CHAPTER V

DISCUSSIONS

The discussions are divided into three parts: 1) the remotely sensed data, 2) the techniques in digitize image processing and ground truthing, and 3) the reef morphology, zonation and classification. The remotely sensed data part deals with the remotely sensed data as applied for reef studying. The techniques in digitizing image processing and ground truthing at the study sites help in understanding the remotely sensed data in order to be able to understand what they are and can apply these techniques to study small and turbid coral reef areas. The reef thematic image and the multi-resolution maps help to view the reef morphology and the results are used for reef classification by the reef pattern. The reef area measurement results explain the overall reef areas and living coral areas. The reef morphology, zonation and classification session helps to interpret the remotely sensed results for studying the coral reef component distribution and reef classification in Samui Reefs.

5.1 Remotely Sensed Data for Reef Studying

In this study there are three remotely sensed data which are good to use to study different reef types. Landsat TM data are the main source of data used in this study. To use the data for image enhancement, a thematic map process can display a false colour image to emphasize on different reef components. The data contain different visible band serve to classify the reef component group. The whole scene image covers a wide area which is easy to locate the study site, and it is suitable for studying a spatial factor affecting the reef, especially the water pattern. Another effectiveness of this type of data is that the cloud may not cover all the area in the image, so a user can select the small area in the image and study in that area. This condition can help a researcher to monitor the reef. However, the resolution of Landsat TM may not be enough to match for studying in a small reef area.

The Spot XS data has a higher resolution compared with Landsat TM but this data can not help the effectiveness of Landsat data because the receiver can obtain unsuitable spectral bands which cannot get through the water as TM data. The data may be used for identifying the shallow reef flat in a small area. However, in this project the result is still not enough to explain the practical process of this data. More research is required to explain this data analysis for reef studying.

The SPOT Panchromatic data are the highest resolution data studied in this project. The problem is the panchromatic data records in BSQ format (Band Sequential) so it needs a special program to transfer this data to BIL format (Band Interleaved by Line) which is used in microBRIAN. This special program can not show the fulscene data, to subset the study area a user may draw the grid line on fulscene map in the paper. When the imagery data is displayed, it can be observed that this data suit for unclassified processing because of the high resolution of this data.

The panchromatic data display clearly the sediment transport pattern and the reef edge (Figure 45). The sediment pattern shows the water movement in that area with a gyre. The black band in the reef area is the reef edge composed of massive coral. However, the reef flat component and the urban settlement are not clearly shown in this image. The result suggests that SPOT Panchromatic data are suitable for analyzing the reef and sea border and may be suited for a water pattern studying in the small area because these high resolution data can be clearly shown the small reef areas such as sand patch. These areas will help to analyze the water transport pattern.

Although this SPOT panchromatic result accommodates the objective to analyze the useful data for studying the small image component, it is not suited for study on the reef because the reef component image classification needs the colour to categorize as TM data (Figure 46). A new idea using the multi-resolution image between Spot XS and Spot Panchromatic is operated to classify the land component (Jupp, 1990). However, in the reef classification the SPOT XS image may not match the objective because the Spot XS dose not contain the spectral band practical for reef classification.

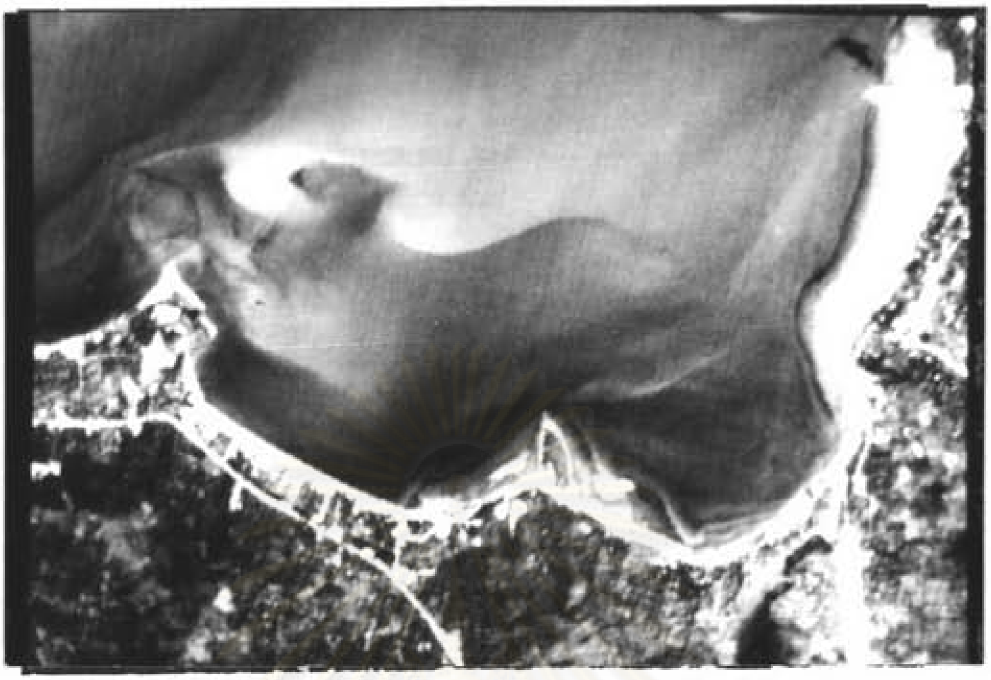


Figure 45. The Spot Panchromatic Image of Mai Kaen Cape.

Figure 46. The Multi-Resolution Map of Mai Kaen Cape.

In this thesis, the multi-resolution between Landsat TM and SPOT Panchromatic is tested. Using these two data, the big problem is the satellite passing time is not the same. So the cloud in those two images may disturbed the result and this method has never been used before. The way to solve this problem is to select TM and SPOT data which have been taken as closest as possible. Clouds covering both images should be carefully selected as not to cover the required reef area. From the image selection during 1986-1989 the best pair of images were selected to be used by this method. The result suggests that this method is very useful for future reef studies.

5.2 Techniques in Digitized Image Processing and Ground Truthing

The techniques are separated into two items, the digitized image processing and the ground truthing. The digitized image processing is composed of unclassified processing, classification and data integration. The ground truthing combines the ground positioning and ground survey technique at the reef study sites.

5.2.1 Techniques in Unclassified Processing

The unclassified processing consists of image enhancement, band ratio and principle component analysis.

5.2.1.1 Image Enhancement

In the image enhancement a true colour image consisting of band 1, 2 and 3 displayed in blue, green and red colour guns is recommended to identify the submerged feature in the reef area. The false colour image composed of band 1, 4 and 3 give an ideal result to observe the sediment and shallow area. It is recommended that this false colour image can be used for identifying the different substrate zones in the reef flat area. For example a sandy zone displays in red shade which is dissimilar to the living coral zone. A false colour map displayed in band 1, 2 and 4 is the ideal fulscene image shows the high contrast of water, land and mangrove areas.

The multi combined image is processed by separating reef, land and water from one another, and enhances them in their suitable stretch value. Using the interactive screen enhancement (mPIC) to separate land, reef and water the result suggests that infrared band is an ideal spectral to cut out the water and reef from land. Band 2 can be used as the band for separating the reef and water from each other. The linear stretching result using the histogram enhancement can be obtained more easily if the graph is displayed in a fulscene histogram and the stretch values are selected by user define instead of using the minimum and maximum values. Smoothing the water will help to enhance the water image. The results are pasted back together and the whole image gives the clear imagery view in each category which will help to observe the area of interest.

5.2.1.2 Band Ratio

The technique to improve imagery data with band ratio is the way to highlight some reef components which are not clearly shown in the histogram enhancement. Using the seagrass ratio in the mud flat area (Hyland, Lennon and Luck, 1989), TM data band 1, 4/3, 5 and 7, is tested. However, the image does not clearly show the seagrass pattern. This result suggests that a band ratio which is used for highlighting the big seagrass bed in the mud flat area may not be useful to study the seagrass in the small seagrass bed within the reef area. The mTRAN results give the idea to use band ratio 2/5, the image displays high contrast between three major areas on the reef flat. While band 4/3, 1, 4 may be useful to classify the seagrass in the reef area.

5.2.1.3 Principle Component Analysis

The principle component analysis (PCA) result suggests that this process is important to separate seagrass and algae in the outer reef flat from each other, and it also helps to feature the various zones of seagrass pixels. Comparing with the PCA result from mangrove area at Ao Ban Don (Thamrongnavasawat, 1991) which can separate the different biomass density and mangrove species. The seagrass result may not highlight in the same way but the outcome in a band 1 with the highest percent canopy shows the low reflectance values in a seagrass bed, when displayed as 0,-1,0. A seagrass bed is shown in the different bright green colour and other areas are shown in black. The classification can be done more easily to locate the different seagrass dense zones. This result suggests that PCA can be used in the reef flat area which needs to identify some important features such as seagrass beds.

For other components in the reef flat, the result displayed many group of pixels separated from one another. This product is clearer for separating the reef component zone than the histogram enhancement result. It recommends that the principle component analysis result is the best product for the unclassified result. And it will help to classify small reefs with mixing components in Samui Islands.

5.2.2 Techniques in Classification

The classification in this thesis is the mixing classification suited for the reefs that have some ground data. The unsupervised classification is tested in some reef areas. However the results are presented in many different sandy component zones. These zones have sand as the major component and they have some coral rubble or other non-living components as the minor. The classification separates these zones because the minor components reflects the light in different ranges. However, these minor components are not so important for reef study. The cluster process is difficult to join these sandy zones together. The results suggest that the unsupervised classification is not suited for reef study.

The supervised classification is better because it shows the reef component by user define. Only the important components are selected and displayed on scene. However, in some reefs the results display the unknown substrate which can not be identified. The results can be improved by ground data. However, it needs a lot of time and research to record these data so it will be possible for studying the reef in small areas. This classification does not match the objective of this project which requires the study of reefs in the wide area.

The mixing classification is the best way to classify reefs around Samui islands, and it recommends that this way can be used in any reefs which have the similar pattern.

The problems in this small reef classification are how to select training sets and how to cluster feature classes. The small reef has a mixing substrate zone so there are many different colour pixels displayed in the image close to one another. It is hard to select the training pixels with the low Chi-square or low error. To solve this problem the histogram enhancement with the user define can help to identify the reef zone with the ground data. The reef knowledge can help to locate the important component zones. For example the sandy substrate usually covers the inner reef flat while the dead and living coral areas are located on the outer reef flat. So the training sets are emphasized in the outer reef flat area. In this area Chi-square is controlled to not be more than 3 while the inner reef flat or the shore line Chi-square may increase to 4 or 5 and training pixels can still be received.

The technique to select the training area is to choose the band colour parallel to the shore, this area usually gives Chi-square result not more than 3. By choosing the training area like a shore transect band, the component will be mixed with the inner reef flat component and outer component which have two different components. So the Chi-square is higher and it needs other training areas. Finally, the selecting technique requires the experience so it needs more examples to do this process more quickly and better.

Although the mixing classification is used, the classification results suggest that there still are many sandy substrate groups. To solve this problem, clustering feature classes may not operate in one process, and are not truly based on the percent of dissimilarity in the dendrogram. The process may start with clustering the classes at 25 or 30 percent of dissimilarity, then displaying those classes and identifying the coral zone, sandy zone or other major reef zones. The re-cluster process is done to select the coral area from the others and to gather in its own class. Other substrates may cluster with the higher percent of dissimilarity (recommended as 35-50 %).

This processing gives good results for identification of the small reefs with emphasis on the coral areas. For example, the reef classification at Mat Lang Island gives 143 feature classes and clusters them to 14 classes with only four classes in the important coral area, such as seagrass and living coral, but ten classes are in sandy areas. The reprocessing is run by developing the selected training sets to 98 feature classes, and the new technique for clustering the classes create 10 classes with 3 classes in coral area, one class in seagrass bed and six classes in sandy areas. This improved imagery result gives more valuable data for small reef thematic map and also the reef study which emphasizes on the coral and seagrass areas.

5.2.3 Combined Raster and Vector Data Techniques

5.2.3.1 Reef and Depth Theme Mapped Topographic Image

The data integration process has many obstructions which require a lot of trail and error. Starting with the program SURFER which is the common program for calculating the average points from the sample points, the sample is taken from the points at contour line crossing the grid map. Using transfer technique, the data from SURFER can be easily located on the image map, and the reef and land themes are overlapped on the depth image.

The depth microBRIAN file in this session processes in itself. Raster data in this process are different comparing with the reef and depth results, because the height data in the land area is needed to make the topography on Tan Island. The process tries to put the height data together with the depth data. However, the result shows the error in the border of land and sea areas because SURFER calculates this area as a combination between the height in land and the depth of the sea. So this shore line is submerged at some points and emerges at the others. If the process is inserted with only some border data, the data will still be in error because it needs all border points to compute the corrected shore line. Using the digitizer it may help this process. However, at this stage the digitizer equipment is not available. To solve this problem two files were made, one file is the depth file which was used in the reef and depth process. Another is the land height data for calculating the land topography. These files were transferred to microBRIAN file and pasted together to become only one microBRIAN file with the depth and height together. This result was used for the perspective three dimension view of Tan Island.

Although this result explains only the integration between the reef and the depth zone, the product supports the hypothesis to use microBRIAN as Geographic Information System (GIS) for explaining the synthesis of remotely sensed data and the raster data. Moreover, the product reveals that it is easier to study about the reef factor using this technique.

The reef and depth zone result used only two channels in microBRIAN file, so there were the other two channels which were not used. These two channels can be used for other data such as sediment pattern, seagrass (for the seagrass bed that located outside the reef area), fishery area, etc. In microBRIAN version 3.0 there are more than 200 channels in the file so it can be used for integrating more data together which will help to study the reef with many factors.

5.2.3.2 Perspective Three Dimensions Image

The top view of the three dimensions of Tan Island overlapping with the reef theme is made for presenting the coastal land use data (Figure 47). The management plan can employ this product for selecting the urban development on land or coastal area without the effect to the reefs. The depth holes in this area are clearly seen in the southern part of Tan Island. This product serves to analyze the sediment zone and water current in this locality.

Figure 47. The Top View of Three Dimension at Tan Islands.

The perspective view of Tan Island was made to observe the floor topography in this area. The result suggests that in the northern part of Tan Island, which is supposed to be Tan Channel, there is a deep sea floor topography, so the perspective view result supports this hypothesis. However, the reef theme cannot be merged with this perspective view because the reef theme does not have the depth data. The result recommends that it needs more studying in this module but this study is the program construction, so it is not in the scope of this thesis.

5.2.4 Techniques in Ground Truthing

There are three main factors that control the ground truthing in the small reef area, the equipment, the mixing reef component and the new program mTRAN. The first factor requires a new technique for locating the ground control point in reef area. If this project has the high equipment as Global Positioning System (GPS) which can locate the ground control point exactly, the new technique will not be used. But the GPS system is very expensive so this technique can help the small project to do a ground truthing in the reef area.

The plastic sheet idea is based on the light reflectance theory that infrared is absorbed in water while the white plastic sheet highly reflects the infrared spectral. A plastic sheet cut in L shape because this shape dose not need much plastic so the cost is cheaper. Using this technique a ground control point can be detected from the image. The result suggests that this method can be used with low cost, however, it needs a lot of worker to hang on the sheet. The plastic may hang over the water which has a depth more than one meter, and it helps to detect the location by selecting the area which has the low infrared reflectance substrate, for example in the dead coral area.

The ground survey technique was developed to suit the mixing components in a small reef. In the past a mLOCAT program was used to locate sample points in GCP file in image (Kuchler, 1985). However this process does not suit the small reef area in Samui Islands because in some areas especially the narrow band of living coral or a patch of seagrass are smaller than 900 square meters which is the Landsat TM resolution area, so the reflectance value in this area displays in a "Mixel" or mixed pixel (Harrison and Jupp, 1989). The transect line method survey for ground truthing described in Bainbridge and Reichert (1988) suggested that the transect line method developed from Benthic Lifeform Line (Dartnall and Jones, 1986) may be used for recording the ground truthing data.

However, the method needs many researchers to do the works in the big reef.

Using Transect Method a line is laid along the living coral area and the reef components parallel to the shore. The coral area in a small reef usually forms in a small patch or narrow band which is not parallel to the shore, so the line may miss a coral area very easily. Another problem is that the reef slope at Samui Islands are usually steep, so the corals change rapidly from one type to another. The line error makes the data present the predominant coral type even though that area has two coral types close to each other but in different zone. Another problem comes from the location of transect line being hard to locate corresponded with the ground control point.

The developed technique in this presentation uses the Benthic Lifeform Line combines with Shore Transect Method (Sudara et al, 1989). The idea is to search for the reef topography and the substrate reflectance area along a transect line. This survey emphasizes on a reef flat because it is easy to locate the starting and ending points. The measurement method is developed for a topography result which suit a mTRAN program. Comparing the data together they can explain substrates corresponded with reflectance spectral. This idea will help a classification process.

A mTRAN program used in this project is suitable for a ground survey method, and it helps to analyze the ground truthing. The problem is a mixed pixel reflects the light which may disturb the analysis. This problem is solved by testing mTRAN program in many areas which has a same major substrate. The reflectance values from the substrate in many areas give a good examination. In one study site, mTRAN was tested in many lines close to one another to get the average values in that area. Using this method the result can supply some essential data for reef thematic products.

5.3 Reef Morphology, Zonation and Classification

5.3.1 Factors Control Reef Morphology and Zonation

The horizontal variations on the reef are caused by the energy conditions, with energy gradient developing from the outer to the inner reef area. Energy condition in turn affects the sedimentary environments and physical processes operating on the reef, producing small but important variations in the height of the reef. Biological zonation results from these physical contrasts but both the morphology and ecology of the reef are not stable through time (Pichon, 1974; Hopley, 1982). These suggestions come along the studies in Great Barrier Reef morphology which has different conditions comparing with Samui Reefs because Samui Reefs are the fringing reef closing to the continental island. However, the reef morphology and zonation theory at Great Barrier Reef may be used as a framework for discussion in the reef morphology and zonation at Samui Islands. Although the theory can support the zonation of Samui Reefs, the major division is different because of the small reef has the narrow area so in each area has the nearly similar energy conditions. It shows that the reef zonation in Samui is mixed with many substrates.

From the imagery result it can be observed that the reefs in the big bay, which is the protected zone, are the wide reefs. Usually these reefs can be easy to observe the zone. For example the reefs at Plai Laem Cape and Laem Yai Cape show the reef flat and reef slope with a clear border. The reefs located along the shore line which is an unprotected area have the mixed reef zones, and it is difficult to locate the border exactly. The reefs at Sor Cape and Hin Khom Cape positively show this morphology.

The reef located in the protected area usually has the separating reef components. Because the wind and wave do not directly affect the reef, the substrate in the reef is controlled by tidal current. The theory of sediment dynamic in the reef (Jell and Flood, 1978; Hopley, 1982) can be used. A heavy sediment will settle on the outer reef while the light one will blow to the inner reef. In the wide and protected reef this phenomenon even be observed by sandy substrate. The imagery result corresponded with a ground data suggests that the inner reef zone is composed of many areas which have different sandy grain sizes, for example at Plai Laem Cape.

In the high wind and wave action areas the reefs usually have the mixing substrate components. The unique substrate may cover the reef area not more than 3,600-5,400 square meters. The reef zone is mixed with heavy and light sediments close to each other depending on the direction of wind and wave action. Taking Plai Laem Reef as an example the area in the northern part is a protected area with the big cape so the zone is separated. The southern part of this reef is an unprotected area so the wind and wave actions make the reef components mixing together.

The reef size is one important factor controlling the reef component zone. In the small reef the wind and wave action can directly regulate the reef component zone. The reef flat is mixed with dead coral and small living coral while a sand patch may be observed in the inner part of the reef. For example the reef at Mai Kaen Cape shows the sand patches in both side. Usually the dead corals are the major reef flat component and shows the mixing reef component pattern.

The reef edge and channel also regulate the reef component zone. The reef edge blocks the wave energy and the inner part has a low energy condition so it has a separated zone, for example Mat Lang Reef. The reef which has a channel, for example Hau thanon Bay, has the mixing component zone because of the tidal current along the channel is strong while the current run through the reef edge is weak. The substrate in the reef area is varied depending on the location.

Base on a hydrodynamic in the reef area and the reflectance spectral theory, it suggests that the reef sediment studying is an important research to classify the reef zone. The works of Jell and Flood (1978), Flood and Scoffin (1978) and Hopley (1982) supported the reef zonation at Great Barrier Reef. However, in Thailand there is no the sediment dynamic research in the reef areas. This project emphasizes on the imagery technique and biological zonation, so the sediment dynamic is only observed among the ground truthing. It recommends that the hydrodynamic and sediment studying is important to classify the reef zone by the physical process, and that study will support the remote sensing studies on the reef morphology and zonation in the future.

5.3.2 Reef Zonation

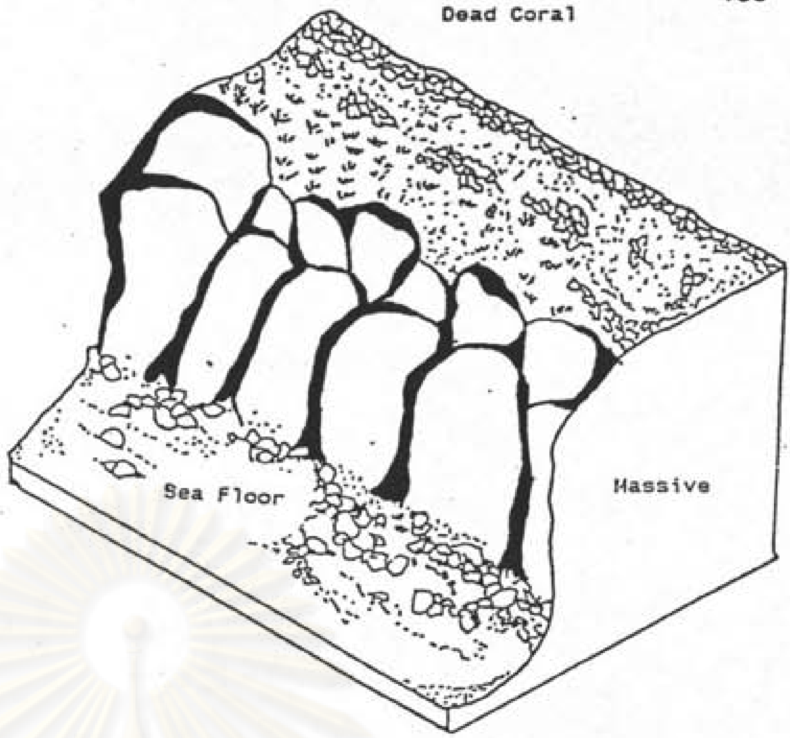
The imagery result identifies the reef in Samui Islands as 3 zones, reef slope, reef edge and reef flat. In each zone the morphology is explained from the imagery result combined with a ground truthing. The small area such as seagrass bed, reef edge and channel is identified in each zone. However, the area may be located in the intersection zones so the classification is used to select the major zone of that area.

5.3.2.1 Reef Slope

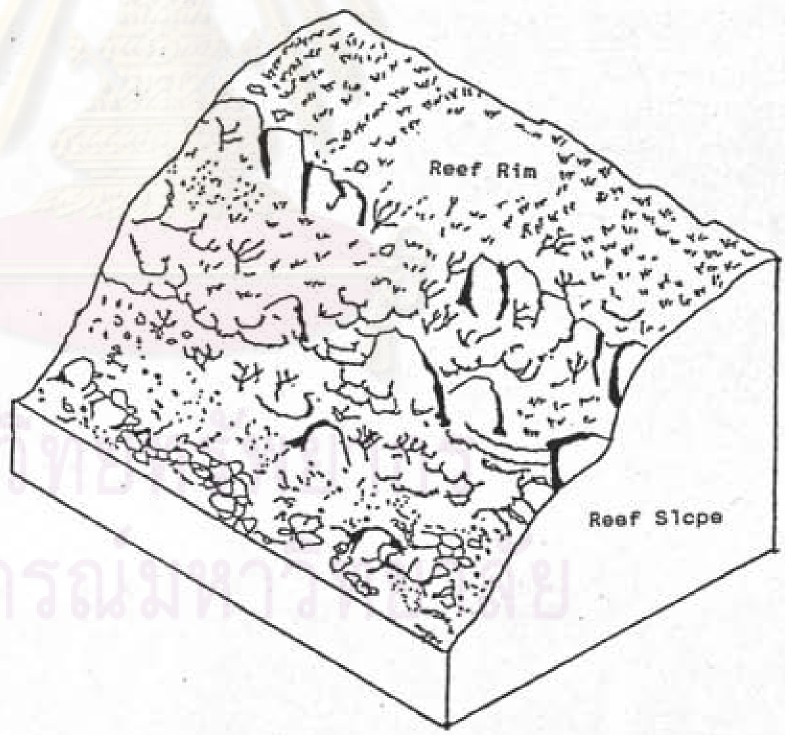
The most productive part in the reef is the reef slope because it is composed of living coral. The remotely sensed classification suggests that the reef morphology controls the situation of this zone. Maxwell (1968) suggested the reef slope coinciding with hard-line reef development contained the highest energy zone of the reef, he recommended that this zone could not be exactly separated from a inner part because it depended on the reef morphology. The results of multi-resolution map, for example Plai Laem Cape, clearly shown the black band of pixels which are identified as reef edge. In the seaward of this area is the reef slope. The remotely sensed results suggest that they can be used to divide the reef edge and reef slope from each other, and it will help to analyze the remotely sensed data within the reef slope area. The results also suggest that the remotely sensed data will help to locate the reef slope area which is very difficult to locate by the ground survey.

Hydrodynamic regimes resulting from depth, position relative to the reef edge, and prevailing wave action produce a zonation that is expressed in coral growth form, encrusting and digitate forms dominating in high-energy locations, branching forms in modulate-energy areas, and massive forms where wave energy is low (Done, 1977; Veron and Done, 1979). However, the coral areas at Samui may not support this hypothesis clearly because the morphology of reef slopes in Samui and that of the Great Barrier Reef are different.

The results from remotely sensed data in the reef slope area shown the different component zonations depending on the reef locations. Using the reef thematic results the reef slope zone in Samui Islands can be separated into two types, the gradual reef slope and the steeply reef slope (Figure 48). The multi-resolution results display the gradual reef slope type with the green pixels of reef rim, for example at Hin Ang Wang and Mat Lang Island. The ground truthing in both areas suggested that usually the depth at the end of the reef slope is 6-10 meters. The gradual reef slope has the high coral diversity and usually the corals have the predominant coral feature. The hypothesis from Great Barrier Reef may be used with this reef slope type, for example at the greater



Steeply Reef Slope



Gradual Reef Slope

Figure 48. Comparing of Steeply Reef Slope and Gradual Reef Slope.

depth species diversity increase and no one species dominates (Veron and Hudson, 1978). However, it recommends that the depth in Samui Reefs are not more than 10 meters while the depth at Great Barrier is 20-30 meters, so the zonation of reef slope at Samui can not be separated into upper and lower reef slopes as The Great Barrier Reef.

The ground truthing suggested that the gradual reef slope usually has the branching coral Acropora spp. and the submassive corals, Pocillopora damicornis and Acropora spp. as the predominant coral features (Figure 49). The massive and encrust coral may be found as a minor coral feature. The reef slope may cover an area up to 100 meters in width. The thematic reef result shows the reefs with gradual reef slope in the eastern part of Samui Island, such as Mat Lang Island and Sor Cape, and some islands in Tan Group, for example Hin Ang Wang and Rapp Island.

Figure 49. The Branching Coral, Acropora formosa, Dominates in The Gradual Reef Slope, The Dead Part Presents in White Colour.

The multi-resolution result displayed the wide gradual reef slope at Hin Ang Wang with the green pixels identified as reef rim, so the ground truthing operated in this area. The data suggest that the reef rim is a flat area locating between reef flat and reef slope with the high percent coverage of small living coral. In the reef rim usually the coral is a submassive coral feature distribute in the predominant form. The coral Acropora spp. and Pocillopora damicornis are the major species in this area (Figure 50). The ground truthing results from other reefs suggested that the reef rims at Samui Islands have these two coral species as the dominant coral in the reef rim. The research on Great Barrier Reef suggests that the reef rim in that area has the same coral form but may be different in the coral species (Veron, 1986). The results proved that remote sensing can be used to locate the reef rim and the ground survey will be done to report the biological condition in that area.

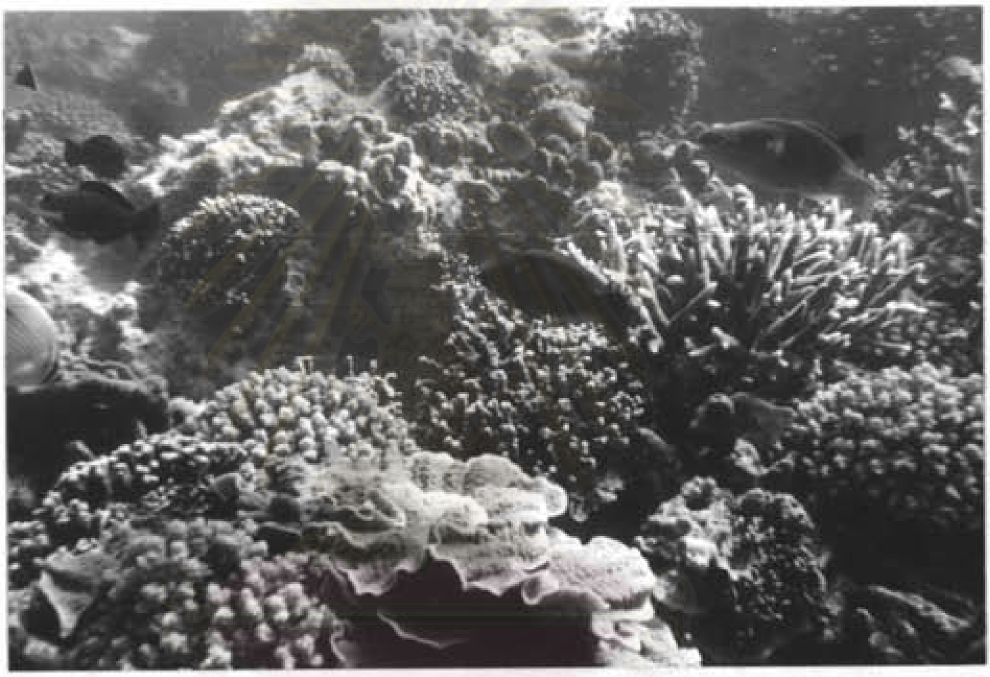


Figure 50. The Reef Rim at Hin Ang Wang.

The steeply reef slope is clearly displayed in some part of the thematic reef image at Samui, Pha-ngan and Angthong Islands. Because this area is very narrow which displays on the thematic reef image only one pixel so the multi-resolution results are used to examine this area. The result from Plai Laem Reef presents two or three pixels of the reef slope area which mean that the steeply reef slope is only 20-30 meters in width.

The steeply reef slope highly contrasts from that in the Great Barrier Reef. The sediment density slicing results present that this reef slope type is located in the high sediment area. The ground truthing at Plai Laem Reef showed the massive coral, Porites lutea, as the dominant coral in this area. This coral species has high tolerance of the sediment effect (Veron, 1986) so it can live in the high sediment zone. The reef shows the high diversity at the greater depth but not so high as the gradual reef slope. The ground truthing at Plai Laem Reef showed that this reef slope has only one or two massive corals packed together with some submassive and encrusting corals as the minor corals.

Finally, the remote sensing results can generate the reef slope area from other reef zones, and it can be used to examine the reef slope characteristic especially the reef rim. Using the ground truthing following the remotely sensed results the data advises that the reef slopes in Samui Islands have two patterns. The ground truthing also presented the dominant coral in each type. The division of reef slopes at Samui Reefs is different from Great Barrier Reef.

5.3.2.2 Reef Edge

The reef edge is the zone located between the reef slope and reef flat. The thematic reef image can separate this zone from the others by the substrate components because the major component in the reef edge is dead coral while the reef flat is sand. The ground truthing checked the substrate components in the reed edge. Based on these results the reef edge at the study sites is divided to reef edge zone, living coral zone and coral rubble zone. The channel and spur which appear only in the thematic reef results from Samui Island are also examined by multi-resolution and ground truthing.

i Reef edge

The remotely sensed results clearly show reef edge zone between the reef slope and reef flat. Usually the thematic reef results do not clearly show the reef edge because this zone is very narrow, so it may detect the reef edge zone in the thematic reef map by observing the area between the coral rubble and living coral groups. The multi-resolution image may be better to display the reef edge morphology. Usually it is used to observe the brown pixels such as at Mat Lang Island or white pixels at Na Tian Island. The remotely sensed results suggest that the reef edges at Samui Islands have many types.

The ground truthing suggests that there are large blocks of coral packed together. The reef edge morphology showed something similar to reef blocks in the Great Barrier Reef because the reef blocks are generally isolated in such locations and are topographically significant enough to appear on marine charts (Hopley, 1982). The dissimilarity between reef edge and reef block is the formation and pattern. Fairbridge (1967) claimed there were two type of reef block origin, those thrown up by waves and those that eroded from the higher reef. Using the ground truthing it is recommended that a reef edge usually is the high place in the reef area, so the reef edge origin came from the coral blowing up from reef slope.

Using the imagery result, the reef edges in Samui Reefs are separated into four types, submerged reef edge, massive reef edge, mangrove reef edge and unvegetated reef edge. This classification is based on the results from thematic reef result and multi-resolution map.

i-1 Submerged and Massive Reef Edge

The thematic reef result at Mat Lang Island clearly shows the coral rubble zone in the band of pixels. This band is supposed to be the reef edge so the multi-resolution technique is used on this area to examine this reef pattern. The multi-resolution result displays the brown band of pixels in this area which are identified as dead corals. The ground truthing checked this area and found that it is a submerged area which only exposed during the low tide (Figure 51). The ground data show that the submerge reef edge is composed of dead coral with turf algae. This reef edge shows two correlations with the reef block. The first correlation is that both reef zones are submerged. The second is that the ground data concerned show that the dead corals at this reef edge are not in original growth similar to those studied by Fairbridge (1967).

The sizes between the reef block and submerged reef edge are nearly the same. The reef blocks at Great Barrier Reef are 200-300 meters in length and 20-50 meters in width (Scoffin and McLean, 1978), while Mat Lang reef edge is 150 meters in length and 20-40 meters in width (measured by the multi-resolution map). An unconventional feature among these reef patterns is diameter of dead coral. The reef blocks are several meters in diameter while the diameter of dead corals at submerged reef edge is approximately one meter.

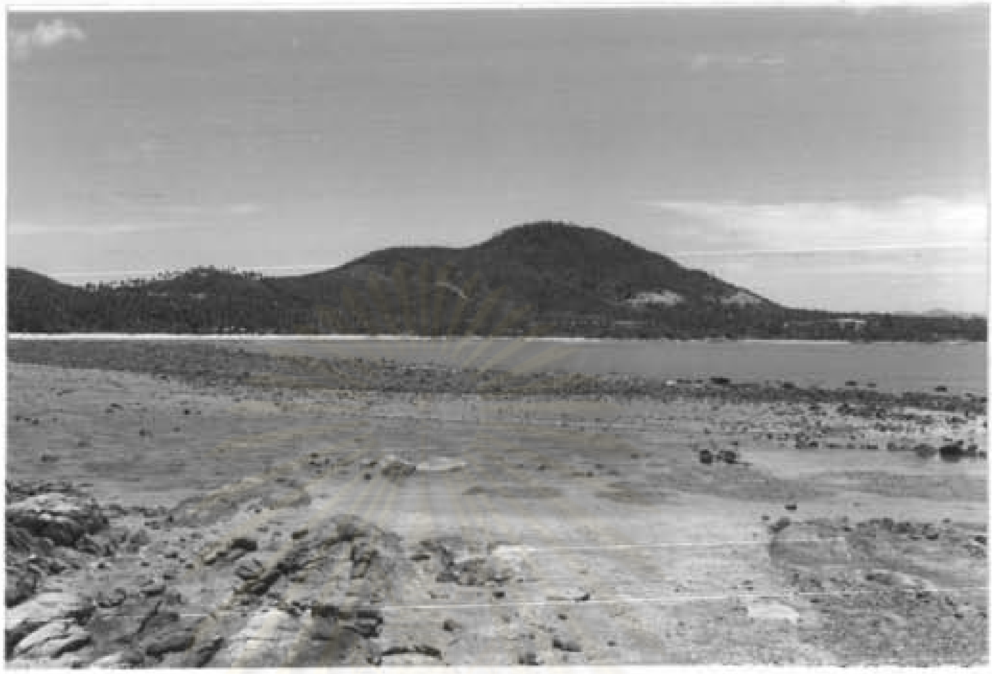


Figure 51. The Submerged Reef Edge During Neap Tide at Mat Lang Island.

The thematic reef result at Plai Laem shows the narrow band of pixels which are classified into the coral rubble areas close to the living coral areas. These areas are displayed in the thematic reef image different from the submerged reef edge at Mat Lang Island. This area may be another type of reef edge. However, it is hard to detect by the thematic reef image so the multi-resolution is required to examine this area. The result shows that the reef edge in the area is different from other reef edge in term of morphology. The ground truthing was done and the result supports the remotely sensed result because the component of this area is the living coral while others are dead corals.

The ground truthing in this reef zone also reported the biological condition. The big massive coral, Porites lutea, is packed together with the scarce head (Figure 52). This may be caused by the high wind and wave effect and the explosive of the coral head during the low tide. The sargassum brown algae dominate in this area which can be seen in Plai Laem image as the patch of brown green pixels. The species vary depending on the wind and wave action. The high wind and wave action cause the living animals to have good attachment organ, for example cowrie and turbo shell. The remotely sensed results suggest that the massive reef edge is usually located with the steeply reef slope, for example Plai Laem Reef. The remotely sensed result at Nai Wog Bay also supports this conclusion. In the reef zone classification at Great Barrier Reef, (Hopley, 1982) did not explain this zone so it may be a distinct characteristic of the Samui Reefs.

Figure 52. The Massive Reef Edge at Nai Wog Bay, Pha-ngan Island.

The thematic reef results from Samui and its surrounding islands shown another reef edge zone. These areas are clustered with the land class, however, they are located on the reef. The classification process tried to emphasize on these reef areas. However, they are very small composed of 5-10 pixels so the classification results cannot explained this area so much. The multi-resolution reef map was used at Mat Lang Island and it clearly presented that this area is the reef edge zone which is different from others because they are exposed all time and the component in this area is different. They can be called as exposed reef edge. The ground truthing suggested that the exposed reef edge consisted of white dead coral because it is exposed to the sun light all the time so the algae can not be encased.

i-2 Mangrove Reef Edge

The multi-resolution result from Hau Thanon which is located far from the shore does not have the vegetation growing on the cay. The imagery results from Mat Lang and Na Tian Islands show the reef edges with mangroves on the top (Figure 53).

Figure 53. The Mangrove Reef Edge at Mat Lang Island.

Stoddart and Steers (1977) noted that, in the Caribbean, islands were formed by colonization by mangroves of shoal areas without the shingle ramparts and the low wooded islands are common. The imagery result suggests that the mangrove reef edges at Mat Lang and Na Tian Islands have the band of mangrove on the top. The few examples on the Great Barrier Reef occupy a high proportion of the reef top and, in places, approach to within 100 m of the upper reef slope (Hopley, 1982). No studies of these islands have been made but aerial photographs indicate great uniformity of species, probably Rhizophora. The multi-resolution result suggests that the mangrove band at Mat Lang Island is only 50 meters from the reef slope and it is a part of reef edge. The ground truthing reveals that most mangrove is Lumnitzera racemosa which is different from Great Barrier Reef, so the mangrove reef edges at Samui Islands have its own characteristic.

i-3 Unvegetated Reef Edge

The thematic reef results suggested that this reef edge is found only at Hau Thanon Reef. The multi-resolution result is identified and it can be concluded that this reef edge has the sand and coral fragments as the major component. In the reefward part the coral fragments are became the major component while the landward part has the sand as the major component. The result concluded is that the wave energy blow the coral fragments from the reef slope, which are distributed in the wide area as the green pixels seen in the multi-resolution map, to the reefward part. While the landward part has the low wave energy so the sediments which come from the water movement in this reef settle down in this area.

The hypothesis explaining the different formations of both reef edge types is that the mangrove reef edge is located close to the continental island so the mangrove from the continental island can be distributed to that area and it is called mangrove reef edge. While the reef edge at Hau Thanon dose not have the mangrove because it is located far from the island.

ii Living Coral Zone

The thematic results show that the living coral areas in Samui Islands are not distributed only in the reef slope. The thematic reef image from Mat Lang Island and Bang Po Island clearly show the living coral area in the reef edge zone. The thematic reef image combined with ground truthing found the living coral zone in the reef edge located behind the reef edge. These living coral areas are found in patch form and the bottom is sand or coral rubble. The result from multi-resolution reef map shows that the colours of pixels in the living coral at the reef edge area and reef slope area are not the same. The ground truthing was done in the reef edge area and suggests that massive and submassive corals are the dominant corals. The different colour of pixels may come from the coral shape. In the reef edge area the massive corals, <u>Porites lutea</u>, are 30-50 centimeters in height, and it has a dead coral head, only at this site corals are alive (Figure 54). While the massive corals in the reef slope area are 1-4 meters in height and they are alive in all part. The source of this dead coral head in the reef edge may come from the low saline water from rain, sun light may kill the coral at low tide or sediment may settle down on this coral head so the coral polyps are dead.

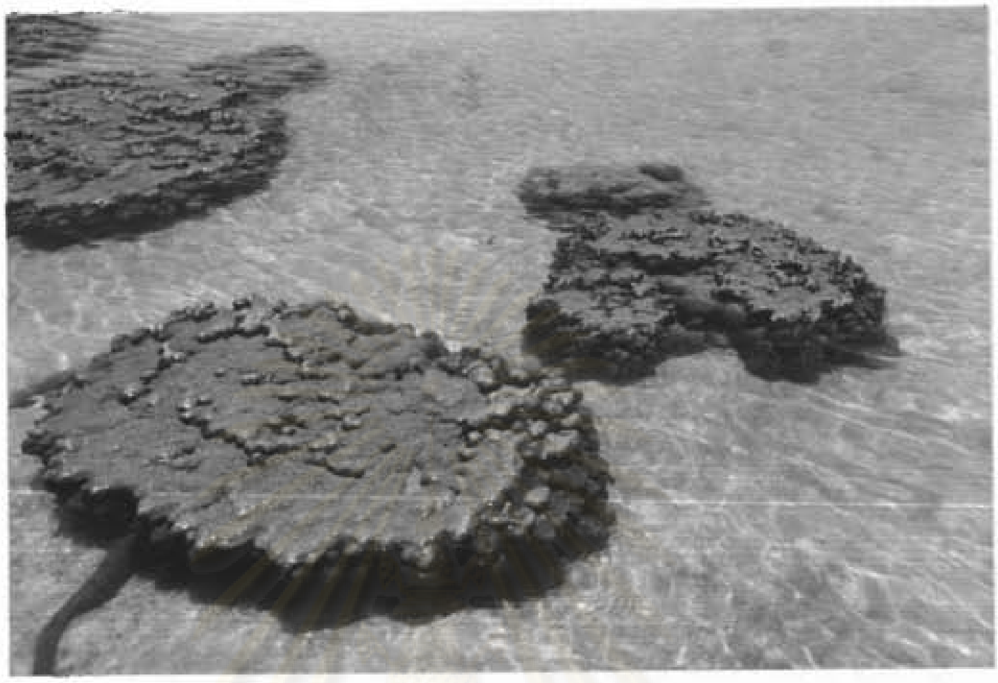


Figure 54. The Massive Coral with The Dead Head at Mat Lang Island.

Along this living coral zone there are other living organisms growing in this area as the minor component. These organisms are algae, seagrass and sponge. The multi-resolution result shows that in some reefs, for example those at Mat Lang Island, there are the patch of different colour pixels displayed close to the living coral in the reef edge area. The ground truthing suggested that those areas have other organisms distributed as the major components while the living coral is a minor one.

The multi-resolution result combined with the ground truthing data reveals that among the patches of other organisms, the algae patch is clearly observed. Stoddart (1969) suggested that the area behind the reef edge dominated with the crustose coralline algae, called "Algal Pavement". In Samui Reefs the imagery result at Mat Lang Island reveals that the algae areas are found in patch form, they do not cover the large area as Great Barrier Reef and the area are dominated with many algae. Another example is the reef thematic result from Nai Wog Bay. Many algae are distributed in this area in patches. The principle component analysis displays the algae patch located in front of seagrass bed, so it can not be grouped as an algae pavement. This project calls it an "algae patch", and the ground data reveal there are many algae species in this area such as Caulopa spp. and Padina spp.. The coral submassive is the minor component with Acropora spp. (Figure 55).

Figure 55. Algae Patch in front of Seagrass Band at Nai Wog Bay.

The reef thematic results from Nai Wog Bay during the winter season (in December) display the large brown algae, Sargassum spp., dominantly in this living coral area of the reef edge. This algae may cover all the reef edge area especially at Tae Nai Island. It is recommended that the colour of this algae is brown and it looks similar to the seagrass leaf in this area, so the remote sensing or aerial photograph studying must carefully examine their data principally from October to March.

The multi-resolution data from the reef edge at Mat Lang Island present sponge, calcareous algae and seagrass as the dominant organism in the living coral area. The imagery result suggests that this area has the high variation components. However, the multi-resolution result can not classify each zone from the others because they are not distributed in patch. The ground truthing reveals that the sponge in this area is the big sponge (Class Calcarea) and it usually grows to 20-30 centimeter in height. The sponge is usually located between the massive coral, Porites lutea. The calcareous algae, Halimeda spp., are scattered around this area on the white sandy substrate. The seagrass, Enhalus acoroides, is distributed on the sandy substrate between the massive coral.

iii Rubble Zone

This area is a morphologically diverse zone characterized by deposition of coarse material from reef edge. The reef thematic results from Samui Islands suggest that this area should be grouped in the reef edge zone because the source of substrate component is the same. Stoddart and Steers (1977) suggested that this area is a feather edge of shingle on the reef flat and is often indistinct in maps. In plan it roughly parallels the edge of the reef. Using the remotely sensed result to map this area it is possible to locate the border between this zone and other zones because the reflectance of dead coral in visible band is higher than the other areas except the sandy reef flat which is far away.

The multi-resolution results suggest that the materials of the rubble zone are dominated by coral fragments. The ground truthing suggests that the origin of this coral fragment came from the reef slope and living coral area in the reef edge. The living coral is absent from this area. Only a few small encrusting corals, Montipora spp. and Plategyra spp., may be found. The major organism in this area is coralline algae and turf algae covering the coral fragment.

The remotely sensed data suggest that although the zone in the reef edge in Samui Islands can be separated into three areas, these zones may not be observed in some reef imageries. In some reef edge, the remotely sensed results present the reef categories in the reef edge area which are identified as channel and spur. These reef patterns control the reef process so the results will be examined.

iv Channel and Spur

From the reef thematic data among the study sites, the channel and spur can be clearly observed only in the reefs located on eastern part of Samui Island. Hopley (1982) suggested that the channel may be erosional and result from pleistocene subaerial sculpture, and probably growth features maintained by movement of water along the channels. He also suggested that the best development was in the windward site. This implication supports the formation of the channel and spur located on the eastern part of Samui which is the high wind and wave effect, and the suggestion indicates that Samui Reefs have the long developmental period.

The research in the Andaman Sea recommends that Surin Island which is one of the biggest reefs in the Andaman Sea dose not has a channel and spur (Thamrongnavasawat and Sudara, 1991). It recommends that the channel and spur at Samui are the rare example of Thailand. From the remote sensing studies on the reef at the eastern part of Thailand, Chang Island, the channel and spur can be observed (Thamrongnavasawat, Siripong and Sudara, 1990). The channels in Chang Islands are located only in the northern part of Kradat Island with a few small channels close to the others. The research suggests that these channels are constructed by the tidal current.

To compare the channel morphology of Samui and Kradat Islands, the false colour images are used. The results suggest that the channels at Kradat Island are smaller and shorter. They are located near the channel border, and the channel is presenting only at the reef edge and absent in the reef flat area. The false colour image from Samui clearly display the channels located from the reef edge through the reef flat and finished at the shore, for example Nan Reef and Hau Thanon Reef. Checking with the multi-resolution result this observation is clearly supported. The ground data reveal that these channels are developed by human, they dug the natural channel for boat transportation (Figure 56). However, a few channels in Samui are still undestroyed and they are located only in the reef edge area, for example the channel at Mat Lang Island. Recently the tourist development at Samui Islands induces the people to develop channels for boat transportation. So many natural channels are being destroyed. From the multi-resolution result there are three boat transportation channels in 1989, but a ground survey in 1991 revealed that the boat transportation channels were five. The development os these channels destroy reef organisms in that area. For example, the seagrass patches at Tan Island are covered with sediment after the channel was enlarged (Figure 57). The impact also disturbs the physical process in the reef area, and it may cause the changing of reef morphology.

The results from reef thematic image and multi-resolution map shown the living coral area in the channel side. Maxwell (1968) described that this living coral can be called as "spur". Kuchler (1986) suggested that the spur can be easy to locate by the remote sensing studies on the Great Barrier Reef. From the remotely sensed data at Samui Islands the spurs are not spotted on the site of the channel. The ground data suggested that the channel in Samui Islands has the site depth only 1-2 meters so the coral cannot be grown. The living coral can be found only in the end of the channel mouth which the ground data reveal that this area may be around 3-4 meters in depth. The multi-resolution displays the suggested spur in brown and dark green patch located on the mouth of the channel, for example Mat Lang Reef and Nan Reef, and the ground truthing suggests that the dominant coral in that area are massive coral. The coral feature at Samui channel is different from that of the Great Barrier Reef because Veron and Hudson (1978) suggested that the spur has the branching coral as the dominant coral.

Figure 56. Boat Transportation Channel at Tan Island.

Figure 57. The Inner Part of The Channel at Tan Island.

The ground data reveal that the size of massive coral depends on the depth of the channel. If the channel is deep, there is a big coral in that area, and usually still living in any part. The channels at Hau Thanon and Mat Lang are good examples for this living coral pattern. If the channel is shallow, there is a small coral and usually the coral head is dead. The results suggest that the size of channel does not control the coral size. For example Mat lang Island has the small grove compared with that at Nan Cape but the coral at Mat Lang is bigger than the coral at Nan Cape. The report from the Great Barrier Reef supported this hypothesis (Jell and Flood, 1978).

The results suggest that the thematic reef map can be used to locate the reef edge in a wide area, while the multi-resolution process can help to study the morphology and substrate components of the cay. A ground truthing is required to check the substrate in each zone and it will help for more understanding of the process that controlled the reef edge.

5.3.2.3 Reef Flat

The imagery results present some reefs with the clear border of reef flat and reef edge, for example Nai Wog Reef and Plai Laem Reef. Nai Wog Reef has a seagrass band as the zone for generating the reef edge and reef flat from each other, while at Plai Laem Reef the rubble zone and the reef flat can be separated in clear borders. Hopley (1982) separated the reef flat at Great Barrier Reef into three zones, an aligned coral zone, a nonaligned coral zone and the sandy reef flat.

An aligned coral zone is the detailed morphology depending on the depth of water over the reef flat at low tide. A nonaligned coral zone is located behind the first zone and receives the lower wave energy. The reef flat may be formed from randomly scattered coral colonies with intervening sand patches. The reef thematic results suggest that the reef flat at Samui Islands may be to smaller to find the aligned and nonaligned coral zones. Another case may come from a lagoon, the Great Barrier Reef has the lagoon in a reef flat and scientists use this lagoon for moderating the aligned and nonaligned modules. However, the false colour image at Samui Islands does not display a lagoon in the reef flat, only a few blue pixels can be observed from the multi-resolution map from Plai Laem and Nan Cape. These patches of pixels are identified as small lagoon which are different from those at the Great Barrier Reef. The reef thematic results suggest that no living coral grows in a reef flat area. The major component of reef flat at Samui Island is sand.

The sandy reef flat described by Flood and Scoffin (1978) is the theory to support the sandy reef flat at Samui. They suggested that the reef flat formed a monotonous area of sand. The sediments were the blanket sands and were normally only a few centimeters thick. The ground truthing confirms this suggestion by digging the reef flat at Mat Lang Island and finding the packed coral fragments and shells at the depth not more than 30 centimeters from the surface.

Cribb (1976) advised that where a shallow cover of water was maintained during low tide, a lot of algae that might vary in their cover seasonally, occurring together with seagrass. The reef thematic results from Nai Wog Bay and the multi-resolution map from Mat Lang Island suggest that the algae and seagrass also cover the sandy reef flat with seasonal changing. The vegetation in the reef flat acts as a binding and baffling mechanism allowing the settling of silt and fine sand, resulting in a sediment with a wide range of size (Hopley, 1982). The results from the study site at Nai Wog Bay and Mat Lang Island support this hypothesis. Although the sediment at Nai Wog Bay presents its surface as coarse sand, the sediment beneath the surface is fine silt. At Mat Lang Island the sediment in the seagrass patch and Halimeda is different, for Halimeda the sediment is fine sand with may be suitable for this algae. While the sediment at a seagrass patch is similar to Nai Wog Bed, the result demonstrates that the sediment in the vegetation may give an idea for classification of the sandy reef flat zone.

The vegetation area in the sandy reef flat is an important zonation, because it produces the high primary production in this area. So many reef fauna stay among the reef flats. The remotely sensed results suggest that the vegetation area can be separated into two zones.

i Algae Area

Taking Mat Lang Island for an example of algae patch on the reef flat, the ground truthing found that the area was covered with a different species of Halimeda. This algae species is different from Cribb's (1966) suggestion, that is, the algae in sandy reef flat at Great Barrier Reef are Padina, Dictyota, Hydroclathrus and Sargassum. The thematic reef image at Mat Lang Island presents the Halimeda area close to the shore. This algae is distributed in patches. In one algae patch the diameter is more that 10-15 meters. However, the algae do not grow close to each other. The distance may be 5-10 centimeters between one algae to the others.

ii Seagrass Area

The seagrass species at Samui Islands are also different from those at the Great Barrier Reef. Cribb (1966) recommended that the seagrass species were Thalassia hemprichii with Halodule spp. and Halophila spp.. The ground truthing at Samui demonstrates that the seagrass on the sandy reef flat is dominated with Enhalus acoroides. The research on seagrass at Samui (Nateekarnjanalarp, 1990) suggests that there are some small patches of Thalassia hemprichii distributed at Tan Island but the ground truthing over there finds that the seagrass is absent because of the construction of boat channels.

The reef thematic results from Samui Islands show two seagrass locations on the sandy reef flat. The seagrass at Nai Wog Bay, Pha-ngan Island, is distributed in the band parallel to shore. This seagrass area can be classified as seagrass beds because they spread over a wide area with dense seagrass. Another seagrass location is located at Mat Lang Island. In this area the seagrass is distributed in patch form. The biggest patch size calculated from the reef thematic process covers the area approximately 17,000 square meters. Comparing with Nai Wog bed which covers more than 120,000 square meters, seagrass at Mat Lang is classified as a seagrass patch. However, this patch has a high density of seagrass. The result concludes that the seagrass density does not control the pattern of seagrass communities in Samui Island.

The reef thematic results suggest that the seagrass bed at Nai Wog Reef is the biggest seagrass bed in Samui islands (Figure 58). This bed is located on a border between the sandy reef flat and the reef edge with the dead coral substrate. The reef classification results suggest that seagrass location along Samui and Pha-ngan islands are on the same substrate as this bed. The result recommends that the reef flat at Nai Wog is suitable for seagrass habitat with the long border of sand and dead coral components, while other reefs have the mixing component so seagrass is not distributed over a wide area. This area is composed of different dense zone so the process can not calculate the total biomass of this area because it needs a biomass in each area for the calculation.

The ground data reveal that seagrass patches in those reefs may have seasonal changing. A ground truthing at Nai Wog serves this seasonal changing hypothesis. A seagrass bed classification corresponded with ground survey at Nai Wog Bay in 1988 concerned this bed had the seagrass location in one location. However, when a ground survey was done in 1991 the bed shape was changed. This suggestion does not come only from the remotely sensed classification, but the ground survey and horizontal photographs support this hypothesis. It recommends that the remotely sensed survey will help to study seagrass seasonal changing. To analyze the total biomass, the ground truthing must inspect not far from the satellite passing time.

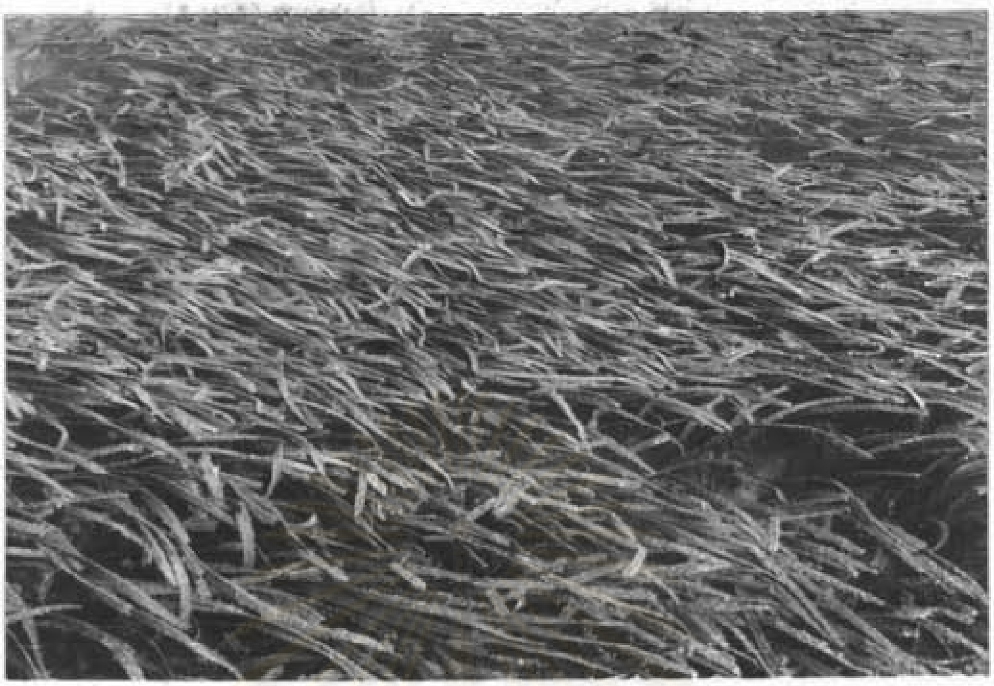


Figure 58. The Seagrass Bed at Nai Wog Bay, Pha-ngan Island.

iii Cay

There is the area on the reef flat that shows a similar pattern to the cay that is reported from Great Barrier Reef. Based on the cay and related coral island, the features are constructed from the biogenic materials of the reef and it is a distinctive morphological zone of a reef. McLean and Stoddart (1978) suggested that the cays of Great Barrier Reef show the great range of size and shape of coral fragments. The ground truthing suggested that the cays at Samui Islands present the similar component. It suggests that a large area is unnecessary (Hopley, 1982), so the cays at Samui which the remotely sensed data calculated as varied from 18,000-34,200 squares meters in area is classified as the cay. It is recommended that this is the first cay group which has been classified in Thailand.

The cay is separated into two types following Hopley (1982), unvegetated solitary island and vegetated solitary island. The cays in Samui have these two types.

An unvegetated cay parallel to the reef front is in reality a form of linear shingle cay (Hopley, 1982) which is one form of unvegetated cays. Similar to other cays at Great Barrier Reef, the cays at Samui are located in the middle part of the reef. The remotely sensed results from all study sites suggest that there are only one locations clearly showing the morphology which is similar to the unvegetated cay type. This site is Tae Nai Island.

The thematic reef image at Tae Nai Island shows that this cay is located in the fringing reef. The ground truthing result found that fine sand is the major component while the coral fragments in this area are very rare (Figure 59). Based on the location of this cay on the leeward site of the island, this cay may be formed by the sedimentation process. Fine sand may be the main cause that make this cay did not have the tree.

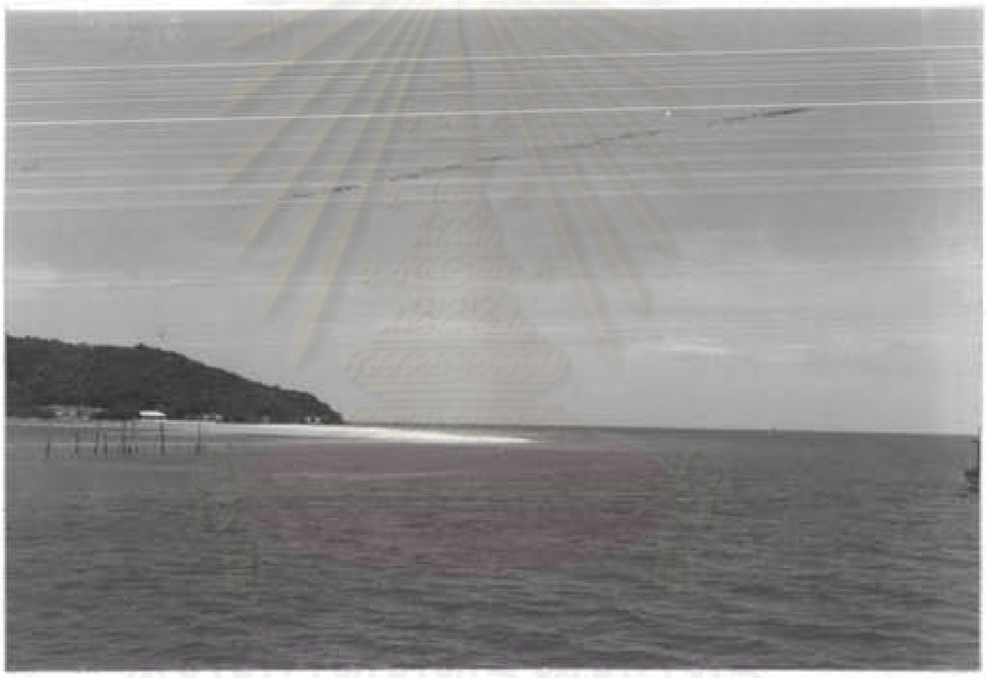


Figure 59. The Unvegetated Cay at Tae Nai Island.

The vegetated cay is formed in the middle part of the reef, and there are some tree grew on the middle part. The multi-resolution result suggests that Hin Ang Wang clearly presents this cay pattern. This cay has two cays located on the patch reef. The image identification and ground truthing data suggest that these two cays have coral fragments as the dominant substrate. The high wind and wave effect may blow the coral fragments from the reef area to these cays. The result also suggests that these cays may be connected together in the future. The ground data reported that the vegetation on this cay are a small bush.

5.3.3 Reef Classification

5.3.3.1 Key to Reef Classification

The classification has been the center feature of traditional geomorphology. Usually the classification runs with the study in the reef development and geomorphology which is called genetic classification. It is surprising that the simple and extremely broad theory of Darwin (1842, cited by Hobley, 1982) is still in common use for describing reef forms. However, the Darwin classification was done in the reefs located in the ocean, the characteristic of those reefs are different from Samui Reefs because of the unlike environment. The reef classification at Great Barrier Reef done by Fairbridge (1950, 1967) and Maxwell (1968) using the reef morphology and result of fractures from reef development during pre-Holocene is common for describing about the Great Barrier Reef. However, the Great Barrier Reef is located in a dissimilar environment compare with Samui Reefs, and the range of Latitude is wide (12° - 24° South) while Samui Reefs has a narrow Latitude range ($9^{\circ}15'$ - $10^{\circ}10'$). The classification which is described above is used only to support the classification in this project.

The key to classify the reefs at the Great Barrier Reef is lagoons. With this reef feature they separate the reefs into four groups, juvenile, mature, senile and ribbon (Fairbridge, 1967; Maxwell, 1968). Using the latitude variation the reefs can be generated in 10 regions (Hopley, 1982). However, the scientists accept the hypothesis that a major control is the morphology of the reef which is correlated with major structure features of the coast. They use the important reef feature to classify the reef.

It recommends that this is the first spatial reef classification in Thailand, because the classification which was described by Sudara, Thamrongnavasawat and Sookchanuluk (1989) used the ground data from the sample reefs. That classification generated the reef by the developmental stage in three types, coral community, coral community development of fringing reef and early formation of fringing reef. The classification groups all reefs in Samui Islands in an early formation of fringing reef type. They suggest that the percentage of living coral covering the area is not an important factor to classify the reef, but the reef morphology and zonation are the important factors.

Based on all classifications which are described above, Samui Reefs are the fringing reefs. The classification will be generated in reef type and reef region. The reef type is separated by the reef feature and the reef region is separated by the sediment density zone which is an important factor controlling the reef.

5.3.3.2 Reef Types

This classification will use the reef morphology which is observed from the imagery results. Although a lack of studying in the development of the reefs in Thailand may cause an error in this classification, the reef morphology and zonation results from remote sensing may help to solve this problem. The reef type is simply generated into two reef types, the fringing reef and the patch reef.

i Fringing Reef

According to the Darwin concept of reef development, fringing reef directly attached to mainland or island are the basic form, mainly characteristic of stationary of rising coasts. So most reef in Samui Islands belong to this type, except a few reefs which are grouped in the patch reef form. In the three main types, fringing reefs are the simplest, apparently the least in need of complex explanation, and also the least studied (Steers and Stoddart, 1977). It is also questionable whether or not fringing reefs form the basic structures of barrier and atoll formation as suggested by Darwin. Such evidence is still lacking and is indicative of the generally small amount of research carried out on fringing reef.

The fringing reef classification uses the main reef feature for generating them. In the Great Barrier Reef, the scientists use the lagoon as the reef feature to generate the reef. In this classification the reef edge which is the important reef feature correlating with the developmental of the reef, and the pattern of the reef edge can be generated in three types. With this classification the fringing reefs in Samui Islands are generated to four types, reef without reef edge, reef with massive reef edge, reef with submerged reef edge and reef with exposed reef edge.

i-1 Reef without Reef edge

The first classification of the reef in Thailand (Sudara, Thamrongnavasawat and Sookchanuluk, 1989) suggests that the reef and the coral community may be divided from each other by the reef edge. Based on this hypothesis the reef without a reef edge may be grouped in the coral community, however, more study of the reef development is required to support this hypothesis.

The reef without the reef edge has the mixing zones. Reef flat and reef slope are hardly separated from each other while the reef edge is absent from this area. The reef starts from the rubble zone and the shore profile smoothly drop. The coral is distributed at the end of the slope with many coral features. Usually the unique coral feature cannot be found in this area. However, in some areas, for example Ao Luk Tao Island, the unique coral area can be detected.

From the imagery result, this reef type cannot exactly locate the site. The reefs are spotted on Bang Po to Sai Cape, Samui Islands, Luk Bay and Sai Lee Beach, Tao Island, Ko Ma, Pha-ngan Island and a lot of them in Angthong Group. According to the randomly reef location, it is hardly to expect what is the factor controlling this reef type. A ground data recommends that most reefs are usually located on the steeply shore profile, except the reef at Tao Island. The reef flat slopes without the zonation, and the small coral may be found in the reef flat area. During the low tide, only the rocks on the shore or a beach are exposed, no reef zone in this area is exposed.

i-2 Reef with Massive Reef Edge

This reef type is a major pattern in Samui Islands, the imagery results suggest that this type can be separated from the reef zonation. In each zone there are the component areas as described in the reef morphology session. The massive reef edge may not be exposed during the low tide, but it is shallow and blocks the wave action. The size shows no significance with the reef pattern. Elsewhere, for example Hin Khom Reef, the reef covers the area only 120 meters in width. In Nai Wog Bay or others, the reefs are 300-500 meters in width.

This reef type usually has the separated zonation. Taking Nai Wog Reef as an example, the reef slope, reef edge and reef flat have clear borders. The seagrass bed in that area is also separated. Plai Laem Reef is one of good examples, the reef flat has a different part of grain size, this recommends that the hydrodynamic in this reef follows the hypothesis which is described above.

i-3 Reef with Submerged Reef edge

This reef type is located on the eastern and southern parts of Samui Islands. A good example is Nan Cape and Set Cape. Somewhere the submerged reef edge may be found in the reef with has an exposed reef edge, for example Mat Lang Island. The result suggests that the submerged reef edge may be developed from the massive reef edge which is located in the high wind and wave action. Although the submerged reef edge can block the wave action better than massive reef edge, the higher effect of wave action makes the hydrodynamic process higher in the inner reef area, so it has a mixed component zone.

i-4 Reef with Exposed Reef edge

The exposed reef edge reefs cover the eastern part of Samui Island. This reef pattern includes the reef with mangrove reef edge and reef with unvegetated reef edge together because the pattern of the reef is similar to the others. These reefs have high wave action, so the reef edge is developed by the coral fragment. It recommends that among the reefs in The Gulf of Thailand, only this area has the reef with exposed reef edge.

The thematic reef image advises that the zonation of this reef is usually mixed with many components. However, the reef zones cover a wide area. The rare reef features, channel and spur, are observed in this reef pattern. It recommends that this reef type has a high developmental stage. All reef type locations are illustrated in Figure 60, 61 and 62.

ii Patch Reef

One important reef pattern in Samui Islands is the patch reef. In the Gulf of Thailand only Samui and Chang Islands have the patch reefs (Thamrongnavasawat, 1990; Thamrongnavasawat and Sudara, 1991).

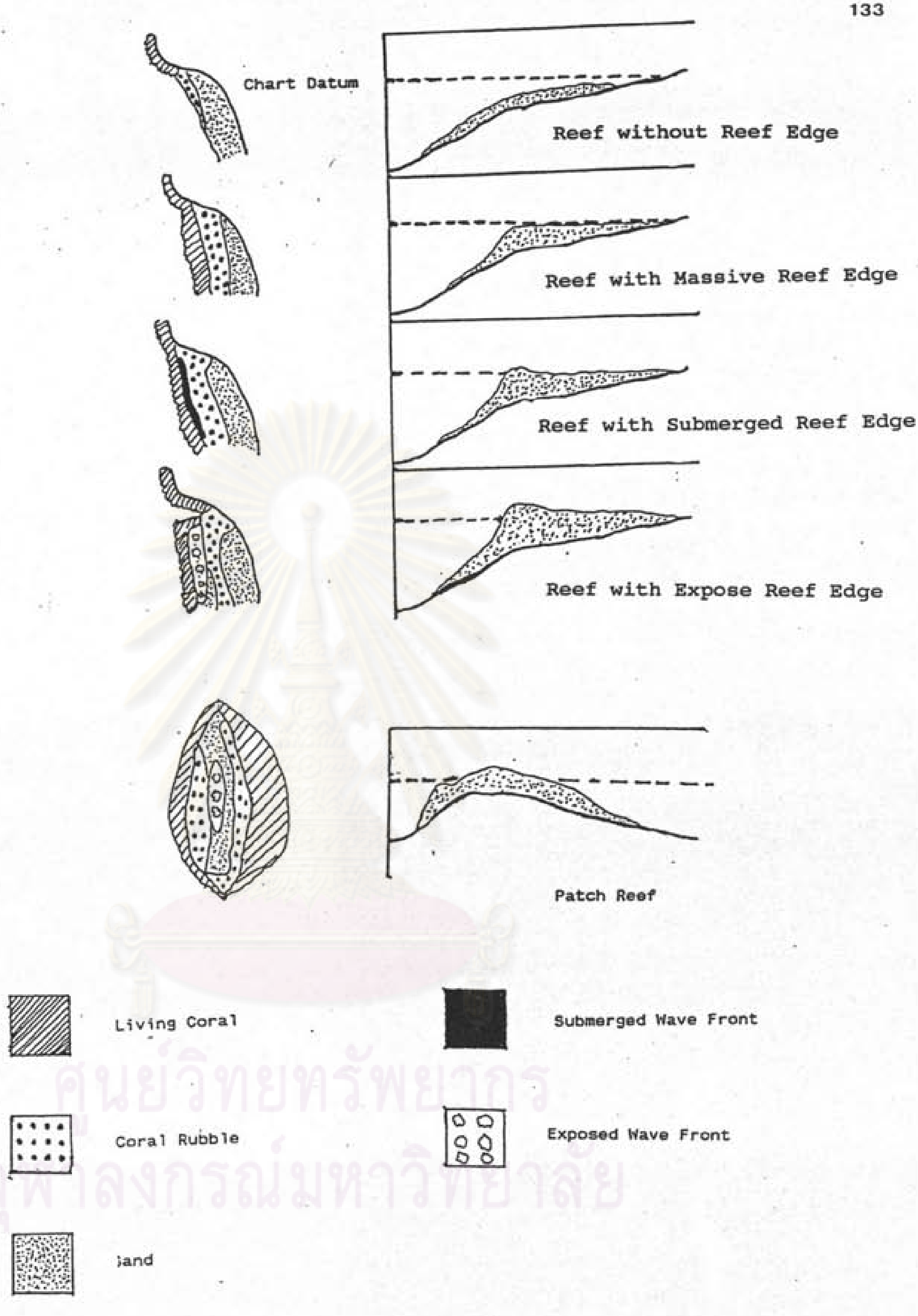
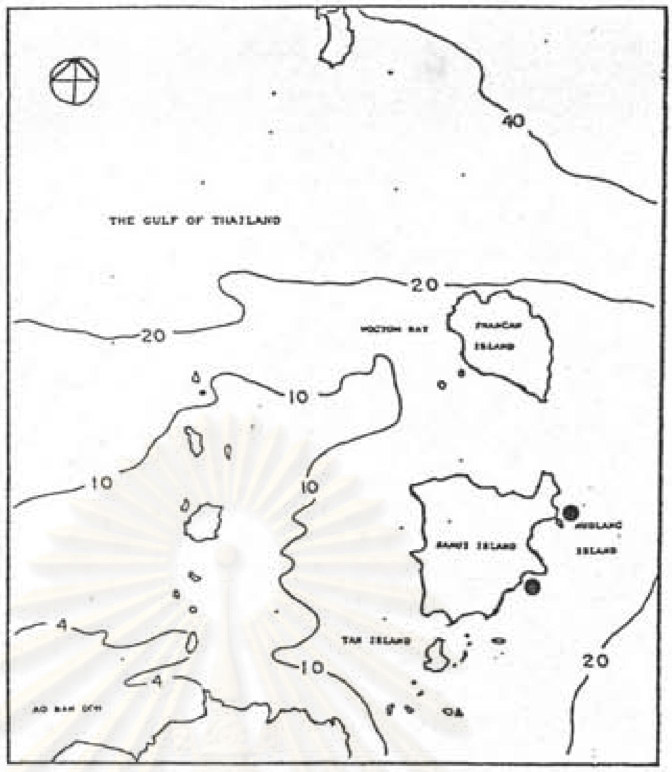
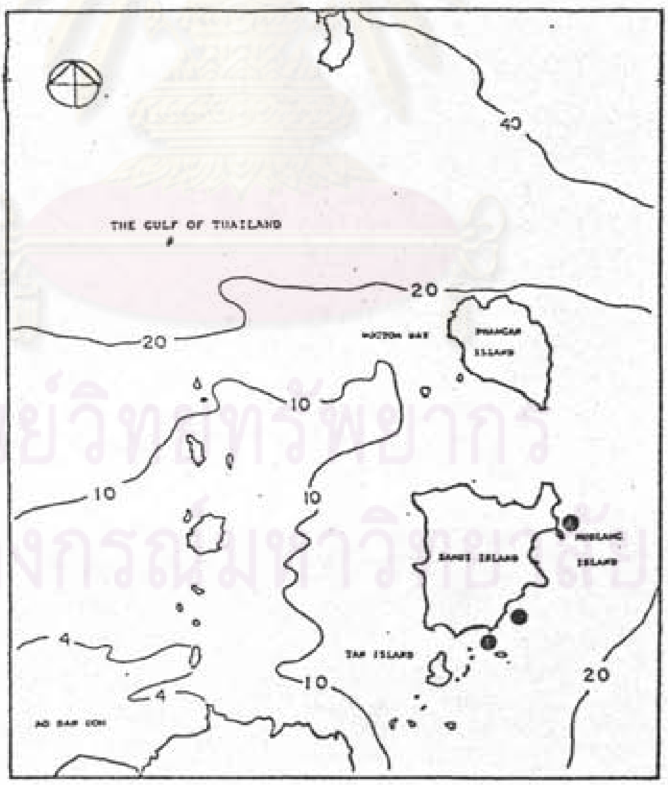


Figure 60. Reef Developmental Stage of Samui Islands.

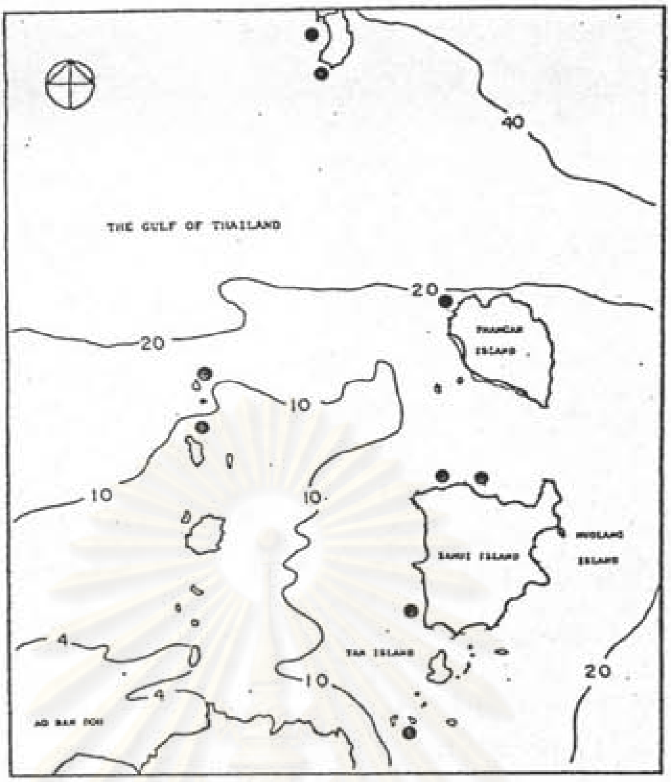


Reef with Submerged
Reef Edge

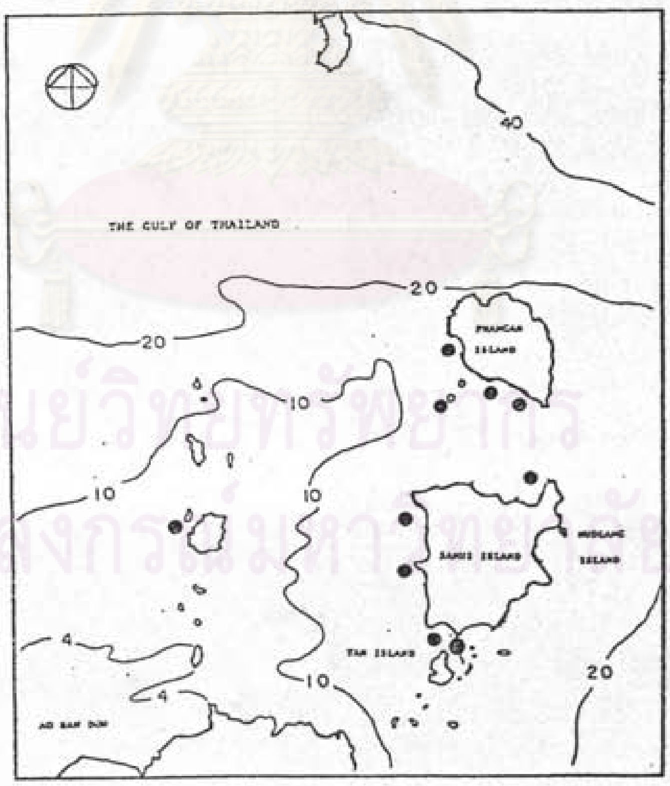


Reef with Exposed
Reef Edge

Figure 61. The Distribution of Reef Without Reef Edge and Reef With Massive Reef Edge at Samui Islands.



Reef without
Reef Edge



Reef with Massive
Reef Edge

Figure 62. The Distribution of Reef With Submerged Reef Edge and Reef With Exposed Reef Edge at Samui Islands.

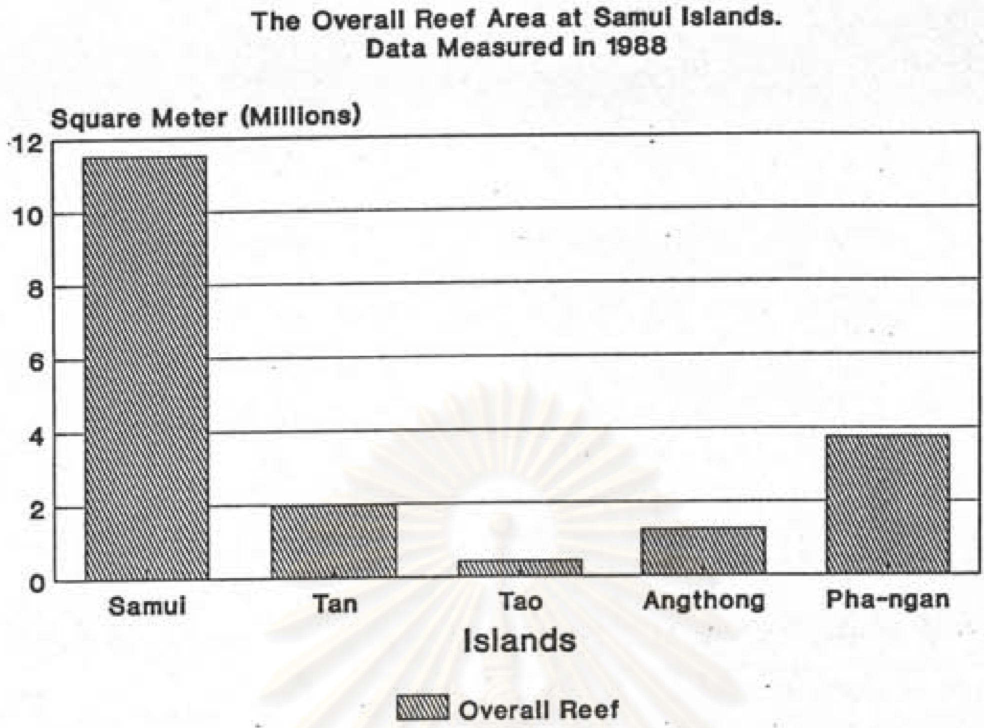
However, the patch reefs in Samui and Chang are different. The patch reefs in Chang Islands are located on the channels of Mak and Kradat Islands. Those reefs are submerged and covered with big massive corals. It suggests that Chang Patch Reefs are located on the shallow sandy area connected to the island, so the patch reefs may be one part of the fringing reefs but the tidal channel separates them from the fringing reef. This patch reef pattern may be similar with the patch reef at Sai Cape because that patch reefs are located not far from the sand patch at the top of the fringing reef. However, the patch reef at Hin Ang Wang is formed in different development.

Hin Ang Wang is more interesting because it is unlike other patch reefs even the fringing reefs among Samui Islands. Remotely sensed data reveal that the island is composed of dead coral and coral fragment. The formation of this coral island is still unknown but the result recommends that this island may be a submerge rocky area with some small corals. The northern part has a massive coral as the major component so it blocks a wave action from southwest monsoon. The southern part of this reef has high turbulence with low wave action so it is suitable for Acropora branching to grow and distribute in a wide area (Veron, 1986). This coral fragments blow up to the inner reef and combine to be a cay. However, the future research on coral drilling is required to support this hypothesis.

5.3.3.3 Reef Area

The results from reef thematic images present the reef area in Samui Islands which is illustrated in Figure 63, 64, 65 and 66. Samui Islands have the largest reef area while Tao Islands have the smallest. However, the reef areas do not correspond with the island areas. Although Angthong Islands have the land area bigger than Tan Islands, the total reef area is smaller. The percentage of living coral in the overall reef area is interesting. Tao Islands have the highest percent of living coral compared with the overall reef area. While Samui Islands have the lowest. If it emphasizes only on one group, for example Samui, the percent of living coral area in Bang Po is the highest while the overall reef area is not the highest. It suggests that the percent of living coral area is not correlated with the overall reef area.

5.3.3.4 Reef Region



95 percent of conference interval

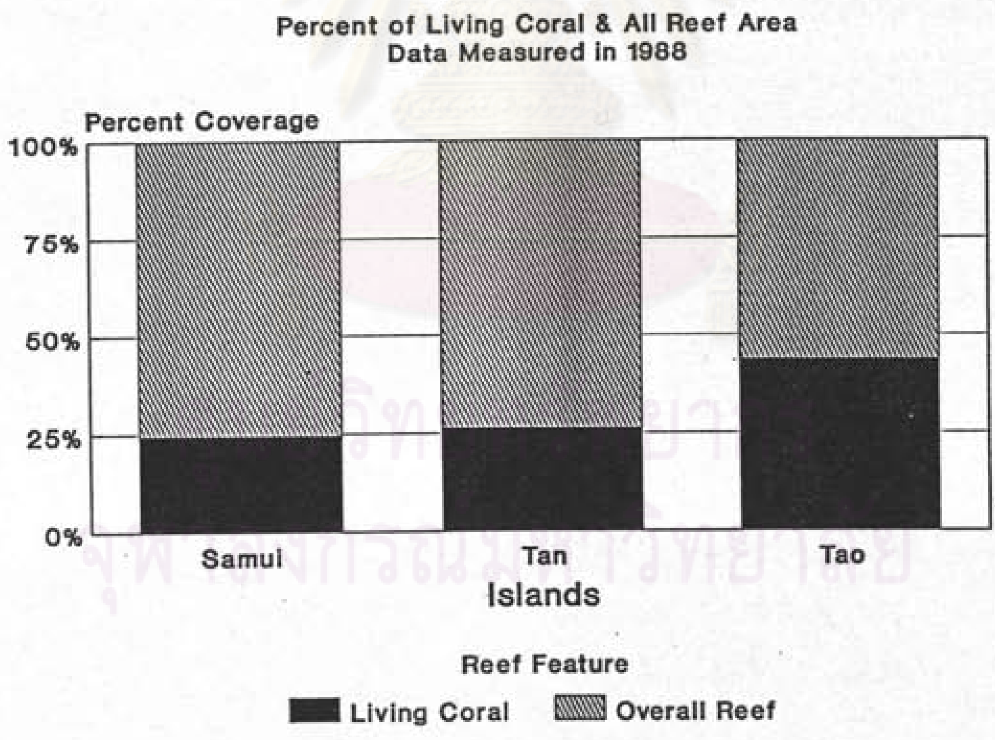
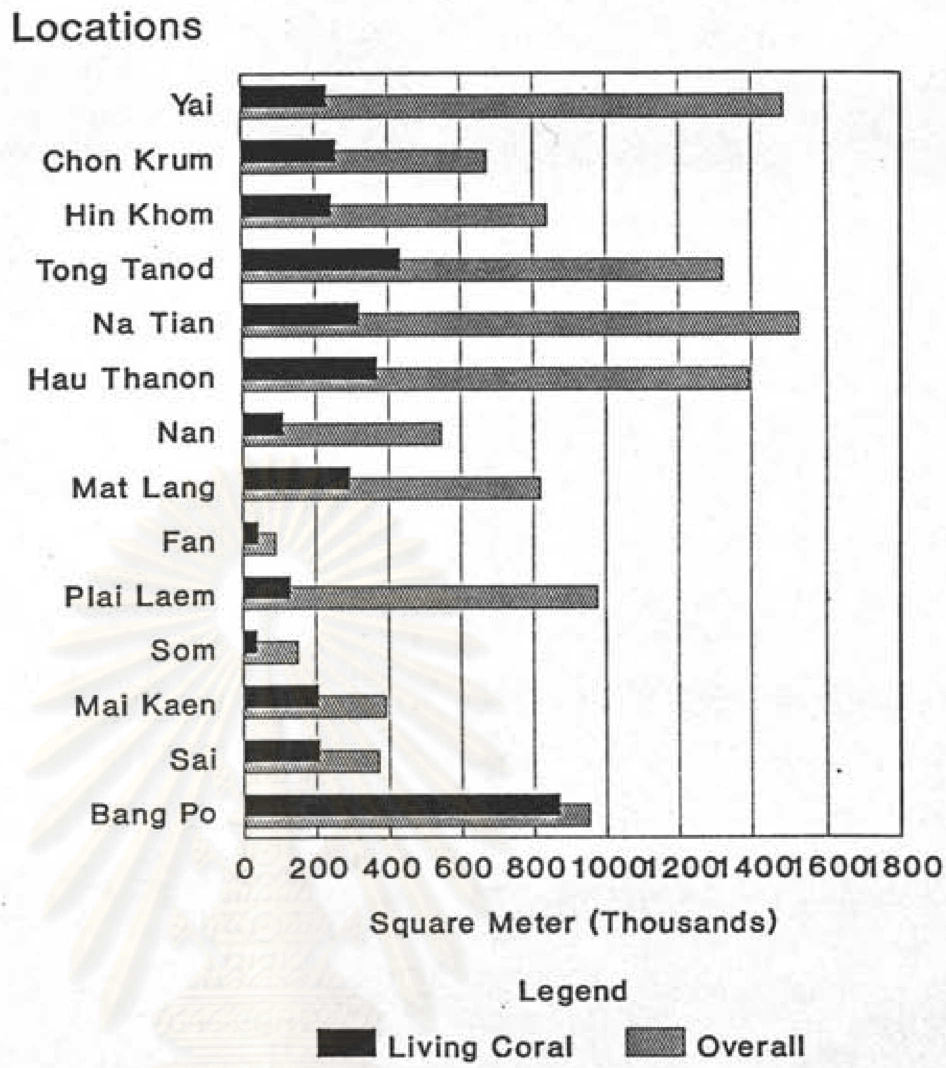


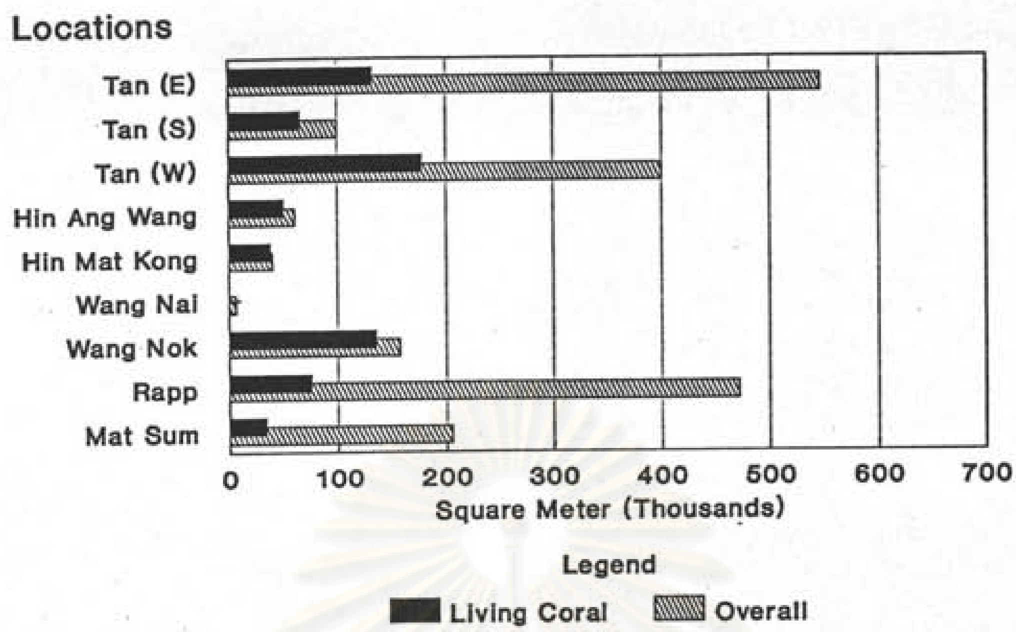
Figure 63. The Overall Reef Areas and The Percent Coverage of Living Coral Area Compare with Overall Reef Area.



95 percent of conference interval

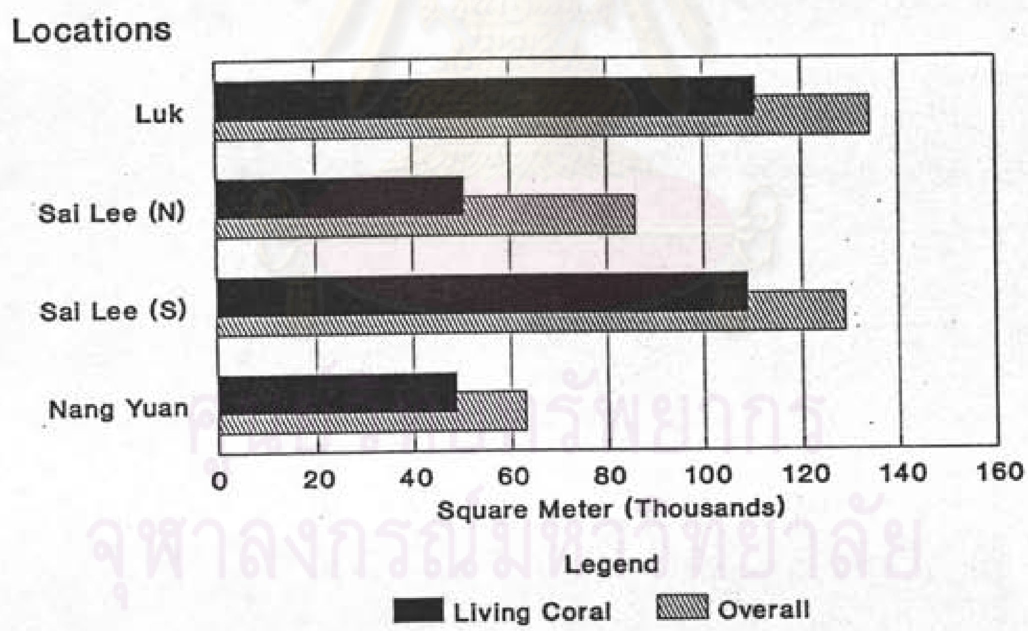
Figure 64. The Overall Reef Areas and Living Coral Areas at Samui Islands.

The Living Coral and Overall Reef Areas.
at Tan Islands.



95 percent of conference interval

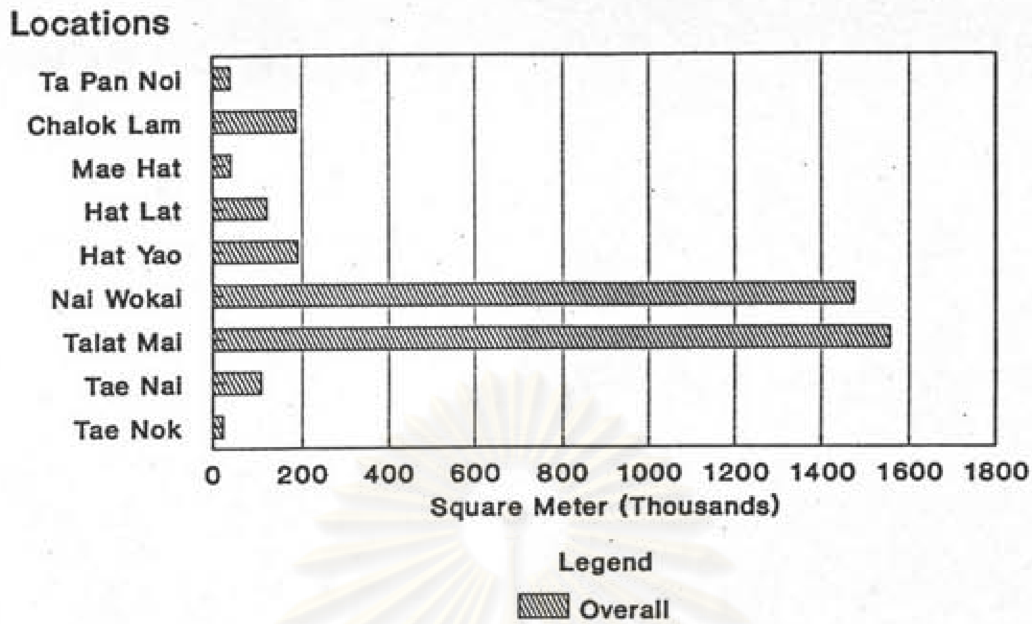
The Living Coral and Overall Reef Areas.
at Tao Islands.



95 percent of conference interval

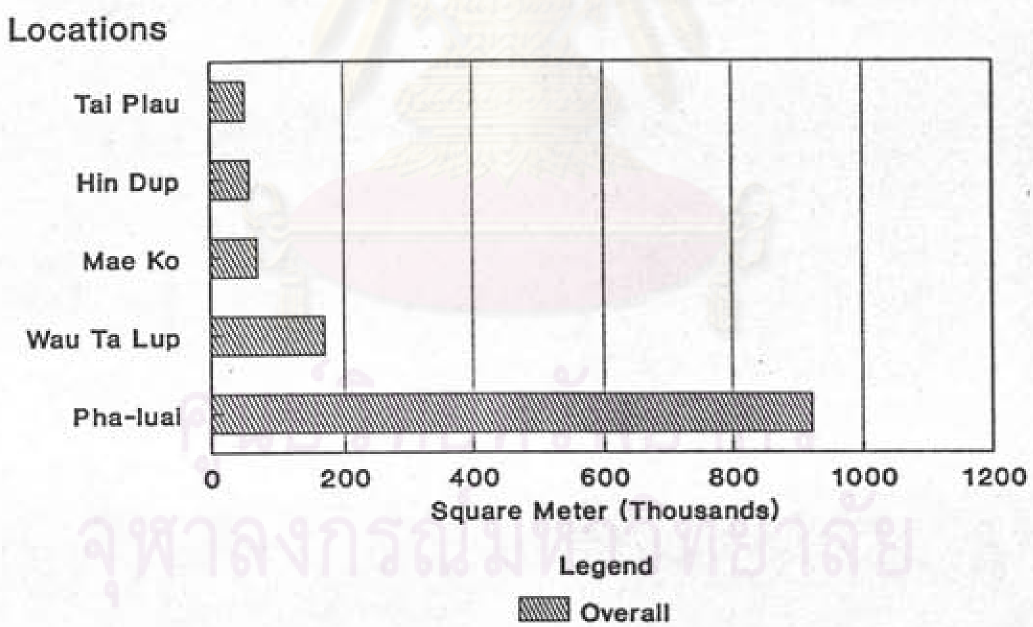
Figure 65. The Overall Reef Areas and Living Coral Areas at Tan and Tao Islands.

The Living Coral and Overall Reef Areas.
at Pha-ngan Islands.



95 percent of conference interval

The Living Coral and Overall Reef Areas.
at Angthong Islands.



95 percent of conference interval

Figure 66. The Overall Reef Areas at Pha-ngan and Angthong Islands.

The reef type classification may give the idea to observe the distribution of the reefs at Samui Islands. However, the complexity of those reefs causes the difficultly in a reef region. This problem is similar to the Great Barrier Reef problem, Hopley (1982) theorized that the reef regions in the Great Barrier Reef followed the latitude. On the other hand, this project will separate reef regions using the sediment zones and the reef types in that area. The results may be used as the knowledge of reef patterns and sediments affecting to the reefs, as well as, the information for reef genetic studying in the future.

The result from the sediment density slicing image dose not cover Tao Islands. The generation is run by the data in another image in the same day and method, so the result is also the same.

According to the sediment density slicing result, the reefs in Samui Islands are located in four sediment zones which will be called zone A, B and C. Zone A to C follow the density of the sediments which are present from low to high zone. However, the reefs in those zones are not the same reef types. The sediment zones are divided by the reef type. The multi-resolution and reef thematic results combined with sediment density slicing help to generate the reef region. The final result separates the reef region in Samui Islands into 10 zones (Table 3 to 7)

- Reef Zone A: This area is the low sediment zone in Ban Don Bay. The sediment from the runoff does not settle in this area. The reefs in this zone are separated into 2 types. Reef zone A-1 is the reef without reef edge and the other reefs are with massive reef edge identified as Zone A-2.

- Reef Zone B: This zone is the medium sediment zone. It is the edge of the sediment from Ban Don runoff. This area has all reef types so they are generated into 4 zones. Zone B-1 is the zone of reef without reef edge, Zone B-2 is the zone of reef with massive reef edge, Zone B-3 is the zone of reef with submerged reef edge and Zone B-4 is the zone of reef with exposed reef edge.

- Reef Zone C: This zone is the high sediment zone which has the reef. The sediment from the runoff comes directly through this area so the reefs have only two zones. Zone C-1 is the zone of reef without reef edge and C-2 is the reef with massive reef edge.