

## Seabed Characterization through Image Processing of Side Scan Sonar Case Study: Bontang and Batam

### *Karakterisasi Permukaan Dasar Laut berdasarkan Image Processing Side Scan Sonar, Studi Kasus : Bontang dan Batam*

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**ABSTRACT:** Acoustic waves propagate through a medium meet the Snell's Law, its energy is reflected and some are scattered back at certain angle. The Side Scan Sonar (SSS) methods use this principle to identify seabed character. The intensity of the backscatter greatly depends on the morphology and sediments texture or rocks distributed on seabed.

The intensity of backscatter waves is a representation of the morphology, sediments texture, and types of rock that distributed on the seabed, therefore it is possible to estimate sedimentary texture and identify the presence of rocks or coral reefs based on this information. In this publication authors estimate sediments texture, rocks or coral reefs based on backscatter intensity through the image processing on the Side Scan Sonar (SSS) image. Intensity will be converted into pixel values on the image with range value 1-255 (gray scale image) and entropy values which are statistical measures of randomness. Entropy value is maximum when most of pixel value image is in the middle of the colour spectrum range (between very dark to very bright), in contrast, it is minimum when pixel value is in the spectrum of very dark or very bright. Based on both parameters, classification is conducted. The classification is carried out on the SSS image at Bontang and Batam that have very different seabed characters.

The classification results using an image processing shows that the distribution of sediment textures consist of 4 (four) classes for either Batam or Bontang. In the Bontang area, very fine sediments were identified which are associated with low value of both intensity and entropy - dark zones in gray scale images, and coarse sediments associated with high value of both intensity and entropy - bright zone in the gray scale image. Similar characteristic is observed in Batam area, which are identified fine sediment (associated to low intensity) - coarse sediments (high intensity). In contrast to Bontang, in Batam the entropy exhibit the opposite value, high value are correlated to fine sediment and vice versa. This might be due to the presence of rocks and sedimentary structures.

**Keywords:** Side Scan Sonar, Intensity, Backscatter and entropy.

**ABSTRAK:** Gelombang akustik sebagian besar energinya dipantulkan memenuhi prinsip snellius dan sebagian kecil dihamburkan balik dengan sudut. Metode Side Scan Sonar (SSS) memanfaatkan prinsip hambur-balik gelombang untuk mengidentifikasi permukaan dasar laut. Intensitas gelombang dari karakter hambur-balik akan sangat tergantung morfologi dan tekstur sedimen atau batuan dari permukaan dasar lautnya.

Intensitas gelombang hambur-balik merupakan representasi dari morfologi, tekstur sedimen, dan jenis batuan yang tersebar di permukaan dasar laut, sehingga sangat memungkinkan untuk melakukan estimasi tekstur sedimen dan identifikasi keberadaan batuan maupun terumbu karang berdasarkan informasi tersebut. Pada publikasi ini akan dilakukan estimasi tekstur sedimen atau batuan berdasarkan intensitas hambur-balik melalui image yang dihasilkan oleh Metode Side Scan Sonar (SSS). Intensitas akan dikonversi ke dalam nilai pixel dalam image dengan rentang nilai 1-255 (gray scale image) dan nilai entropi yang merupakan ukuran statistik ketidakteraturan dari image. Entropi akan maksimum ketika nilai pixel kebanyakan di tengah dari rentang spektrum warna dan sebaliknya akan minimum ketika nilai pixelnya berada di spektrum warna sangat gelap atau sangat terang. Berdasarkan kedua parameter tersebut, kemudian dilakukan klasifikasi. Klasifikasi dilakukan pada data SSS Bontang dan Batam yang memiliki karakter permukaan dasar laut yang sangat berbeda.

Hasil klasifikasi dengan image processing memperlihatkan pola sebaran tekstur sedimen masing-masing terdiri dari 4 (empat) kelas baik untuk Batam atau Bontang. Pada area Bontang teridentifikasi sedimen sangat halus yang berasosiasi dengan intensitas dan entropy rendah - zona gelap pada gray scale image dan sedimen kasar yang

berasosiasi dengan intensitas dan entropy tinggi - zona terang pada gray scale image. Karakter yang sama juga teramati pada area Batam, yaitu teridentifikasi sedimen halus (berasosiasi dengan intensitas rendah) - sedimen kasar (intensitas tinggi). Namun, berbeda dengan di Bontang, di Batam nilai entropi menunjukkan nilai yang sebaliknya, yaitu nilai tinggi berkorelasi dengan sedimen halus, dan sebaliknya. Hal ini diperkirakan akibat keberadaan batuan dan struktur sedimen.

**Kata Kunci:** Side Scan Sonar, Intensitas, Hambur balik dan Entropi.

## INTRODUCTION

Seabed imaging has been developed since 1960 coincide with improvement of Side Scan Sonar (SSS) technology. This instrument is an array of transducer that arranged to emit an acoustic pulse having broad beam width in the vertical plane perpendicular to the sonar's direction of forward motion (across-track) and narrow beam width in the horizontal plane (along-track), Chesterman *et al.*, 1958; Somers and Stubbs, 1984 in Tamsett, 1992; and Blondel, 2009. Seabed imaging has become common tool for geological and geophysical investigation. It could help a geologist to characterize seabed based on acoustic return that is reflected by the seafloor.

Acoustic wave which is emitted by side scan sonar will be reflected and its intensity depends on seafloor material such as sediments, rock, coral reef, and seafloor roughness. Intensity of acoustic return converted to grey-level pixel value (0-255) as seabed image of side scan sonar. (Cervenka and de Mustier, 1993; Daniel, *et al.*, 1998; Moreno *et al.*, 2014, Burguera and Oliver, 2015; Zhao *et al.*, 2017.).

Seabed image passing through some processing sequence to remove and attenuate noise that appear due to velocity contrast in the sea water, contrast between sea water and seabed and ambient noise. Processing sequence include noise filtering, geometric correction, and radiometric correction. Seabed characterization then can be done to this seabed image by using image processing based on grey-level value of every pixel. Characterization classified seabed into sediment type, sediment structure, rocks, and coral reefs also combination among these components, for example seabed possible to classify into sand with or without sand wave.

This publication has objective to characterize seabed at two different location, Batam and Bontang Waters. Seabed Characterization at Batam Waters varies due to geological setting, depositional environment. From its seabed characterization able to distinguish sediment textures, coral reef/rocks and sediment structures such as sand waves or ripple. While at Bontang Waters, the seabed characterization is quite simple, only about sediment textures classification.

## Stratigraphy Sequence

The first study area, at Batam Waters had been classified into seven stratigraphic unit (Kusnama, *et al.*, 1994). Unit distribution are described on Figure 1 (top). All these stratigraphic unit contribute to the sediment distribution onshore either its textures or its types. The seven stratigraphic unit as follows:

**Qa : Alluvium Sands**, yellowish red, composed mainly of quartz, feldspar, horblende and biotite, may be a result of weathered granite erosion; conglomerate composed of granites, pebbles, metamorphics and sandstone, unconsolidated, swamp deposit; and raised coral. The unit overlies unconformably the older rocks and forms the river and coastal deposits.

**Qtg : Goungon Formation** : White tuffaceous sandstone, fine-medium grained, parallel lamination, and siltstone is commonly found; dacitic tuff and feldspathic lithic tuff, white, fine-grained, locally altered with tuffaceous sandstone, parallel and cross laminations; reddish white tuff and grey siltstone which is slightly carbonaceous and contains plant remains. The formation overlies unconformably the Tanjung Kerotang Formation and was deposited in fluvial environment. Thickness of formation is about 200 m. the age of unit is Plio-Pleistocene.

**Tmpt : Tanjungkerotang Formation** : Polymict conglomerate with components of granite, quartz sandstone, feldspars and metamorphics embedded in the matrix of well consolidated coarse sandstone; graded bedding and cross lamination are commonly found; deposited in fluvial and coastal environments. On the basis of superposition, the age of the unit is Mio-Pliocene. Thickness of the formation is around 600 m.

**Kss : Semarang Formation** : Reddish arcose sandstone, medium-coarse grained, well bedded, graded bedding, well consolidated; intercolated with thinly bedded, light grey claystones; deposited in fluvial and transition environments; the formation overlies conformably the pancur formation. Based on the superposition, the age of the formation is Late Cretaceous. Thickness of formation is around 500 m.

**Ksp : Pancur Formation** : Reddish shale with pencil structure, contains quartz veinlets, about 2 m thick; intercolated with quartz sandstone, well bedded, well sorted, parallel and convolute lamination 2-10 cm thick; conglomerate is reddish grey, poorly sorted, 50 – 100 cm thick, composed mainly of quartz sandstone,

red shale and slate with coarse sandstone matrix. Thickness of this formation is 300 m. Locally, the formation forms channel deposit and overlies uncoformably the pulaupanjang formation. The age of the formation is presumed to be Early Cretaceous, on the basis of superposition.

**Trsd : Duriangkang Formation :** Dark-grey shale with pencil structure, brittle and slightly carbonaceous, alternated with quartz sandstone, light grey, micaceous, poorly sorted and well consolidated. Shale and sandstone ratio is 3:1; well exposed in Batam Island with type locality at Duri Angkang River. Based on the index fossils, *Pterophyllum bintanense* sp. And *pterophyllum bintanense* cf *contiguum* Schank, the formation is Rhaetian age (Late Triassic). The formation was deposited in lake to shallow marine environments. Thickness of the formation is around 600m.

**Trg : Granit :** Granite, reddish – greenish grey, coarse grained; composed of feldspar, quartz. Horblende and biotite; mostly ore primary texture. The granite forms batholith, pluton which is widely exposed mainly in the Batan and Bintan Islands; weathering and penneplainsation processes produce economic deposit of bauxite. Based on location and mineral composition, it can be grouped into some granite pluton e.g. Kawal Granite Pluton in Bintan and Nongsa Granite Pluton in Batam Island.

The second study area is at Bontang Waters, in this area the stratigraphic sequence was based on Sukardi *et al.* (1995), grouped into six unit as follows (Figure 1, bottom):

**Qal : Alluvium :** Clay and silt, sand and pebble, of a coastal and river deposits.

**Tmpk : Kampung baru Formation :** Sandy clay, sandstone with intercalation of coal and tuff. Locally contains thin layers of iron oxide and limonite concretions. Considers to be Late Miocene to Plio Pleistocene age, Deltaic to shallow marine depositional environment. The thickness ranging from 500 to 800 m.

**Tmbp : Balikpapan Formation :** Sand, clay, silt, tuff and coal, within alternation of quartz sandstone, clay, silt occur cross bedding and parallel laminations. Locally containing an intercalation of coal with bedding thickness about 20-40 cm. Claystone, grey, brittle, contains of muscovite, bituminous, iron oxide. Fossil contents are *Cycloclypeus annulatus*, *C. innormatus*, *C. Communis*, *Cycloclypeus* sp. *Lepidocyclina rutteni*, *L. sumatraensis*, *Miogypsina irregularis*, *Operculina* and *Operculinella*, which indicated as Middle Miocene-Late Miocene. The thickness of formation is about 2000 metre. Depositional environment is a delta front to delta plain. The formation is conformably overlain by the Kampungbaru Formation.

**Tmpb : Pulaubalang Formation :** Interbedded sandstone, claystone and siltstone, locally intercalation of coal seam, limestone or calcareous sandstone. The age of this formation is upper part of Lower Miocene to lower part of Middle Miocene. Sedimentation was probably occurred at prodeltaic environment which locally is patch reef.

**Tmp : Pamaluan Formation :** Claystone, with intercalation of thin bedded of marl, sandstone and coal. The upper part consist of sandy claystone which contains plant remain and thin coal seam. Generally, the lower part is more calcareous and fossiliferous than upper part. It is correlated to the upper part of Lembak Formation (Toml). Depositional environment was about deep to shallow neritic.

## METHODS

Seabed characterization would be done with image processing using two extracted value from SSS data; intensity and entropy. Intensity of echo that represented by bright or dark of every pixel on image. Entropy which is statistical measures of randomness, its value is maximum when most of pixel value image is in the middle of the colour spectrum range (between very dark to very bright), in contrast, it is minimum when pixel value is in the spectrum of very dark or very bright.

### Entropy

Entropy is calculated on image processing, is defined as follows (El-Owny, 2013):

$$E(j) = \sum_{j=1}^N I(j) \cdot \ln(I(j))$$

Where  $E(j)$  is entropy of image,  $I(j)$  is the value in the  $j^{\text{th}}$  pixel of the windows size of image, windows size and windows step must be define before calculate the entropy, smaller windows size gives more detailed classification (Fakiris and Papatheodorou, 2009; Chesapeake Technology, Inc, 2017).

### Intensity

Average intensity is represented by average brightness simply to calculate for defined windows size, the average is defined as follows:

$$B(j) = \frac{\sum_{j=1}^N I(j)}{N}$$

Where  $B(j)$  is Intensity of image,  $I(j)$  is the value in the  $j^{\text{th}}$  pixel of the windows size of image, windows size and windows step must be define before

calculate the entropy, smaller windows size gives more detailed classification (Fakiris, E. and Papatheodorou, G., 2009.; Chesapeake Technology, Inc, 2017).

Entropy and intensity as a result of image processing will have value ranging from 1 to 255 represented by dark to bright colour on grey scale image. Combination of both parameters is used to classify seabed into four classes of sediment textures with or without sediment structures which is depends on geological and physical oceanography condition.

Workflow of seabed characterization include several stages. Stage begin with processing of SSS data, mosaicking and creating grey scale image. Qualitative interpretation was carried out against SSS image to determine number of class, subsequently initial image processing implemented with certain parameters, windows size, windows step and number of class. Image processing provide values of intensity and entropy, each value transformed into the maps that give overview of intensity and entropy distribution. Image processing results was then compared with qualitative interpretation. In case it does not match, we repeat image processing with some adjustment parameters (Figure 2).

## RESULTS

Seabed imaging has been done at Bontang and Batam Waters. In Bontang, side scan sonar data has fifteen line, each line has 600 – 700 meters in length. In Batam Waters use seventeen line with the length of each line between 2000 – 2500 meters. Pre-processing is important to be applied before doing image processing. Several step must be done especially navigation editing, bottom track, slant range correction and amplitude normalization. In Pre-processing step, it must avoid to apply gain that perform local normalization, gain correction applied to small part of data, which is it could change amplitude locally, that will make the amplitude not represents the seabed condition.

Seabed characterization results have shown that pre-processing and parameter adjustment of image processing is good enough. It was validated by no existence of nadir artefact, there is no class are clustered along the nadir.

Image processing classified seabed character into four classes based on entropy and intensity calculation. Results of classification based on pixel value entropy and intensity ranging from 1-255 (Table 1).

Seabed character at Bontang shows a gradational texture, it is proven by regularity of classification based on entropy and intensity. Lower entropy and intensity is classified into class 1, higher entropy and intensity is classified into the next class. Meanwhile Batam shows differently, higher entropy and lower intensity is classified into class 1 and lower entropy and higher

intensity is classified into the next class. Range of pixel value which is used to classify at Bontang has regularity while range of pixel value classification at Batam is irregular.

Classification results are made into the maps to understand distribution of each type sediment. Intensity and entropy data are already in grid format, grid format of intensity and entropy are combined so these value will represents each class. Finally do contouring to delineate sediment distribution (Figure 3, 4 and 5).

Interpretation was also applied to the result of classification. It will represent type of sediment texture. At Bontang region class 1 is interpreted as very fine sediment; class 2 interpreted as fine sediment; class 3 interpreted as medium sediment; and class 4 interpreted as coarse sediment. At Batam region class 1 interpreted as coarse sediment to coral/rock; class 2 interpreted as medium to coarse sediment; class 3 interpreted as medium to fine sediment; and class 4 interpreted as fine to very fine sediment.

Several features observed on SSS image were considered particularly because the intensity in these feature were not only influenced by sediment types but also influenced by presence of port pile structure, slope and sediment structures such sand wave, ripple mark and mega ripple; (Figure 6, 7 and 8). Supervision was necessary to be applied in order to make the result of classification is in accordance with the qualitative interpretation.

## DISCUSSIONS

### Bontang Region

Sediment deposited in this area is strongly influenced by rocks formation on the land and its process. These rocks formation will be the source of material that deposited onshore (Sukardi, *et al*, 1995). Based on stratigraphic sequence there are three types of sediment textures that possibly deposited such as sand, clay, silt and mud. These textures will contribute to acoustic character that recorded on side scan sonar data. Coarse grain sediments give more backscatter than fine grain sediments so it will be seen brighter on side scan sonar image (Blondel, 2009; Chang *et al*, 2010).

Seabed character based on acoustic backscatter at Bontang region has been classified into four class (Table 1). Sediments distribution varies from very fine to coarse grain sediments, with predominant grains are fine to medium grain sediments. Seabed characterization derived from image processing method has fairly well defined the distribution of sedimentary textures but in some areas it is distorted by acoustic backscatter due to the structure such as port piles in the north that is marked by high intensity - bright image mosaic (Figure 6), and the presence of slope areas in the

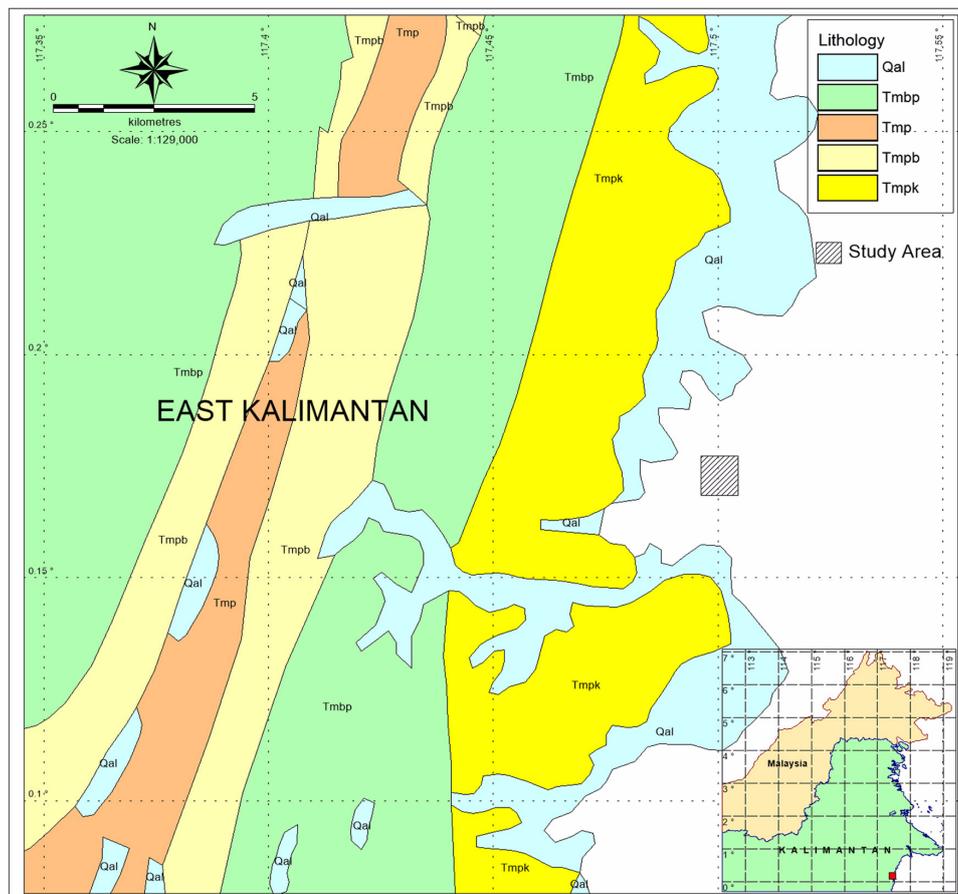
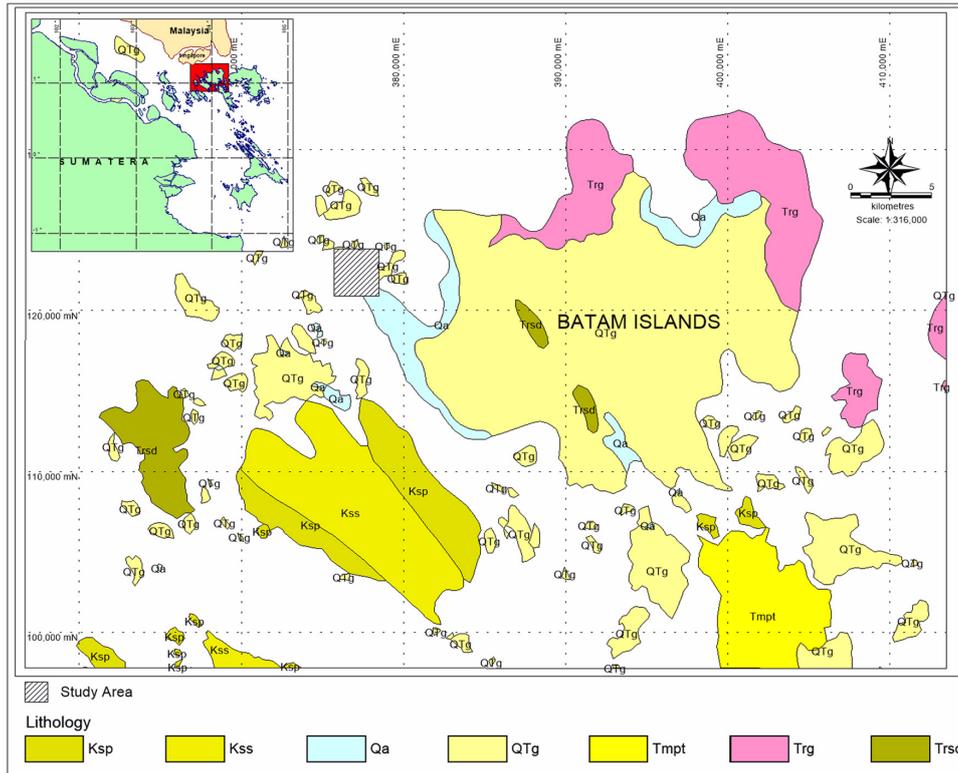


Figure 1 Geologic map shows stratigraphic unit at Batam Waters, Kusnama, *et al.*, 1994 (top) and Bontang Waters, Sukardi, *et al.*, 1995 (bottom).

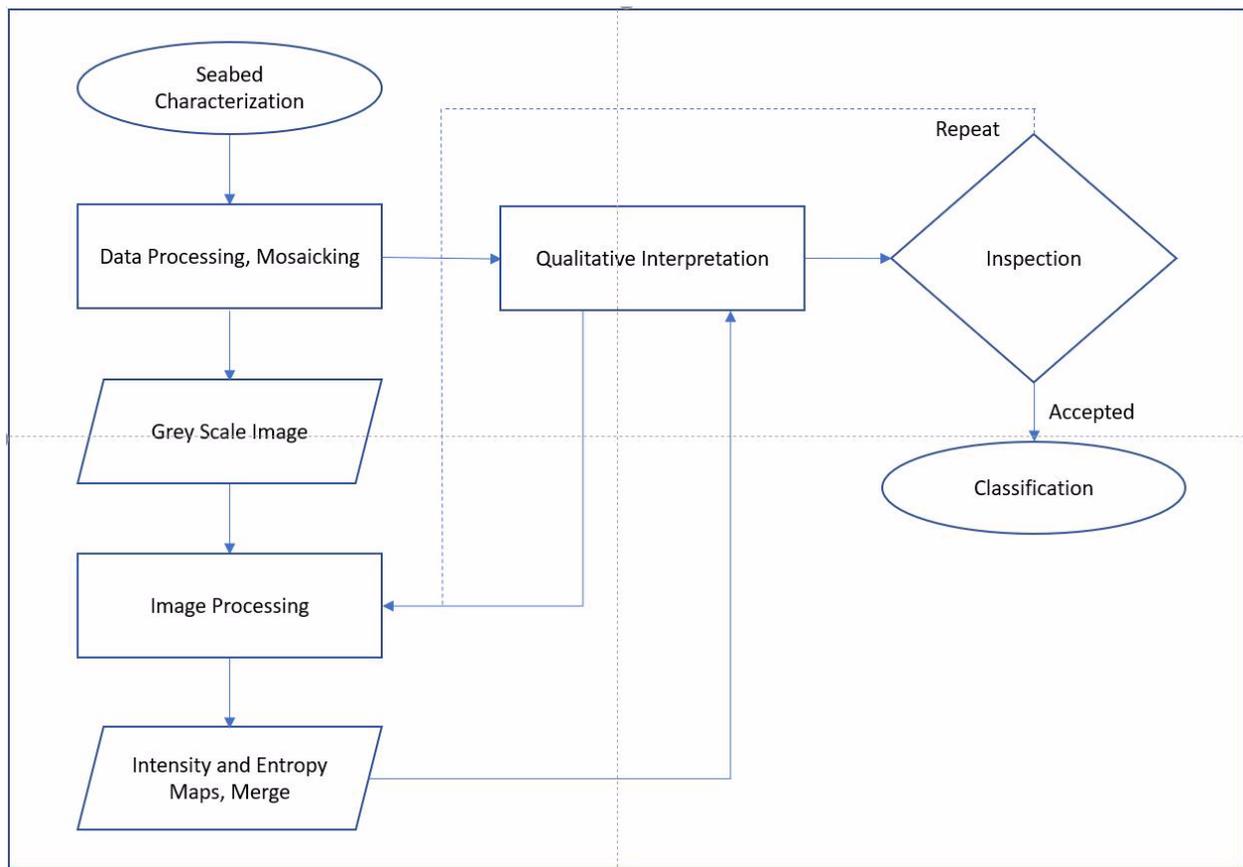


Figure 2. Workflow of seabed characterization based on SSS data

Table 1. Class classification as a result of image processing on both location.

Bontang			Batam		
Seabed Character	Entropy	Intensity	Seabed Character	Entropy	Intensity
Class 1 (Very Fine)	1-75	1-48	Class 1 (Very Fine – Fine)	87-255	3-200
Class 2 (Fine)	71-153	33 - 99	Class 2 (Fine – Medium)	58-116	143-225
Class 3 (Medium)	142-213	86-165	Class 3 (Medium – Coarse)	38-65	206-237
Class 4 (Coarse)	204-255	155-255	Class 4 (Coarse – Coral/Rock)	1-40	224-255

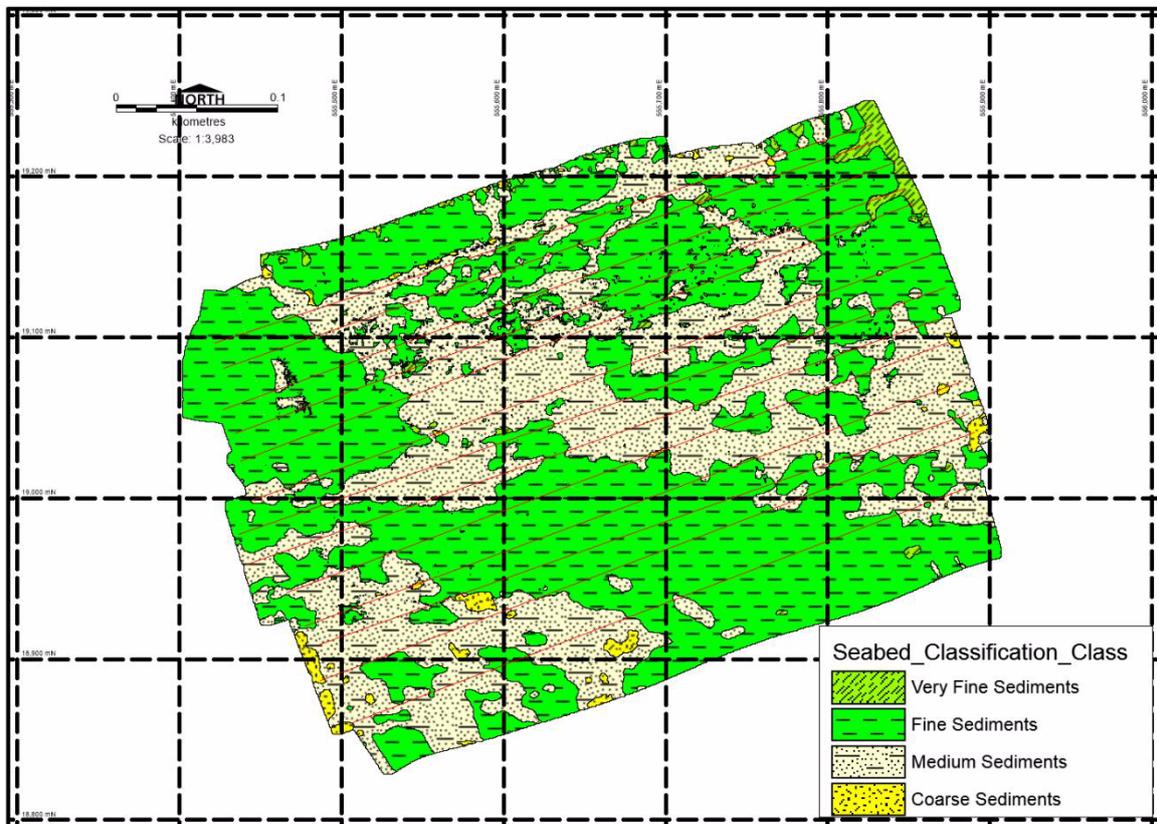
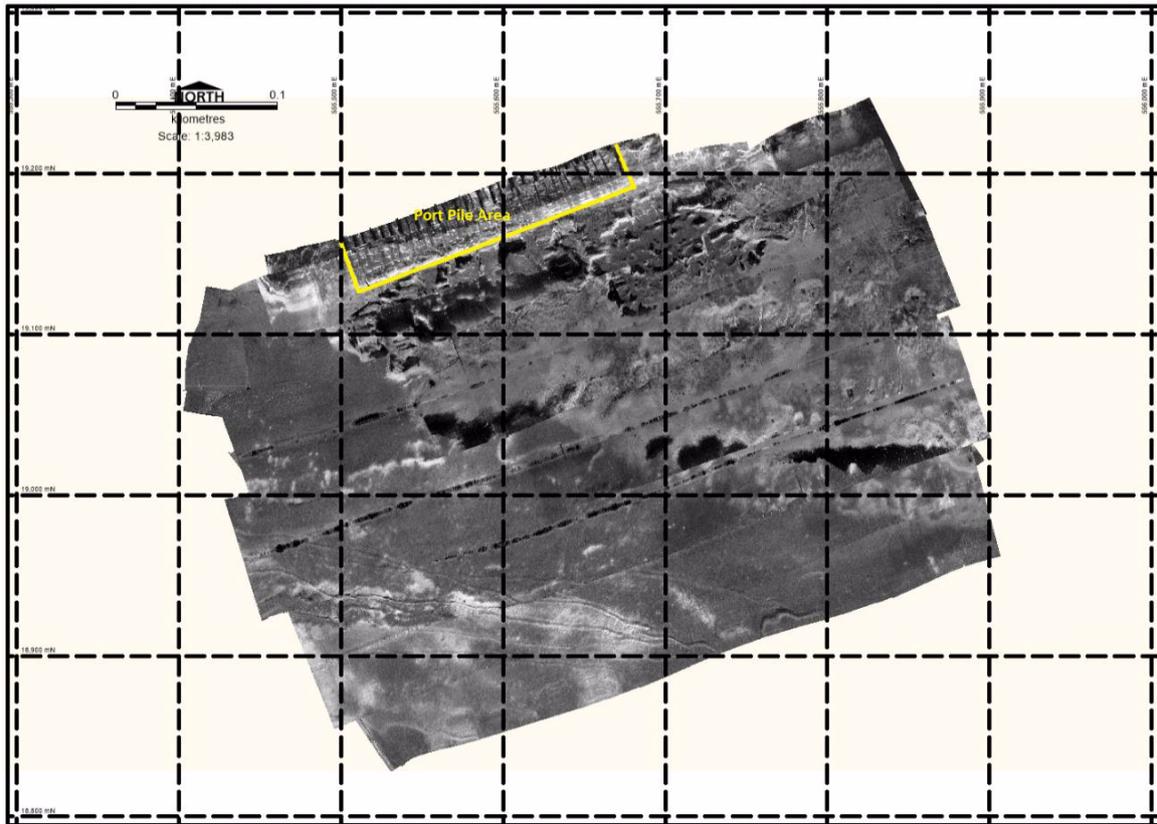


Figure 3. Seabed Classification at Bontang Waters, (top) mosaic of side scan sonar (bottom) show four classification from very fine to coarse sediments.

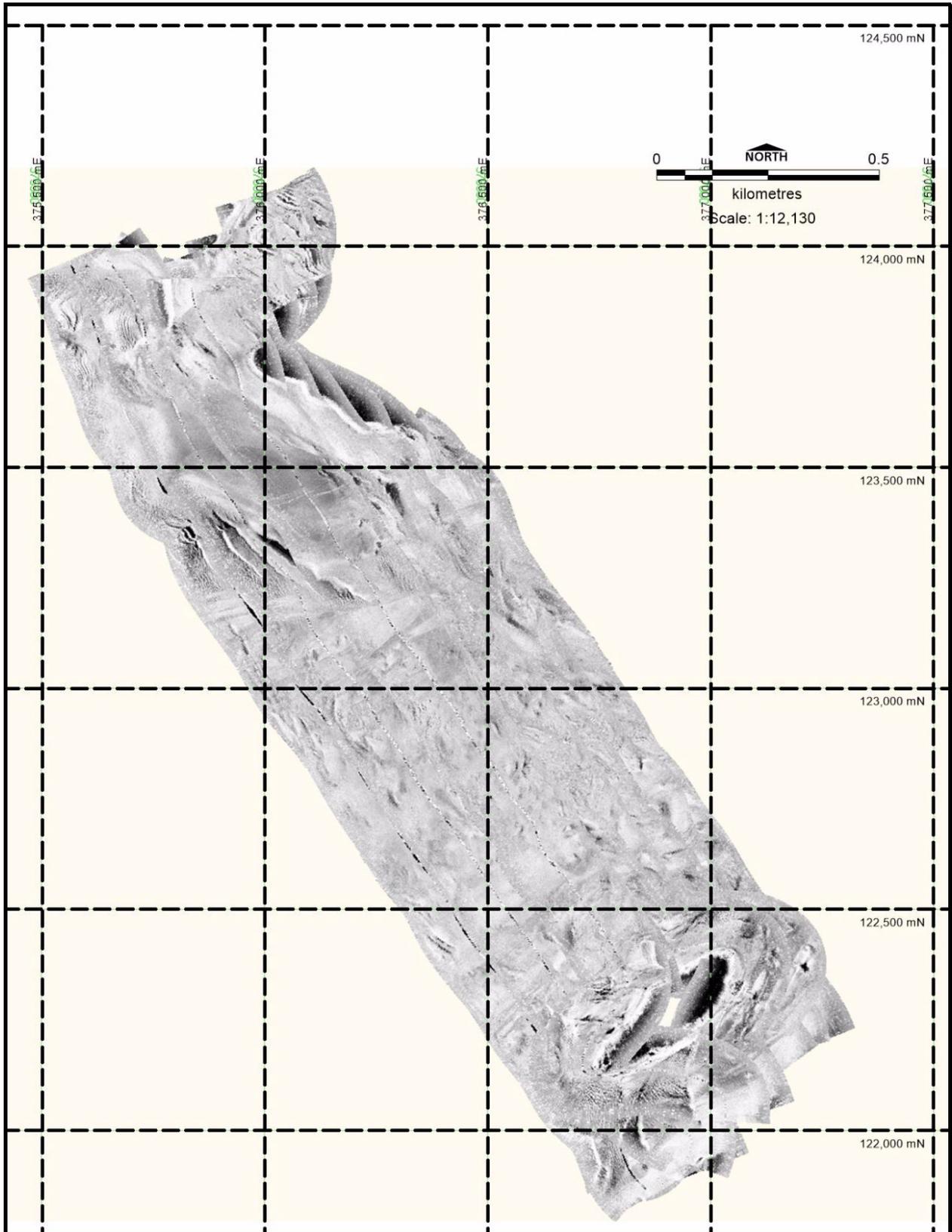


Figure 4. Seabed Classification at Batam Waters, mosaic of side scan sonar.

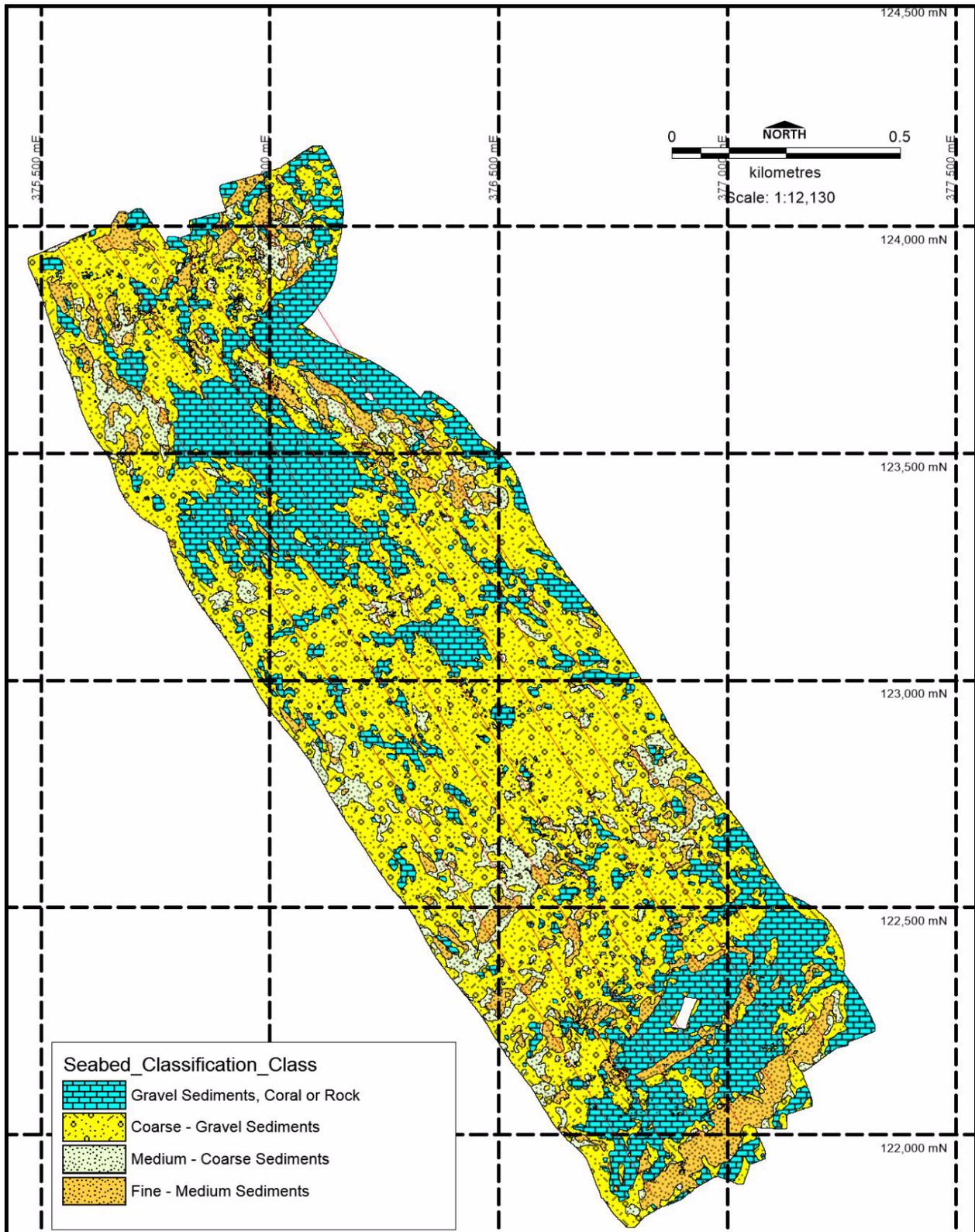


Figure 5. Seabed Classification at Batam Waters, shows four classification from rocks, coral and sediment.

middle that marked by high and low intensity (bright or dark on SSS image) (Björn et al., 2017).

Classification of sediment texture was conducted based on acoustic character backscattered from seabed. It has regularity on adjustment of pixel value for both entropy and intensity. It also has regular classification that lower intensity and entropy is classified to finer sediments, in contrast, higher intensity and entropy is classified to coarser sediments. Very fine grain sediments are associated with entropy 1 -75 and intensity 1-48, fine grain sediments are associated with entropy 1 -75 and intensity 33-99, medium grain sediments correlated to entropy 142 -213 and intensity 86 – 165, and coarse grain sediments are correlated to entropy 204 - 255 and intensity 155 – 255.

Distortion on acoustic backscatter due to presence of building structure or slope will affect the result of classification, this acoustic scatter will interfere primary acoustic reflected back from seabed. Classification distortion can be seen on lineament with almost west-east direction of medium sediment class at northern part of Bontang region.

Seabed character besides sediment texture that commonly appear on side scan image are shadow zone. The shadow zone associated with object, feature or slope that has a height compared to the seafloor around it. Sometimes shadow zone are followed by bright zone, it depends on position of towfish SSS towards the object or the feature.

Other characters that also appear on the seabed in the port pond are undulating seabed due to the activities of ships during both entering and leaving the port. This character can be seen exactly in the southern part of the port structure.

### **Batam Region**

Geologically, Batam Islands are located at Southeast Asian tin belt, extending from Myanmar, Thailand, Peninsular Malaysia and Indonesia – eastern part of Batam Islands (Schwartz, *et al.*, 1995). Western part of Batam Islands are dominated by alluvium, Goungon, Semarang and Pancur Formation. All of these rock formations will be a source of the sediments distribution around the research area.

Sediment classification texture in Batam region has irregularity on adjustment of pixel value for both entropy and intensity. Lower intensity and higher entropy classified to coarser sediments, rocks or coral, in contrast, higher intensity and lower entropy are classified to very fine - fine sediments.

Result of image processing has classified seabed of Batam region into four class (Table 1). Gravel, rocks or coral are classified with entropy 87-255 and intensity 3-200, coarse to gravel grain sediments classified with entropy 58-116 and intensity 143-225, medium to

coarse grain sediments are correlated with entropy 38-65 and intensity 206-237, the last, fine to medium grain sediments are described with entropy 1-40 and intensity 224-255.

Sediments distribution varies from very fine to coarse grain sediments including rocks or coral, with predominant grains are medium to coarse grain sediments. Seabed characterization interpreted from the image processing method has fairly well defined the distribution of sedimentary textures, however it could not distinguish between rocks or coral. Region which is classified to class 1 although visually not indicated as coral or rock, is interpreted as an area of rock or coral that has been covered with sediment.

Mosaic of side scan sonar has shown acoustic character of rock or coral on the seabed. This character could be seen in the northern and southern part of study area, which is indicated dominantly by dark region. Based on the acoustic wave principle, Backscatter intensity from the rock or the coral should be higher or brighter in the form of an image. This feature occurred because the rock surface is generally undulated so that the backscatter of the acoustic wave will be reflected in all directions which will affect the magnitude of the intensity. Actual seabed character on side scan sonar image shows a random change between high and low intensity, see Figure 7.

Sedimentary structure such as sand wave, ripple mark and mega ripple has been identified at Batam region (Figure 8). These structures are distributed in the northern part and southern part nearby the presence of coral or rock and in some area close to the coastline. This seabed characteristic commonly appears associated with strong sea current (Baas, 1978; Amos, *et al.*, 2017).

Bontang and Batam has shown different seabed characteristics, one of them is the presence of sediment structure that has been identified only in Batam. The sediment structure will lead to certain sediment type and ocean character with strong currents.

### **CONCLUSIONS**

Seabed characteristic based on side scan sonar can be done to distinguish and classify sediment textures qualitatively and quantitatively. Classification consider intensity and entropy which are extracted from SSS data through image processing. Intensity represents types or texture of sediment on seabed but less representative on rough seabed morphology, while entropy value has function to edge detections of feature or identify boundary.

Seabed at Bontang region characterized into four class of sediment textures; very fine, fine, medium and coarse sediment. Very fine sediment associated with low intensity and low entropy value meanwhile coarse

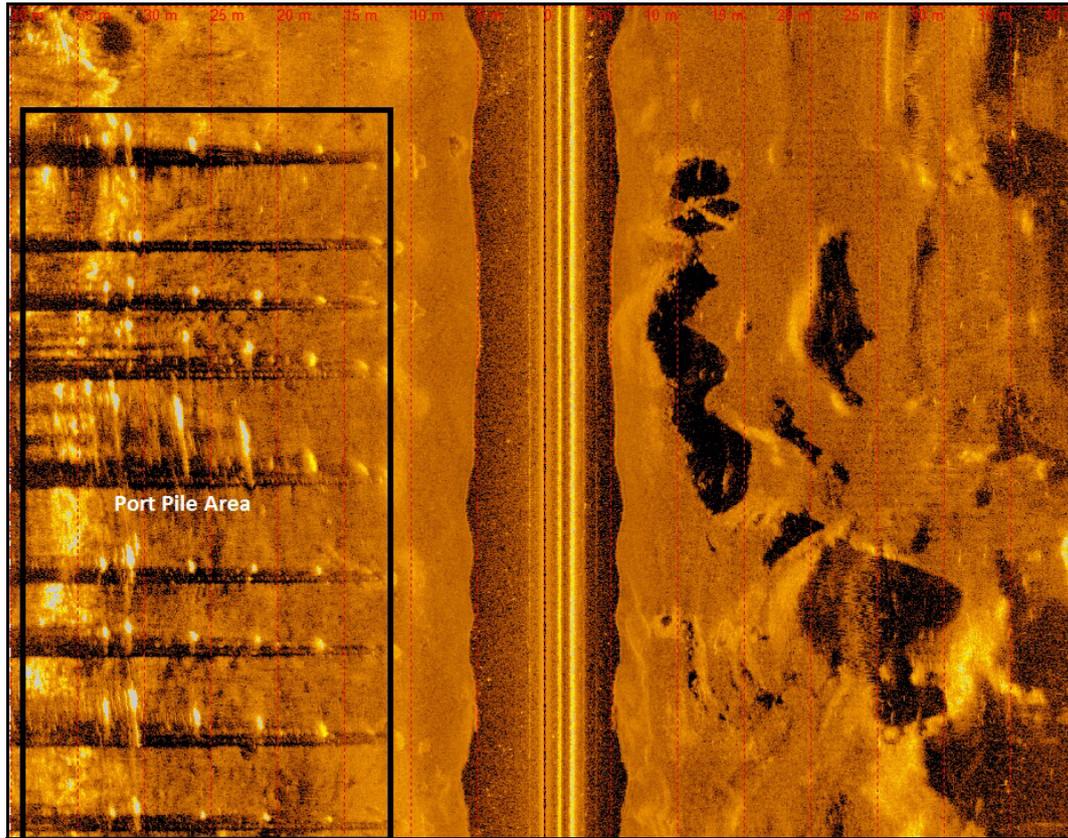


Figure 6. Port pile area recorded on SSS, it made distortion to sediment classification.

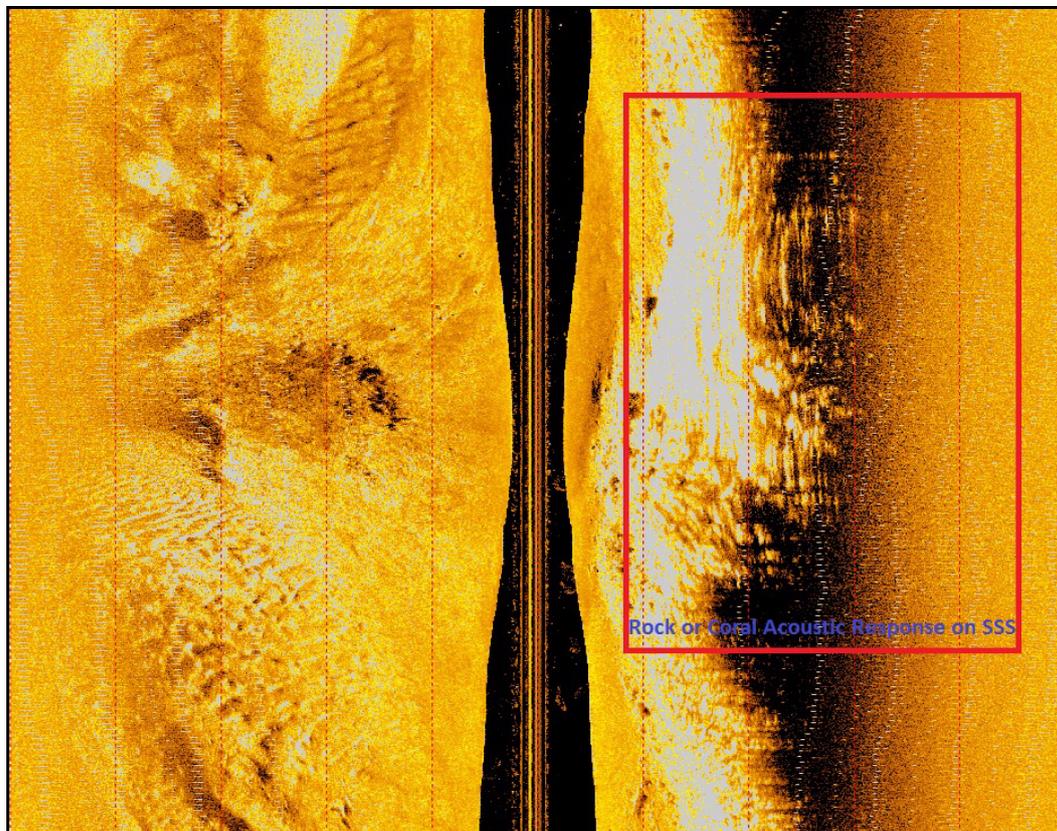


Figure 7. Rock or coral acoustic response has shown random change intensity on SSS image.

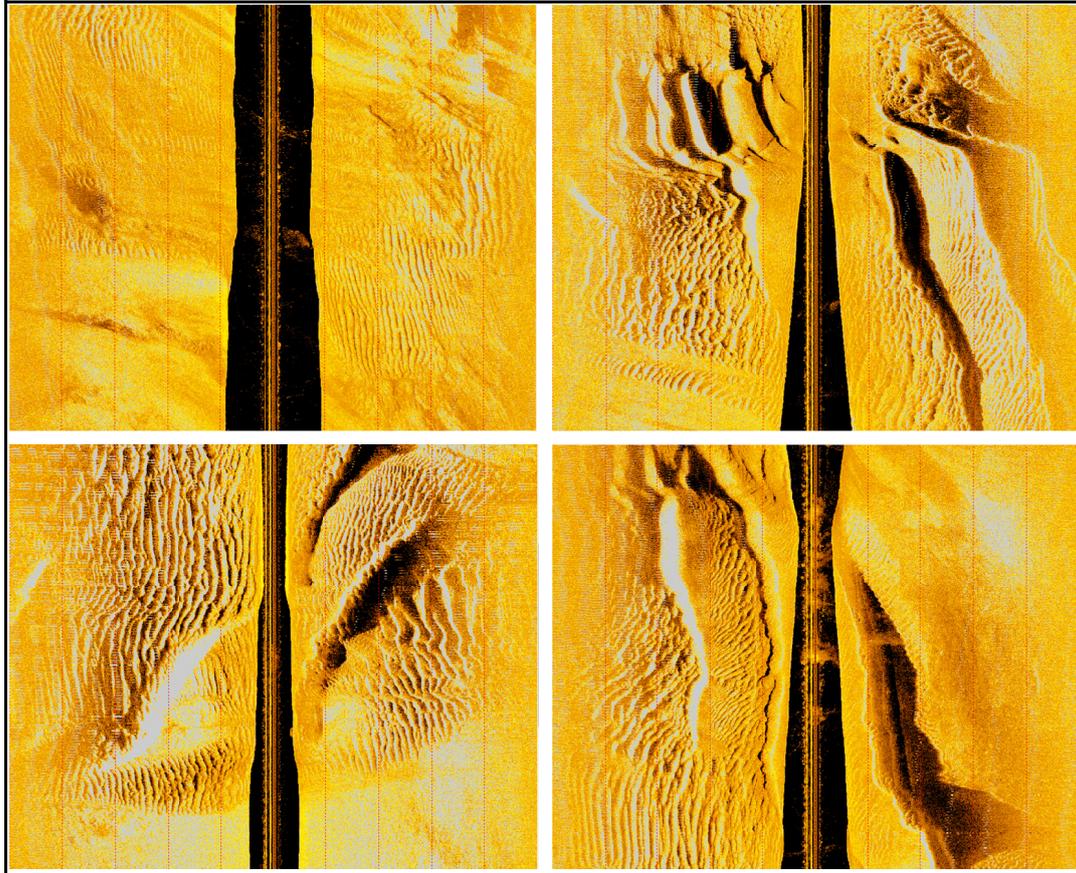


Figure 8. Sediments structure in the form of sand wave, ripple mark and mega ripple identified at Batam region.

sediment associated with high intensity and high entropy value. At Batam region seabed is characterized into four class; gravel to coral or rocks, coarse to gravel sediments, medium to coarse sediment and fine to medium sediment. Fine to medium sediment associated with low intensity and high entropy value meanwhile gravel, coral or rocks associated with high intensity and low entropy value.

Quantitative classification using intensity and entropy parameter could mislead–characterization of seabed, therefore it must be accompanied with qualitative classification.

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