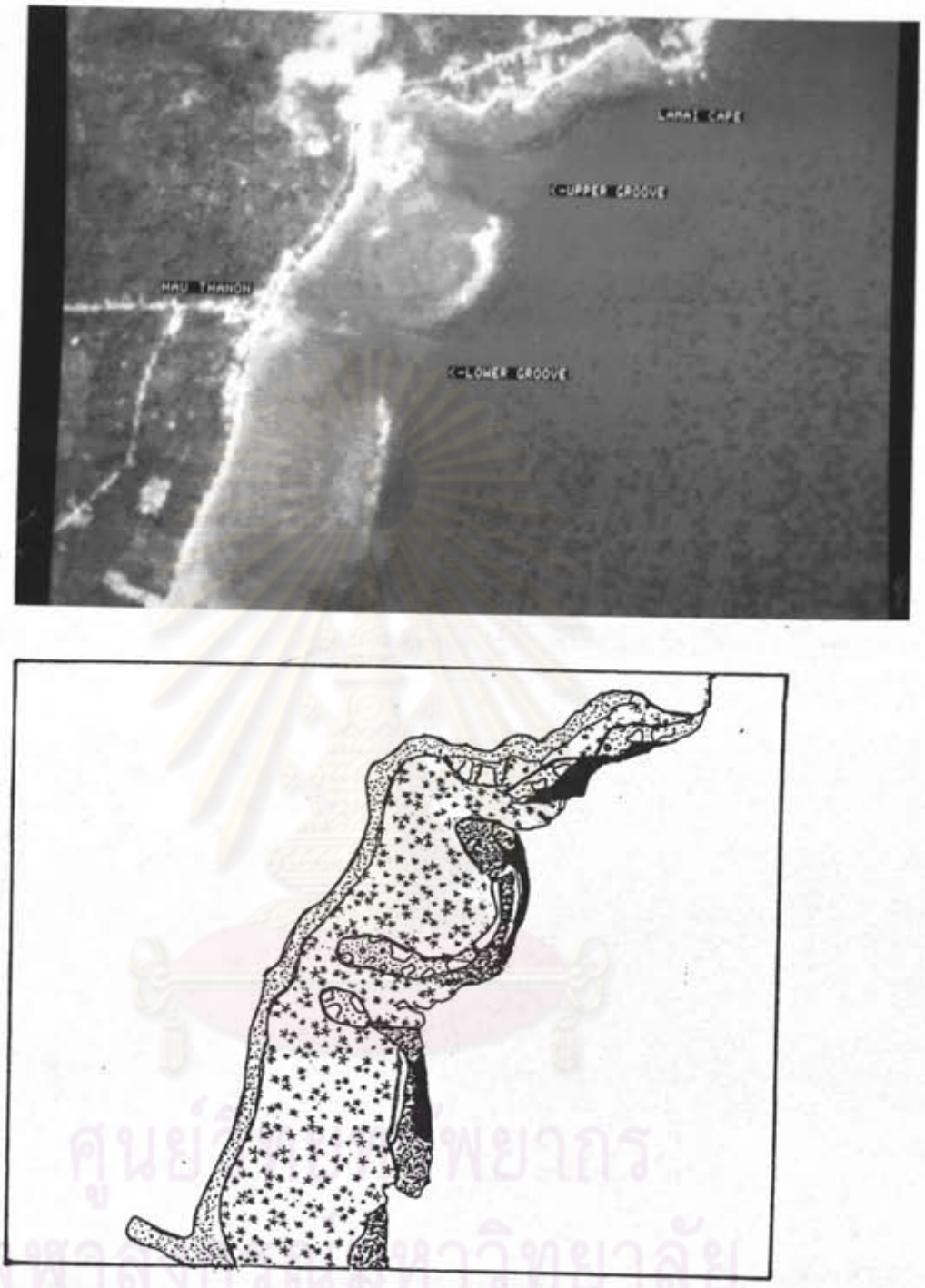


Figure 40. The Multi-Resolution Map of Hau Thanon Bay.

massive coral areas called spur.

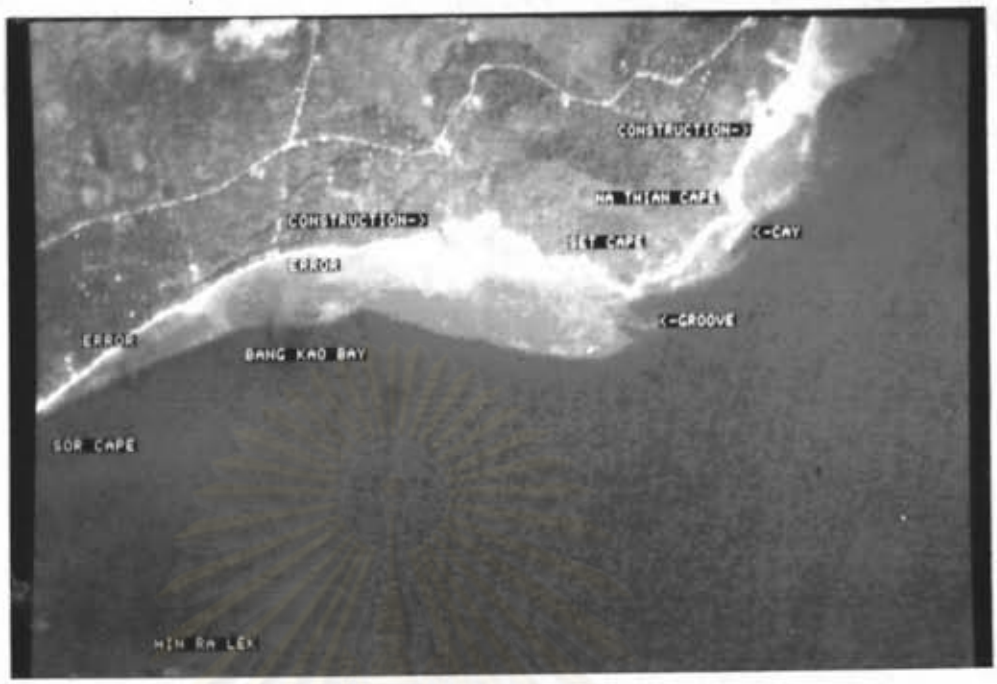
The coral areas on this reef are displayed in blown and dark green. Near Lamai Cape the living corals are distributed in clump. In the area outside of the reef edge, the reef front is mixed between living corals area in the brown and green pixels band clearly displayed on the image. That area is identified to be very dense of massive coral.

The inner reef flat of Hau Thanon Reef has the mixing substrate components similar to Nan Cape. The dominant is sandy substrate. A few blue pixels are scattered over the inner reef flat which is identified as the small lagoon. In the southern part of inner reef flat the image displays a clump of bright pixels with some brown pixels on the edge. Compared to the pixel demonstrating the soil on the shore next to this area, it may suggest that there are anthropogenic effects on the reef. Perhaps the channel dredging for boat transportation channel was made in this area. Ground truthing is required to support this recommendation.

The reef near the end of Na Tian Cape has the small exposed reef edge displayed in white band (Figure 41). This reef edge was formed in the unprotected area. The narrow brown band in front of that can be observed next to this reef edge. This area is identified as a high living massive coral zone.

From Na Tian Cape to Set Cape the reef is narrow (Figure 41), the reef flat has a mixing zone between living coral and dead coral as the predominant substrate. Living coral can still be found growing together in brown and green pixels scattered around this area. In front of Set Cape a narrow brown pixels band of massive coral is displayed clearly. Then, the reef is cut by the big channel which has many dead coral and sand in the bottom. Based on some blue and green pixels along the channel, it suggests that this channel is wide but shallow which differs morphologically from other channels along the eastern part of Samui.

Although the reef at Bang Kao Bay is wide, the living coral area is very narrow which rapidly drops at the reef edge. The reef slope is very steep in this area. On the reef flat the distinction between the sand and dead coral is rather clear. The inner reef flat is composed of sand which is displayed as white areas while the



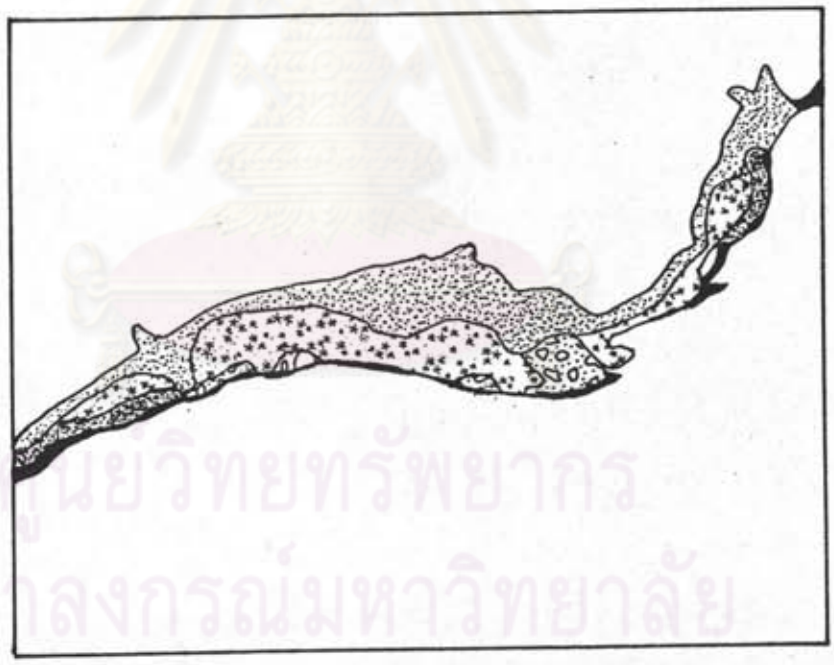


Figure 41. The Multi-Resolution Map of Na Tian and Sor Cape.

outer reef flat which is the dead coral area is presented by the blue area with some green spots. Some white and brown spots dispersed from the shore on the reef flat served to represent some source of sedimentation from construction.

The end of this image is Sor Cape which has the reef continuing from Bang Kao Bay (Figure 41). This reef run along the shore and becomes narrow until it comes towards the shore at the end of Sor Cape. The inner reef flat is narrow and sandy also with many small lagoons as indicated by the blue within the narrow band of the white pixels are absent. This reef has the reef edge displayed in dark green pixels. From a ground survey it is suggested that this reef edge has some small submassive corals. In front of this reef edge the shore profile drops. The major coral found here is branching coral with some massive corals as coral head mixed together.

There is another reef in the southern part of Samui Island called Hin Ang Wang. This reef is different from others because of this reef is the coral island or cay (Figure 42). The island consists of two exposed reef flats. The one on the left is the longer and broader than the one on the right. The size of the left reef flat is 40 meters in width and 200 meters in length while the size at the reef flat on the right is smaller, only 10 meters in width and 30 meters in length. A patch of purple pixels identified as a big massive coral located at the edge of this reef and next to that the imagery shows the sea area. This result suggests that the reef slope in this area is very steep.

The southern part of this island has the reef flat similar to the northern reef flat. However, at the edge of this reef flat is a green band identified as the reef slope. Ground data reveal that the area consists of dense branching coral, Acropora spp.. The reef slope is hardly separated from this reef edge. Ground data suggests that the reef slope in this area is flat and the major coral feature is branching coral. Massive corals are absent in this area.

4.2.2 Topographic Image

In this session the Landsat remotely sensed imagery is the prime source of data for production of topographic map. The basic method of linking raster data is by planer coordinates, so the image

Figure 42 . The Multi-Resolution Map of Hin Ang Wang.

must be rectified first. Using the grid coordination from the topographic map this imagery map produces with the error 13.2 meters in X axis and 8.6 meters in Y axis.

SURFER is the program producing the depth raster data. However, there is a problem with SURFER. If the process starts with selecting the imagery border and using this size for SURFER, a program will automatically create the pixel size which is not suited the imagery pixel size. Therefore, the obstruction can be run by producing for the pixel size in SURFER program same as the size in microBRIAN, then the automatic program in SURFER will provide the area border. This area is chosen and overlapped on the Landsat image. Using this method 34,682 pixels in the Landsat image cover Tan Island. The 238 depth point from the army map put in SURFER and the program analyses 34,628 depth pixels as the ASCII file. The depth points as the raster data are transformed to the imagery data with mTRADE. The products from this operation are separated in two outputs, the reef and depth theme mapped topographic image and three dimensions view of Tan Island.

4.2.2.1 Reef and Depth Theme Mapped Topographic Image

The result in this session would be to produce using the depth theme from the raster data, and join with the reef and land theme which come from the image analysis, mapped on the image. In the SURFER process the depth points are analyzed using the depth contour and the points on the border of land area. Some shoreline points are put in because they will help to investigate the true depth point. This raster data is transformed to microBRIAN file, this file is composed of microBRIAN data as the depth in 1 meter being transformed to 1 microBRIAN radiometer as the vector data. However, the depth data in Tan area is recorded from 0-27 meter so the vector data is presented between 0-27. mOVRLY is used to create five depth themes overlaying on the image composed of 3-4 meters, 5-9 meters, 10-14 meters, 15-19 meters and 20-30 meters. The reef classification result is composed of land theme and reef theme overlaid on the image. This result is the final product (Figure 43).

The depth zone combined with the reef area suggests that the result gives the essential data to study in the depth factors controlling the reef type. According to the depth zones, the reefs

in Tan and Mat Sum Islands can be separated into two parts, the shallow reef, and the deep reef. The reefs at Mat Sum Island, the eastern part and southern part of Tan Island are the shallow reefs located at the 5-9 meters depth. While the reefs in the western and northeastern parts of Tan Island are the deep reef located in the 10-14 depth zone. Ground data reveal that the reefs in this area are found to be corresponded to the image processing result. Using the SCUBA diving and echo sounder from the eastern part of Tan Island to the western part of Mat Sum Island the depth is less than 10 meters. In the northwestern part of Mat Sum Island the depth in this area is only one or two meters. However the depth from topographic map was recorded in 1973. This zone may have the sand patch which changes rapidly so the depth in this area may be different from the depth eighteen years ago.

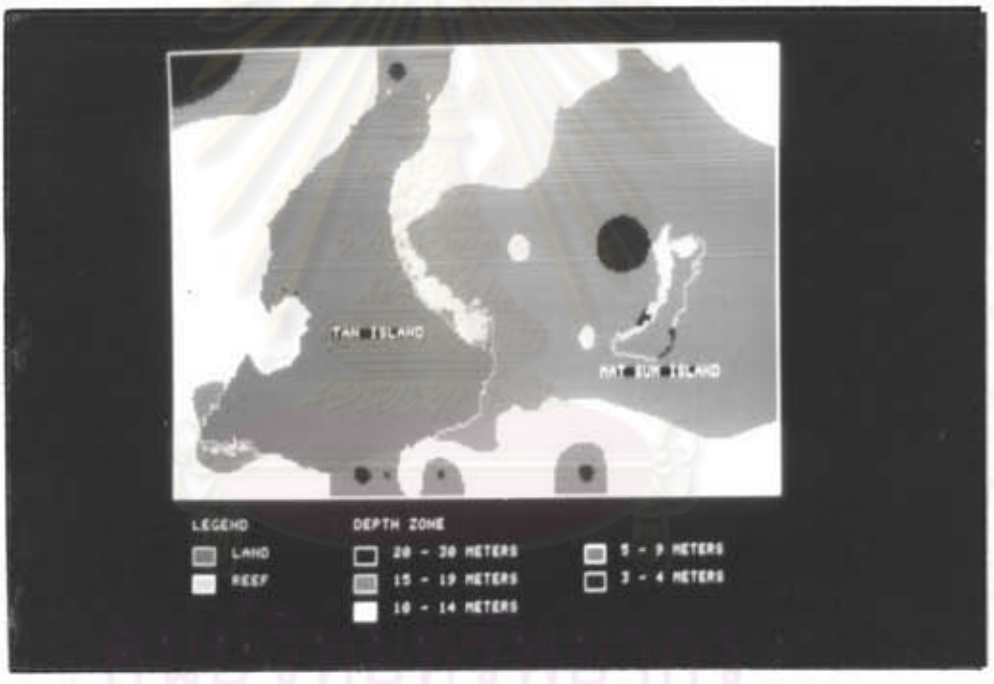


Figure 43. The Depth and Land Mapped Topographic Image of Tan Island.

From the produced map the topographic sea floor in this area is shown. In the northern part of Tan Island is the Tan channel which is the deep area connecting Samui and Tan Islands. Since it is rather an open space without any islands in this direction, the reef is reponed to the strong current, high wind and wave action. The survey diver found the strong current coming from west to east, and the bottom was the steeply rocky shore.

The shallow basin comes from the eastern site of Tan Island covering Mat Sum Island. This area is a high sediment zone which is blown from the bottom, the sediment concentration in which confirms this conclusion. In the western and southern parts of Tan Island there is the deep basin with some deep holes so the big reef cannot form in this part. Only the reef in a semiprotected bay in the western part of Tan Island can be formed as wider reef.

The reefs in the shallow depth zone have the massive type as the dominant group while the reef in the western part of Tan Island has the dominant coral are the branching and massive corals. This suggestions are confirmed by the ground truthing in this area.

4.2.2.2 Three Dimensions Image

The depth microBRIAN file in this session processes in itself. Raster data in this process are different compared with the reef and depth result, because the high data in the land area is provided to make the topographic on Tan Island. The process tried to put the high data together with the depth data. However, the result shows the error in the border of land and sea area because SURFER calculates this area as combination between the high inland and the depth in the sea so this shoreline is submerged at some points and emerges at the others. If the process inserted only some border data as the depth process, the data would still be in error because it needs all border point to compute the correct topographic map. Using the digitizer it will help this process. However, in this project there is no digitizer equipment. To solve this problem two files were made, one file was the depth file which was used in the reef and depth process, the other was the height file used on the land.

Using the height in each pixel the program calculated the slope aspect. Then the program transformed them to the topographic map which was displayed in two dimensions. This result is not a good presentation because it is hard to notice the depth. m3D was used to calculate the three dimensions of Tan Island (Figure 44).

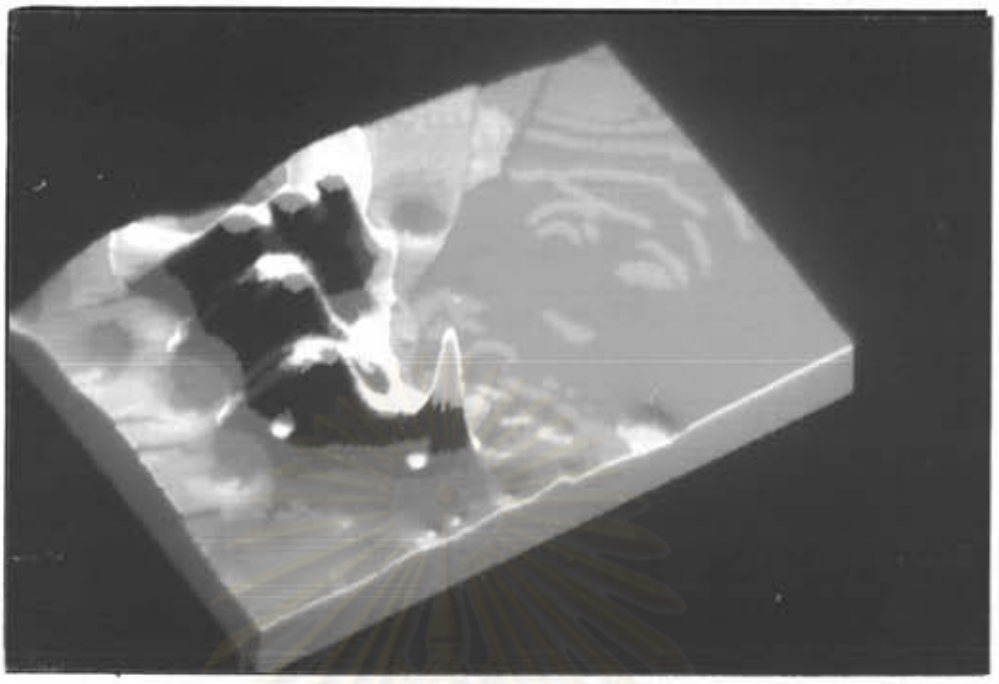


Figure 44. The Three Dimensions Perspective Image of Tan Island.