# Mineralogical Characteristics and The Pedogenetic Processes of Soils on Coral Reefs in Ambon

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**Abstract**

The mineralogical characteristics of soils developed on coral reef parent materials in Hitu and Wailiha, Ambon, were investigated regarding to the relationship to pedogenesis. The analyses concerned with the characteristics of soil chemical, physical, and mineralogy of the rock fragment and sand, silt and clay fractions are to investigate the pedogenesis processes. Both soil profiles indicate the clayey texture, slightly neutral reaction, high cation exchange capacity, base saturation, and iron oxide. The mineralogical analyses of rock fragments and sand fractions indicate that besides carbonate minerals, silicate minerals were also found. The clay mineralogy showing the domination of kaolinite, gibbsite, and goethite, reflects that the soil is intensely weathered. Pedogenesis process showing the clay translocation, indicates that the weathering process has been occuring under the tropical influence.

**Keywords:** Coral reef, mineral, pedogenesis, characteristics, Ambon

***Sari***

*Tanah berbahan induk batu karang yang berlokasi di Hitu dan Wailiha, Ambon diteliti karakteristik mineralnya dalam kaitannya dengan pedogenesis. Analisis tanah yang dilakukan adalah analisis kimia, fisika, serta analisis mineral yang mencakup analisis mineral fragmen batuan, fraksi pasir, debu, dan lempung untuk mendukung informasi pedogenesis yang telah berlangsung pada profil tanah di kedua lokasi tersebut. Hasil analisis kimia dan fisika menunjukkan bahwa kedua profil tanah ini mempunyai tekstur lempung, pH yang mendekati netral, kapasitas tukar kation, serta kejenuhan basa dan oksida besi yang tinggi. Hasil analisis mineral fragmen batuan dan fraksi pasir menunjukkan bahwa selain mineral karbonat terdapat juga silikat. Hasil analisis mineral lempung yang menunjukkan dominasi kaolinit, gibsit dan goetit, mencerminkan tanah dengan tingkat pelapukan lanjut. Proses pedogenesis yang memperlihatkan translokasi liat menunjukkan bahwa tanah ini sudah berkembang lanjut di bawah pengaruh iklim tropis.*

***Kata kunci:*** *batu karang, mineral, pedogenesis, karakteristik*

## Introduction

Coral reef composed of the skeletons of living coral, minerals and organic matter develops through biotic processes of corals and calcareous algae. It is a typical parent rock normally found on islands and shores where the temperature of the sea is sufficient high during the whole year. Although corals are found both in temperate and tropical waters, reefs are formed only in a zone extending at most from 30°N to 30°S of the equator. This parent rock has specific characteristics due to its composition, and the soil developing on these rocks possibly also have specific characteristics related to this material. Coral reefs form one of the parent rocks on islands in the Maluku Province. In Ambon, an island in the Maluku Province, coral reefs can be found in the outer arc of the island, juxtapose to the inner arc formed by a volcanic chain.

As located in a tropical environment, Ambon has an intense weathering for long periods. Soils developing in this area are influenced by the mineral suites of the parent material and by how they specifically weathered. In a stable geomorphic environment, the parent rock may have however only a subtle influence on the characteristic of the resulting soil. Therefore, the influence of the weathering is more pronounced.

Ambon has a unique combination on its parent rock material: coral reefs in the outer arc juxtapose with a volcanic chain in the inner arc. Coral reefs contribute sedimentary parent materials, while the volcanoes produce the volcanic parent material. This unique combination is completed with an intense weathering due to its tropical condition. There will be an interesting study to know the mineralogical compositions and the soil developments related to the combination of coral reef, volcanoes and the tropical environment.

This paper is to discuss the mineralogical characteristics of soil developing on coral reefs and surrounding parent material in Ambon and their relationships to pedogenesis.

## Geological Setting and Physiographical Environment

The locations of soil profiles are at Hitu and Wailiha on the island of Ambon, part of the Maluku Islands (Figure 1). The island has an area of 775 km², mountainous, well watered, and fertile. The Maluku Islands are located on the Australian Plate, lying at the east of Sulawesi, west of New Guinea, and north of Timor. The complexity of geology in the Maluku Province is strongly dictated by the movements of three large tectonic plates in the region: the Indian-Australian Plate, the Eurasian Plate and the Philippine (Western Pacific) Plate. According to Van Bemmelen (1970), the oldest formation of Ambon in the Upper Triassic is a strongly folded series of shales and sandstones with an intercalated limestone belt. The sandstones probably consist of detritus of granites, gneiss and schist. In the Late Jurassic, andesitic constituents were found. Roughly, the province can be divided into two parts: the

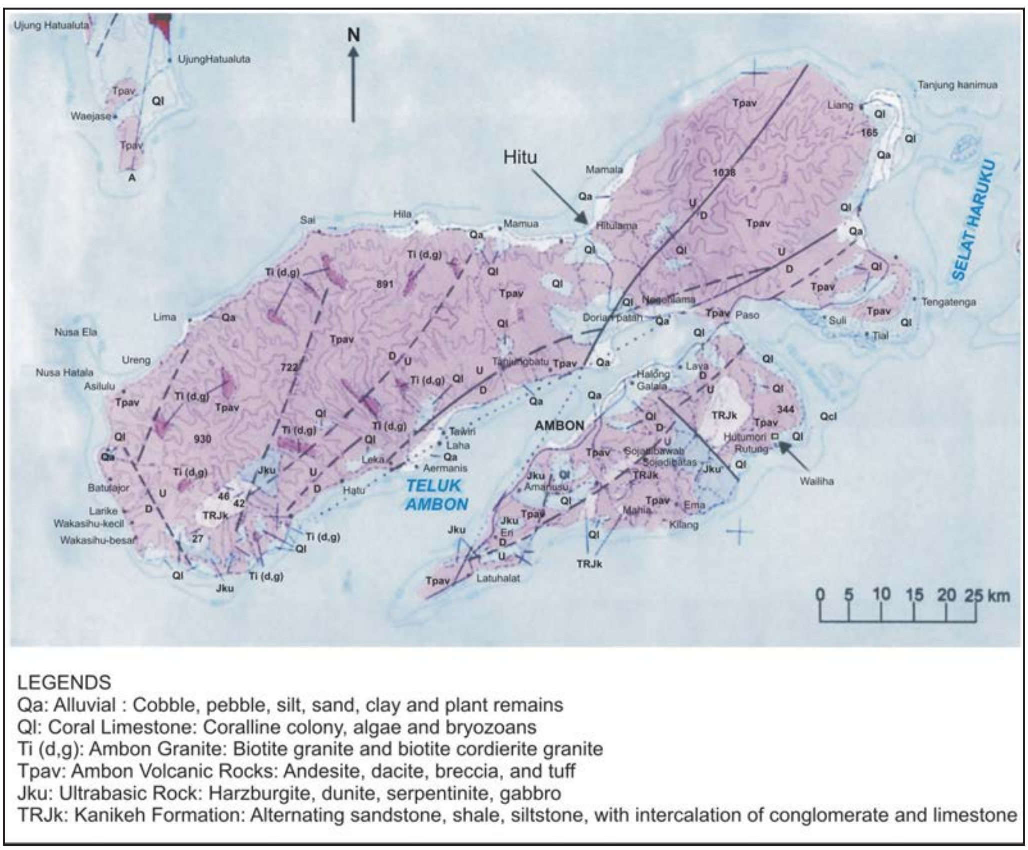


Figure 1. Locality and geological map of the studied profile (geological map after Tjokrosapoetro *et al.*,1994).

northern part of the province which is formed by the magmatic arc of Halmahera and the southern part of the province which is formed by the Banda Arc. In turn, the two arc systems can be clearly divided into inner and outer arcs.

The sides of the two arc systems are strikingly different. In the south, the islands of the outer arc are built up of contorted, mostly calcareous mudstones, sandstones, and limestones. The outer arc begins in the south-west with the uplifted coral reefs of the Leti and Babar island groups, and continues along the arc. Somewhat east of this, the outer arc is composed dominantly of raised coral reefs and a complex of sedimentary rocks.

The inner arc is geologically quite different. It forms a continuation of the large arc system of Sumatera, Java and Bali and it is formed by a chain of volcanic islands. The volcanic rocks of Ambon are composed of biotite and pyroxene dacites and augite andesite which partly occur as a volcanic breccia. Cordierite in fragments and as small idiomorphic crystals is common, and garnet was also found. The various rock types grade into each other. Verbeek (1905, in Van Bemmelen, 1970) proposed the name ambonites for these volcanic rocks which are characterized by the occurrence of cordierite, garnet, bronzite, mica, hornblende, andesite and also liparite. Martin (1907, in Van Bemmelen, 1970) ascribed a Late Tertiary or even Quaternary age to the ambonites on account of unweathered condition, the occurrence of hot springs with $H_2S$, and the absence of Tertiary deposits between the volcanic rocks and the overlying Quaternary coral reefs.

In some parts of the inner arc, the volcanic rocks are overlain by marls, having age of Late Tertiary or Quaternary. A few pumice layers are intercalated and coral reefs form a cover. In Hitu, globigerina-marls were deposited after the erosion of deep valleys in volcanic rocks. The oldest raised coral reefs showing a tilt of about $5^0$, while the younger ones, lying at lower levels, are horizontal.

According to Kuenen (1948, in Van Bemmelen 1970) in the Quaternary, an intermittent uplift occurred. Reef rocks were deposited upon the older formations and extensive deposits of debris were also formed. The deposition of coarse detritus reefs may indicate the presence of temporary minor subsidences or prolonged periods of stability.

According to Tjokrosapoetro (1994) (Figure 1), during Pliocene in Ambon, volcanic activities occurred. The activities created the Ambon Volcanic Rocks (Tpav) consisting of andesitic lava, dacite, volcanic-breccia, tuff-breccia and tuff. During Late Triassic to Jurasisic time the Kanikeh Formation (TRJk) was deposited which comprises alternating sandstone, shale, siltsone, with intercalation of conglomerate and limestone. Coralline Limestone (Ql) and conglomerate (qt) of Pleistocene age were unconformably deposited on top of the Fufa Formation

The climate in most areas of Ambon can be classified as a tropical rainy isothermal climate. According to Köppen's classification, the climate in the north area is classified as Afwaiw', while in the south is Awaw' (FAO, 1997). According to Schmidt-Fergusson (1951) this area is classified as type B. Mean annual rainfall is around 2000 mm with the maximum rainfalls occuring in May, June and July; minimum rainfalls occur in September, October and November. Around 9 months of the year are wet, 3 months are dry (Loran, 1991). Annual mean temperature is $25^o$ C. Temperature is fairly uniform during the whole year and the variation never exceeds $5^o$ C. In the hottest month (April), the temperature is $28^o$ C, and in coldest month (August) the temperature is $24^o$ C. The mean monthly value of relative humidity is ranging from 77 % (January) up to 86 % (June). Potential evapotranspiration varies from 3.6 to 5.1 mm/day. This area has an udic moisture regime and isohyperthermic temperature regime (Soil Survey Staff, 1990). The region is further characterized by predominantly wet, lush, tropical, and monsoon forests (Kyle and Ken, 2005).

## Mineralogical Characteristics of Coral Reefs

Coral reefs are concretions produced by living organisms. Some reefs are formed by calcareous algae, others by molluscs or polychaeta, but most of the reefs in the world are composed of hermatypic coral which contains microscopic symbiotic algae (Bigot *et al.*, 2000). The mineralogical composition of coral reefs depends upon the organisms which composed them (Schroeder and Purser, 1986). Coral reefs which are built by carbonate sedimentary rocks (Constant, 1986), contain more than 50 % of carbonate minerals and these minerals comprise $CO_3^{2-}$ with one or more cations of $Ca^{++}$, $Mg^{++}$ and also $Fe^{++}$ (Kerans *et al*., 1986). Calcite, aragonite and dolomite account for more than 90 % of carbonate minerals of coral reefs (Scherer, 1986). They form as grains and cements in the body of corals (Tucker and Hollingworth, 1986). Besides those minerals, there are also other minerals which build coral reefs as minor components (Schroeder and Purser, 1986). They are chert, phosphorite, pyrite, goethite (Scoffin, 1987) and gypsum (Tucker and Wright, 1990).

Coral contains not only the mineral of $CaCO_3$ from the coral skeleton, but also contains many ionic minerals that are a natural chelate due to the zooxanthellae that grows on the coral. Rugose corals built their skeletons of calcite and have a different symmetry from that of the scleractinian corals, whose skeletons are aragonite. However, there are some unusual examples of well preserved aragonitic rugose corals in the Late Permian. In addition, calcite has been reported in the initial post-larval calcification in a few scleractinian corals. Nevertheless, scleractinian corals which arose in the Middle Triassic may have arisen from a noncalcifying ancestor independent of the rugosan corals which disappeared in the Late Permian (Kleypas and Gattuso, 2007).

Mineralogical composition of soils on coral reefs is derived from the mineralogical composition of the reef itself. According to Sevink and Verstraten (1979), clay minerals can contain illite and smectite, while heavy minerals consist of epidote and andalusite. Ufie (1985) found that in heavy minerals there were staurolite and garnet, while light minerals comprise quartz and plagioclase.

## Sampling and Analytical Methods

Soil samples were taken from two profiles of Hitu and Wailiha (Figure 1). Samples were taken from every identifiable horizon: bulk samples for routine physical-chemical and mineralogical analyses, whilst rock fragments were collected for studying their mineralogy and fossil content.

The routine physical-chemical analyses were done, mainly according to the methods described in "Procedure for Soil Analysis" (Van Reeuwijk, 1992), Allison (1965), and Mehra and Jackson (1960). All data were reported on the basis of < 2 mm materials. The mineralogy was studied by X-Ray Diffraction (XRD), with and without treatments. Mineralogical composition was described according to De Connick and Van Ranst (1991). Fossils found in the coral were identified according to Cuvillier (1961), Horowitz and Potter (1971), and Adams *et al*. (1984).

## Result and Discussion

The Hitu profile located 115 m above sea level was built up on a weathered limestone with a 16% slope (Figure 2), in the south-eastern and smaller portion of the peninsula by a narrow neck of land. Its chemical and physical properties are presented in Table 1. The profile description is presented in Table 2.

The soil reactions are slightly neutral from the upper to the lower horizon (5.75 – 5.31). The pH is higher in the upper horizon due to the presence of pieces of calcium carbonate concretions. The values of pH KCl (5.21 – 4.25) are lower than pH $H_2O$ indicating a net negative charge of the exchange complex throughout the horizons. The organic content decreasing with depth, indicates that the acti-

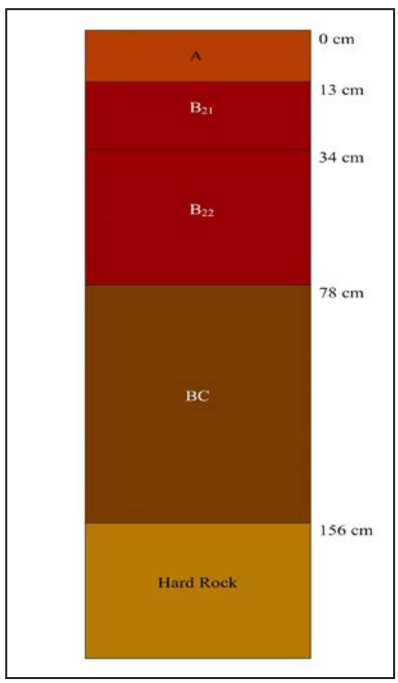


Figure 2. Profile of a limestone sequence in Hitu.

Tabel 1. Chemical and Physical Properties of Hitu Profile

| Properties | | Horizon | | | |
|---|---|---|---|---|---|
| | | A | $B_{21}$ | $B_{22}$ | B/C |
| pH $H_2O$ 1 : 1 | | 5.75 | 5.56 | 5.53 | 5.31 |
| pH KCl 1 : 1 | | 5.10 | 5.36 | 5.21 | 4,25 |
| Organic C | % | 3.62 | 0.43 | 0.16 | 0.16 |
| Organic matter | % | 6.23 | 0.74 | 0.27 | 0.27 |
| Total N | % | 0.16 | 0.05 | 0.04 | 0.03 |
| C/N | | 22.60 | 8.60 | 4.00 | 5.30 |
| $Fe_2O_3$ dithionit (soil) | % | 23.43 | 31.94 | 29.01 | 25.36 |
| $Fe_2O_3$ dithionit (clay) | % | 31.57 | 21.57 | 28.96 | 26.21 |
| $Al_2O_3$ dithionit (soil) | % | 3.86 | 3.86 | 3.67 | 5.88 |
| $Al_2O_3$ dithionit (clay) | % | 3.61 | 3.52 | 3.31 | 3.50 |
| $Fe_2O_3$ oxalate (clay) | % | 15.27 | 6.45 | 3.86 | 7.78 |
| Exchangeable Ca | cmol $kg^{-1}$ | 11.45 | 5.93 | 6.85 | 10.03 |
| Exchangeable Mg | cmol $kg^{-1}$ | 1.66 | 0.25 | 0.48 | 0.66 |
| Exchangeable K | cmol $kg^{-1}$ | 0.10 | 0.08 | 0.07 | 0.16 |
| Exchangeable Na | cmol $kg^{-1}$ | 0.10 | 0.09 | 0.22 | 0.10 |
| Sum of basic cation | cmol $kg^{-1}$ | 13.31 | 6.35 | 7.62 | 10.91 |
| CEC $NH_4OAc$ pH 7 | cmol $kg^{-1}$ | 34.58 | 21.36 | 39.50 | 22.60 |
| Base saturation | % | 38.49 | 29.73 | 19.29 | 48.45 |
| Sand | % | 8.50 | 0.30 | 0.40 | 0.40 |
| Silt | % | 21.40 | 24.60 | 24.60 | 24.60 |
| Clay | % | 70.10 | 75.10 | 75.00 | 75.00 |
| Textural class | | Clay | Clay | Clay | Clay |
| CEC Clay | % | 50.56 | 28.25 | 52.32 | 30.13 |
| CEC after corrrection of organic matter | % | 32.34 | 26.29 | 51.60 | 29.41 |
| Heavy mineral in sand fraction | % | 11.37 | 7.20 | 3.35 | 6.62 |
| Light mineral in sand fraction | % | 88.63 | 92.80 | 96.35 | 93.38 |

Table 2. The Profile Description of Hitu

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0 – 13 | Dark reddish brown (5 YR 3/2); clay, weak, fine to moderate subangular blocky structure; slightly sticky and plastic when wet, very fine to fine roots. |
| $B_{21}$ | 13 – 34 | Yellowish red (% YR 5/6); silty clay; weak, fine to moderate subangular blocky structure, slightly sticky and plastic when wet; few fine and medium roots; few small hard spherical manganiferous concretion. |
| $B_{22}$ | 34 – 78 | Yellowish red (5 YR 5/8); silty clay; moderate to strong coarse subangular blocky structure; few small hard spherical manganiferous concretion; very few fine strongly weathered rock fragments. |
| BC | 78 – 156 | Dark red (2.5 YR very moderate subangular blocky structure 3/6); silty clay; weak; moderate subangular blocky structure; few coarse strongly weathered rock fragments |
| | > 156 | Hard rock. |

vity of organisms is more pronounced in the upper horizon. Exchangeable cations, especially Ca, are high at the top and in the lower horizons. This is due to the presence of fragments of calcareous rock in the top horizon, and influence of calcareous parent material in the lower horizon. This value pattern is followed by the sum of basic cations and base saturation. Free iron is present from the top down to the lower horizons, and that free iron of the clay fraction is relatively higher than free iron of the total soil. Free aluminum is also present in the total soil and in the clay fraction, but less than free iron content. There are differences of the texture classes found in the laboratory and in the field. The soil texture from the laboratory analysis is clay throughout profile. Meanwhile, the soil texture from the field observation is clay loam to silty clay. The differences are possibly due to the high exchangeable Ca making the soil aggregation and giving the imitation silty feeling of the clayey texture.

The Wailiha profile is located 10 m above sea level with a 4 % slope, and built up on a weathered limestone (Figure 3). Its chemical and physical properties are presented in Table 3, while the profile description is presented in Table 4.

The profile location that is just 10 m above sea level, close to the coral reefs, makes the influence of calcareous parent materials is more pronounced. This contributes to pH $H_2O$ value which ranges between neutral (7.47) in the upper horizon and slightly neutral (5.55 and 5.68) in the lower horizon. The basic cations, CEC, and base saturation are also high. This value is the typical of soil developing on the calcareous parent material.

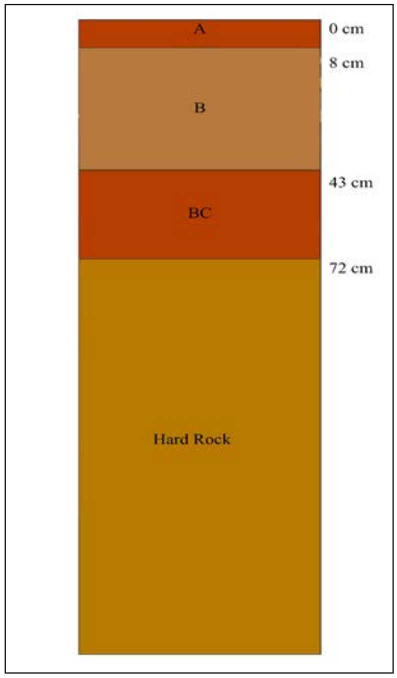


Figure 3. Profile of a limestone sequence in Wailiha.

Tabel 3. Chemical and Physical Properties of Wailiha Profile

| Properties | | Horizon | | |
|---|---|---|---|---|
| | | A | B | B/C |
| pH $H_2O$ 1 : 1 | | 7.74 | 5.55 | 5.68 |
| pH KCl 1 : 1 | | 6.71 | 4.51 | 4.56 |
| Organic C | % | 3.28 | 0.39 | 0.82 |
| Organic matter | % | 5.64 | 0.67 | 1.41 |
| Total N | % | 0.68 | 0.05 | 0.04 |
| C/N | | 4.82 | 7.80 | 20.50 |
| $Fe_2O_3$ dithionit (soil) | % | 7.14 | 8.70 | 9.38 |
| $Fe_2O_3$ dithionit (clay) | % | 10.90 | 8.86 | 9.20 |
| $Al_2O_3$ dithionit (soil) | % | 1.51 | 2.46 | 3.44 |
| $Al_2O_3$ dithionit (clay) | % | 2.99 | 3.86 | 2.72 |
| $Fe_2O_3$ oxalate (clay) | % | 6.15 | 5.68 | 4.84 |
| Exchangeable Ca | | 53.95 | 32.88 | 32.88 |
| Exchangeable Mg | | 2.76 | 1.59 | 2.35 |
| Exchangeable K | cmol $kg^{-1}$ | 0.16 | 0.23 | 0.19 |
| Exchangeable Na | cmol $kg^{-1}$ | 0.16 | 0.23 | 0.19 |
| Sum of basic cation | | 57.00 | 34.97 | 35.63 |
| CEC $NH_4OAc$ pH 7 | | 69.55 | 58.19 | 69.60 |
| Base saturation | | 81.45 | 60.10 | 51.19 |
| Sand | | 26.50 | 1.90 | 4.20 |
| Silt | | 8.40 | 9.70 | 9.20 |
| Clay | | 65.10 | 88.40 | 86.70 |
| Textural class | | Clay | Clay | Clay |
| CEC Clay | | 108.64 | 65.82 | 80.27 |
| CEC after correction of organic matter | | 89.51 | 64.31 | 77.02 |
| Heavy mineral in sand fraction | % | 1.80 | 0.72 | 0.75 |
| Light mineral in sand fraction | % | 98.20 | 99.28 | 99.25 |

Table 4. The Profile Description of Hitu

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0 – 8 | Very dark brown (10 YR 2/3); silty clay loam; weak, fine, granular structure; slightly sticky and plastic when wet, many very fine to fine roots. |
| B | 8 – 43 | Yellowish red (5 YR 4/6); clay loam; moderate to medium subangular blocky structure, sticky and plastic when wet; few small hard manganiferous concretions; few coarse strongly weathered rock fragments. |
| B/C | 43 – 72 | Reddish brown (5 YR 4/3); clay loam; strong moderate subangular blocky structure; sticky and plastic when wet; few small hard manganiferous concretions; few coarse strongly weathered rock fragments. |
| | > 72 | Hard rock. |

The organic carbon decreases with depth in the range of 3.22 – 0.82 %. Total nitrogen also decreaes with depth (range of 0.68 – 0.04 %). Such pattern causes the increasing value of C/N ratio with depth (range of 4.82 – 20.50). The free iron content is high, from 7.14 to 9.38 % in the soil, 9.20 to 10 % in the clay. The free aluminum ranges between 1.51 and 3.44 % in the soil and 2.72 – 3.68 % in the clay fraction, although there is no pattern of free iron and aluminum with depth. The sand fraction is only pronounced in the upper horizon. The silt fraction remains practically the same throughout the profile; and the clay fraction is dominant in all horizons; giving the clay textural class. However, the high exchangeable Ca gives the difference results between laboratory analysis and field observation, where the texture falls into silty clay loam to clay loam.

## Mineralogical Properties

X-Ray diffraction analysis was carried out for silt and clay fractions, as well as for rock fragments of both profiles. The mineralogy of sand fractions was analyzed with polarizer microscope. The identification of X-Ray patterns was mainly based on the De Conninck and Van Ranst (1991).

The analysis of rock fragments with X-Ray shows that they comprise calcite as indicated by a distinct and sharp reflection at 0.305 nm (Figure 4). It contains possibly also the other calcium carbonate minerals like aragonite and dolomite, but their reflections were not detected. The domination of calcite in rock fragments is the typical mineral of rock developing from calcareous parent material (Scherer, 1986; Gattuso *et al*., 1998; Perrin, 2003).

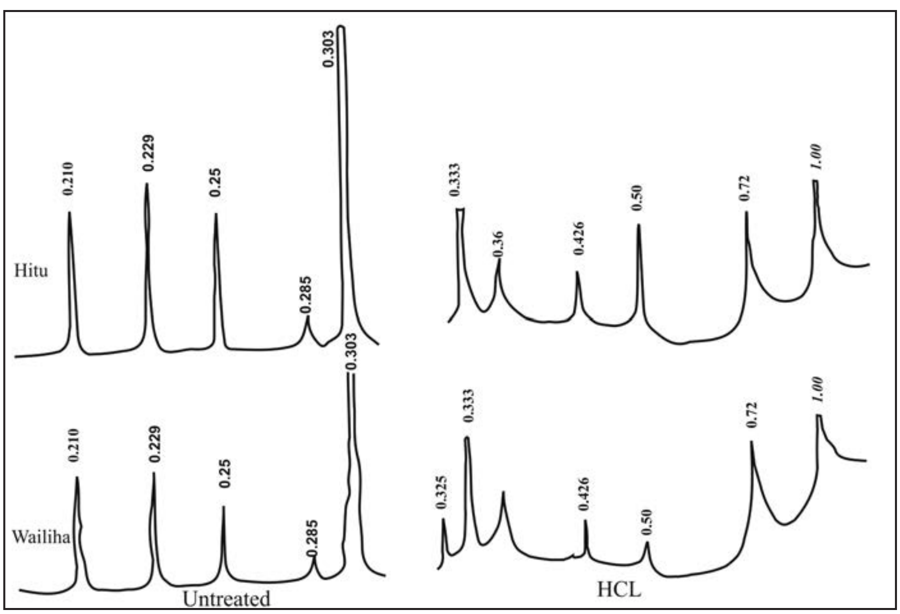


Figure 4. XRD patterns of untreated and HCL treated of rock fragments of the studied profiles.

Table 5. Heavy Minerals Composition in the Fine Sand Fraction

| Profile/ Horizon | Heavy Minerals Composition | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Opaque (%) | Augite | Diopside | Hyper sthene | Kyanite | Garnet | Staurolite | Zircon |
| Hitu | | | | | | | | |
| A | 97 | ** | * | - | - | - | - | - |
| $B_{21}$ | 92 | ** | ** | - | ** | - | - | - |
| $B_{22}$ | 95 | - | ** | * | - | - | * | * |
| B/C | 97 | - | - | * | - | *** | - | - |
| Wailiha | | | | | | | | |
| A | 97 | - | - | - | - | ** | * | - |
| B | 96 | ** | - | * | * | - | - | ** |
| B/C | 98 | * | - | - | * | * | - | - |

The non-carbonate fraction shows that the rock contains mica, kaolinite, and quartz which are indicated by the reflection at 1.00, 0.72, and 0.426 nm respectively. These minerals however, are not the dominant mineral normally found in the coral reefs. This indicates that rock fragments of the profile possibly not only from the coral reef origin, but also from other sources. Since mica and quartz are the rock forming minerals of the volcanic origin, they inform that volcanic activities had contributed as the parent rock to those profiles. Calcite, aragonite and dolomite form the soil on the coral reefs together with minerals released from volcanic origin like mica, kaolinite and quartz.

Heavy minerals of the fine sand fraction are grouped into opaque and transparent minerals (Table 5). The transparent heavy mineral types of both profiles are rather similar. Augite, hypersthene, kyanite, garnet, zircon, and staurolite are found in Hitu and Wailiha. The exception is only for diopside which is only found in Hitu.

The transparent heavy mineral compositions in the sand fraction indicate that the parent materials of these soils are not only from the coral reef but also from the other parent material. Augite, hypersthene, kyanite, garnet, zircon and staurolite are not the typical sedimentary minerals but also from the volcanic origin. Augite is found in igneous rocks, for example in gabbro and basalt (Deer *et al*., 1992). Diopside and hypersthene are some of the heavy mineral components found in the soil developing from pumice or volcanic activity (Shomei and Toshikazu, 1998; Gribble, 1988).The typical heavy minerals found in the coral reefs like calcite and aragonite seems quickly decay within a few years, especially in the tropical environment where the temperature and rainfall are high during the whole year (Perrin and Smith, 2007). Considering the geology of Ambon, the presence of active volcanoes on this island (Honthaas *et al*., 1999) gave the possibility that material was added during the eruption. The highest mountains, Wawani (1100 m) and Salahutu (1225 m) are active volcanoes. Their eruptions possibly contributed a certain amount of material that is still weatherable.

An order of mineral resistance to weathering established from more to less resistant are zircon > garnet > augite (Velbel, 1999). Mineral weathering patterns in the different soils are complex and they depended upon a variety of factors including inherent crystallographic, mineralogical, physical, and chemical properties of the minerals as well as interaction between the various factors that contribute to soil formation. At least in an acid pedochemical environment, zircon is the most reliable mineral on which to base a pedogenetic index. Nevertheless, in strongly weathered profile zircon showed an evidence of pedochemical weathering (Tejan-Kella *et al*., 1991).

According to Mange and Mauver (1992) and Cherniak and Watson (2000) those minerals can be classified as unstable minerals (augite, diopsite, hypersthene), moderately stable minerals (kyanite), and stable minerals (garnet, zircon, staurolite). The presence of garnet, staurolite and zircon as the stable minerals indicates that those soils had strongly weathered (Klein, 2002). On the other side, the presence of augite, diopside, and hypersthene as unstable minerals, and kyanite as moderately stable mineral gives a perception that these soils are not strongly weathered.

The silt fractions of both profiles contain quartz, chlorite, gibbsite and goethite. In Hitu, there are also kaolinite and feldspar, while in Wailiha possibly there is kaolinite or haloysite. The presence of halloysite is an interesting matter because halloysite is a mineral which normally occurs in the soils from volcanic deposits (Dixon, 1989). Its occurrence is possibly due to the presence of volcanoes in the Ambon Island.

Kaolinite is the dominant component in clay fraction of all profiles. Gibsite and goethite are also present in all profiles. Vermiculite in Hitu may indicate that in interlayer space cations are still present. Such a behavior is typical for minerals which are indicated in the literature as Al-vermiculite, or hydroxy-Al interlayered vermiculite, or Al-chlorite (Van Ranst *et al.*, 1979). A small amount of chlorite is found in Hitu.

The presence of kaolinite, gibbsite and goethite indicates that all profiles contain strongly weathered material. Kaolinite is the typical clay mineral of soils developed under a humid tropical climate (Dixon, 1989). It has been commonly described as a weathering product of feldspar, although almost all primary silicates have been listed as a precursor mineral of kaolinite. Gibbsite is common in soils that have undergone a very strong weathering under a tropical climate. It is a product of extremely advanced weathering, where the environmental conditions are favourable for leaching of basic cations and Si. The association of kaolinite, gibbsite and goethite is the common feature of major soils under a tropical condition. Vermiculite can be found in tropical areas with a high rainfall, as an alteration product of mica or chlorite. In this soil, mica is found in the parent rock and chlorite is found in the silt fraction.

### Soil Classification and Pedogenesis

The soil classification is based on field data, physical-chemical and XRD analyses, and micromorphological properties.

In Hitu, the soil has an ochric epipedon and cambic subsurface horizon while its texture is clay throughout. The soil temperature regime is isohyperthermic with an udic soil moisture regime. Paralithic contact is found below 156 cm. The base saturation ($NH_4OAc$) is more than 16 % but less than 50 %. Kaolinite is dominant in the clay fraction. Therefore, according to Soil Survey Staff (1990) this soil can be classified as a Typic Dystropepts, clayey, kaolinitic, udic, isohyperthermic. Meanwhile, on the basis of FAO classification (1989) this soil is classified as Dystric Cambisol.

In Wailiha, the soil has an ochric epipedon and argilic subsurface horizon. The texture is clay, with kaolinite as a dominant mineral. Base saturation is more than 50 %, whereas a paralithic contact is found below 72 cm. The soil temperature regime is isohyperthermic and the soil moisture regime is udic. Based on Soil Survey Staff (1990) this soil is classified as Ultic hapludalf, clayey, kaolinitic, udic, isohyperthermic. On the other hand, according to FAO classification (1989) it can be classified as Haplic Luvisols.

Soil depths at the bottom of coral reefs are much thicker than those of the top of the coral reefs (Hseu *et al.*, 2004). However the pH value, organic carbon and carbonate contents at the top of the coral reef are higher than those at the bottom. High clay content is found in all soils because of the strong illuviation of clay. Translocation of clay and free Fe within the soil is significant. However, illuviation of clay is identified by differently oriented clay coating in the argilic horizons. Calcium carbonate is being dissolved from the coral reef, but its precipitation has not been found in the soil.

## Conclusions

Mineralogically, the soil on coral reefs in Ambon is derived not only from the coral reef origin but also from other sources like volcanic activities. It is characterized by the presence of heavy minerals like augite, diopside and hypersthene besides carbonate minerals such as calcite and aragonite. Its mineralogy is also influenced by the weathering condition which normally occurs in soils of a tropical zone. The presence of kaolinite, vermiculite, gibbsite, and goethite in the clay fraction in all horizons of both profiles characterizes the soil.

The pedogenesis of both profiles indicates the high clay content found in all soils is due to the strong illuviation of clay. This is an indication of influences of a tropical environment enabling the clay to translocate to the lower horizon. The translocations of the clay and free Fe within the soil are significant.

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