PART 2

HYDROLOGY AND DYNAMICS

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1 - THE BAY OF AMBON

1.1. - Hydrological descriptors

A total of 19 hydrological stations in the Bay of Ambon had been worked out. The following description is the result of the cruise and it is mainly intended to deal with several hydrological parameters especially their horizontal distribution at the surface and near the bottom.

Maps 3 to 9 show respectively the horizontal distributions of temperature, salinity, oxygen, phosphate, nitrite, silicate and chlorophyll contents at the surface, and maps 10 to 15 show the horizontal distributions of the same parameters near the bottom, except for chlorophyll.

1.1.1. - At the surface

Temperature (fig.3)

The horizontal distribution of temperature in the bay has more or less uniform values. The temperature varies from 28.6°C to 30.2°C, and shows the highest value in the apex of the inner bay and the lowest value in the outer bay just next to the Banda Sea. The relatively low temperature in the outer bay might be due to the direct influence of the Banda Sea.

Salinity (fig.4)

The salinity distribution shows a clear horizontal variation. The salinity increases from the inner bay towards the outer bay and the Banda Sea. In the outer bay the salinity ranges between 33.6°/oo and 34.0°/oo while in the inner bay it ranges between 32.6°/oo and 33.5°/oo. The dilution of fresh water discharge from several small rivers flowing into the inner bay is considered to be a main important factor that causes the low salinity in the inner bay. On the other hand, the high salinity greater than 34.0°/oo in the mouth of the bay, likewise for temperature, might be caused by the direct influence of the high saline water from the Banda Sea.

Oxygen (fig.5)

The value of oxygen content in the bay is nearly uniform. It is mostly higher than 4.0 ml/l, except at a few places, such as, in the middle and northern parts of the outer bay where a value lesser than 4.0 ml/l is found.

Phosphate (fig.6)

The phosphate content in the inner bay is ranging between 0.5 and 1.0 μmol/l except at a limited place in the middle part of the inner bay a value of less than 0.3 μmol/l is recorded. In the outer bay the phosphate content is almost everywhere less than 0.5 μmol/l, but at few places near the coast, especially in front of the city of Ambon, a higher value of more than 0.5 μmol/l is observed.

Nitrite (fig.7)

As in the case of phosphate the nitrite content in the inner bay is higher than that in the outer bay. The nitrite content in the inner bay shows a wide range of variation, it varies from 0.7 to 2.0 μmol/l and the highest value is found in the apex of the bay. In the outer bay the nitrite content is smaller, ranging between 0.4 and 1.0 μmol/l with a relatively high value in the middle part of the outer bay.

Silicate (fig.8)

The silicate content in the inner bay is between 13.0 and 68.0 μmol/l and the highest value is recorded in the tip of the bay. In the outer bay it is much lower, and varies from 3.0 to 10.0 μmol/l. The gradual decrease of silicate content from the inner bay towards the outer bay is clearly seen.

Chlorophyll (fig.9)

The chlorophyll content decreases gradually from the inner bay towards the outer bay. In the inner bay the chlorophyll content varies between 0.5 and 0.7 μmol/l and shows the highest value in the apex of the bay. In the outer bay the chlorophyll content is smaller and has a more widerrange of variation, it ranges between 0.1 and 0.6 μmol/l. The value drops quickly towards the Banda Sea and in the mouth of the bay it becomes less than 0.1 μmol/l.

It is worth to mention that the high content of phosphate, nitrite as well as silicate in the inner bay seems to be associated with the effect of several small rivers flowing into the inner bay and carrying nutrients from the land into the bay. The higher nutrient content in the inner bay is also reflected by the higher content of chlorophyll. And the relatively high phosphate content at few places near the coast in the outer bay, especially in front of the city of Ambon, might also be associated with the influence of a river passing by the city and carrying nutrients and organic matter before it enters the bay.

1.1.2. - Near the bottom

In dealing with the distribution of hydrological parameters near the bottom a first and important consideration which should be born in mind is the depth of the sea bottom, since the values of the hydrological parameters are in general a function of depth. It will apply to the Bay of Ambon in particular to the outer bay which has more irregular and greater depths.

Temperature (fig.10)

The inner bay is not only narrow but it is also shallow therefore the expected value of each hydrological parameter near the bottom will not differ much from one station to another station.

In the inner bay the temperature near the bottom is almost uniform, and varies from 26.3 to 28.5°C. In the outer bay the role of the depth of the bottom is very clear as it is reflected by a wide range of temperature variation from 8.4 to 28.2°C. The high temperatures are recorded at shallow places along the coast and the low temperatures are recorded at deeper places in the middle part of the bay. The decrease of temperature from the inner bay towards the outer bay and the Banda Sea is mainly due to the increase of the depth of the sea from the inner bay towards the outer bay.

Salinity (fig.11)

The salinity in the inner bay is completely uniform, and ranges around 34.0°/oo. In the outer bay the salinity varies from around 34.0°/oo to more than 34.5°/oo. The low values, slightly higher than 34.0°/oo are recorded at shallow places along the coast, and the high ones, more than 34.5°/oo at deep places in the bay .

Oxygen (fig.12)

The oxygen content in the inner bay shows values between 2.0 ml/l and 3.8 ml/l and the lowest value is found in the tip of the bay. In the outer bay the oxygen content ranges between 2.5 ml/l and 4.5 ml/l, and it is clearly observed that the low values are found at shallow parts while the high ones at deeper parts of the bay.

Phosphate (fig.13)

The phosphate content in the inner bay is uniform, ranging between 0.6 and 0.7 μmol/l. In the outer bay, on the other hand, the phosphate content shows a wide range of variation. The value between 0.4 and 1.0 μmol/l is recorded at shallow places near the coast and the value greater than 2.0 μmol/l is found at deeper places in the middle part of the bay.

Nitrite (fig.14)

In the inner bay the nitrite content is recorded between 0.5 and 2.2 μmol/l and showing the high value in the apex of the bay. In the outer bay the nitrite content is much lower, it is in general between 0.05 μmol/l and 0.2 μmol/l but just in front of the city of Ambon a high value greater than 0.5 μmol/l is recorded. This high value of nitrite at limited place in front of the city of Ambon as already mentioned previously, might be associated with the effect of a river passing by the city and carrying nutrients as well as organic matters into the bay.

Silicate (fig.15)

The silicate content in the whole bay shows a wide range of variation. In the inner bay it ranges between 1.6 and 22.2 μmol/l, and the high value is recorded in the tip of the bay. In the outer bay the silicate content varies very widely from 2.2 to 59.7 μmol/l, and indicates the high value at depeer place in the mouth of the bay just near to the Banda Sea and the low one at shallow places near the coast.

The distribution of the hydrological descriptors in the Bay of Ambon will certainly be associated with the water exchange between the inner bay and the outer bay, and also by the water exchange between the bay and the Banda Sea. The water exchanges will in turn be governed by the current pattern as well as the character of the tide in the area.

1.2. - Currents

1.2.1. - Moorings on the sill

The results of measurements achieved during 7 days are represented in fig.16. An harmonic analysis was performed on the data and revealed the following features :

The main variability of the currents is concentrated around the tidal period. The tidal currents are important and the tidal ellipses are nearly rectilinear and oriented along the bay's axis with the following ccharacteristics.

At 7 m maximum speed: 32 cm/s direction 71°
At 14m maximum speed: 14 cm/s direction 73°

A interesting feature is the existence of a near residual flow directed towards the inner bay (6 cm/s in the 69° direction at 7 meters, 15 cm/s in the 58° direction at 14 m), which is more important in the lower layers. This means that a residual outflow must exist either in the surface layer or in the right part of the channel. The entrance of water in the inner bay through the deeper layer is connected with the phenomenon of internal tide in the outer bay (see further) and this phenomenon probably explains the persistancy in the inner bay of cold water in the layer deeper than the sill depth (fig.17).

1.2.2. - Profiles in the bay (figs. 18,19,20 & 21)

The current profiles achieved in the outer bay are illustrated in fig. 18 to 21 (station 31), where the currents are presented using their components along the axis of the bay (54° in comparison with geographical north) and perpendicular to the axis (144° id°). The main feature observed during this experiment is the presence of a very important internal wave of tidal period. The amplitude of the interface displacement exceeds 150 meters. This phenomenon wich is under study has probably the character of a standing wave and is due to the fact that the period of the fondamental internal oscillation of the outer bay lies close to that of the semi-diurnal tide.

It is interesting to compare the values of several hydrological parameters in the Bay of Ambon observed during the CORINDON-IV cruise to those that had been measured previously by the Ambon Field Station.

The following table contains the average values of temperature, salinity, oxygen and phosphate contents measured by the Ambon Field Station in April (Yusuf, 1979) and those observed during the CORINDON-IV cruise in April 1981.

Table 1

	Inner Bay		Outer Bay	
Parameter	April 1975	April 1981	April 1975	April 1981
T°C	29.98	29.99	29.53	29.00
S°/oo	31.79	33.09	33.59	33.83
O_2 ml/l	4.16	4.55	4.11	4.77
PO_4 µmol/l	0.51	0.64	0.70	0.41

The values of each parameter are mostly comparable, except for lower salinity in April 1975 in the inner bay and for higher phosphate content in April 1975 in the outer bay. The low salinity in April 1975 is thought to be associated with the rainy season which may have started earlier in 1975. There were three peaks of rainfall recorded in 1974/1975, namely in July and September 1974 and in April 1975 (Yusuf, 1979). The possible factors that may cause the high value of phosphate in April 1975 in the outer bay remains questionable. Yusuf (1979) also noted that the monthly average temperature at the surface in the outer bay is relatively lower than that in the inner bay, and the same for phosphate content. For salinity, on the other hand, its value in the outer bay is higher. The results of CORINDON-IV are also showing the same pattern.

Based on the temperature measurements in the Bay of Ambon from 1973 to 1978, Wenno (1979) drew as conclusion that the vertical temperature distributions in the outer bay are strongly influenced by the monsoons. During the east monsoon the temperature in the surface layer is relatively low, ranging between 24.6 and 26.9°C, and the thermocline is found at about 100 m depth. This condition is more or less stable from year to year. During the west monsoon the temperature in the surface layer is higher, it is between 28.2°C and 28.8°C ; the depth of the thermocline changes from year to year and fluctuates from 50-70 m to 150-200 m. This fluctuation of the thermocline depth is associated with the weather variations from one west monsoon to another. The strong winds prevailing during the west monsoon have much effect on the surface layer. The mixing between surface layer and layer underneath will take place intensively due to the strong winds, waves and currents.

For the comparison the vertical temperature distribution along the Northeast-Southwest cross-section (stations 4,6,1,7,9,11,14 and 16) in the Bay of Ambon is shown in figure 17. It shows that the temperature in the surface layer is slightly higher, varying from 27.0°C to 29.0°C, and the thermocline is found at about 80 m depth. The deepening of the isotherms below the surface layer, particularly at station 11, might be due to the tides in the area. An indication of this kind of deepening of the isotherms is also shown by the west monsoon's cross-section presented by Wenno (1979). Of course the short term fluctuations of the thermal structure, as revealed by the measurements at fixed point, may considerably modify the pattern of the cross-section.

2 - THE BANDA SEA

2.1. - Hydrological descriptors

As part of the CORINDON-IV cruise a number of hydrological stations along two cross-section in the Northern Banda Sea were also worked out. The first cross-section was the Ambon-Buru cross-section (stations 20 to 25) and the second one was the Ambon-south cross-section (stations 20,26 to 28). The vertical distributions of temperature, salinity, oxygen, phosphate, nitrate, nitrite, silicate, and chlorophyll contents are respectively shown in figures 22 to 29 for the first transect, and in figures 30 to 37 for the second transect.

An attempt to give a general description for each parameter along the two cross-sections is presented in the following note.

2.1.1. - The Ambon - Buru cross-section

Temperature (fig.22)

A uniform distribution of high temperature is found in the surface layer. In this homogeneous layer the temperature decreases slightly downwards from around 29.0°C to 26.0°C at about 90 m depth. Below the homogeneous layer the thermocline layer is found, as it is revealed by a very rapid decrease of temperature from around 26.0°C at 90 m depth to around 19.0°C at about 130 m depth. In the lower boundary of the discontinuity layer, at about 250 m depth, the temperature is between 14°C and 13°C. In the greater depths the temperature continue to decrease with depth and at about 600 m depth it reaches 6°C.

Salinity (fig.23)

The salinity at the surface is around 33.8°/₀₀, it increases with depth and reaches the maximum value of more than 34.8°/₀₀ in the layer between 1 60 m and 2 80 m depths. This kind of tongue of the salinity maximum is clearly observed in the western part of the cross-section. As described by Wyrtki (1961) the salinity maximum in this area indicates or characterizes the presence of the Southern Subtropical Lower Water within the discontinuity layer. Below the depth of 300 m the salinity decreases again downwards, but only slightly, and at 700 m depth (station 20) it is around 34.6°/₀₀.

Oxygen (fig.24)

In the eastern part of the section the oxygen content in the surface layer is always greater than 4.0 ml/l, and at greater depth a relatively high value of around 2.5 ml/l is still recorded. In the western part of the section the oxygen content in the same layer is less than 4.5 ml/l, and at a relatively shallow place, at 250 m depth, a value of 2.0 ml/l is already observed. For the whole cross-section the oxygen content varies from 4.0 to 4.5 ml/l in the discontinuity layer.

The low oxygen content at shallow level, especially in the eastern part of the section, might be considered as an indication of the possibility that Intermediate Water having low oxygen content from the greater depth be presents in this layer. It will only happen if an upward motion or upwelling takes place in the area. However, the distributions of the other parameters, such as, temperature, salinity and nutrient contents do not reveal a clear concommitant indication of the possibility of upward motions, either in the surface layer or in the discontinuity layer. And as already noted by Wyrtki (1957), the upwelling in the Banda Sea (in the eastern part) just begins in April and will end in September. The other possibility that may cause the formation of the low oxygen content in this layer is the biological processes, and of course a conclusion about this question can only be expected after the biological processes have been examined.

Phosphate (fig.25)

In the surface layer the phosphate content varies 0.2 and 0.5 μmol/l, and shows the relatively high value between 0.4 and 0.5 μmol/l in the middle part of the section and the low value of less than 0.3 μmol/l either in the eastern or western parts of the section. The value of the phosphate content increases with depth and it reaches nearly 3.0 μmol/l at depth of about 600 m.

Nitrate (fig.26)

As in the case of the phosphate the low nitrate content is recorded in the surface layer and it will increase with depth. In the surface layer the nitrate content is everywhere less than 0.5 μmol/l. At the deeper layers the phosphate content in the eastern part is generally higher than that in the western part of the cross-section, as it is clearly shown by the value of station 21 compared to that of the other stations. The value at station 21 at any depth is always higher than that of the stations in the western part of the cross-section.

Nitrite (fig.27)

From the surface down to 50 m depth the nitrite content is less than 0.1 μmol/l. It will increase with depth and reaches the maximum value of more than 0.3 μmol/l in the layer between 50 m and 100 m depths, and even a greater value of more than 0.5 μmol/l is found at station 23. Beyond the 100 m depth downwards the nitrite content decreases and everywhere in deeper layers the recorded values are lesser than 0.1 μmol/l.

Silicate (fig.28)

In the surface layer, from the surface to the depth of 100 m, the silicate content is low, ranging between 0.1 and 0.5 μmol/l and showing the high value in the eastern part of the cross-section (near to Ambon). The silicate content will then increase very rapidly downwards and at about 550 m depth it reaches 50 μmol/l.

Chlorophyll (fig.29)

The chlorophyll content at the surface is low, it is less than 0.5 μg/l in the western part and around 0.1 μg/l in the eastern part of the cross-section. A high value of more than 0.3 μg/l is recorded in the layer between 30 m and 80 m depths. From 80 m depth downwards the chlorophyll content decreases and in the deeper layers it is always less then 0.05 μg/l.

2.1.2. - *The Ambon - South cross-section*

Temperature (fig.30)

The vertical distribution of temperature along the cross-section is more or less uniform, particularly from the surface down to 75 m depth. Within the surface layer the temperature is ranging between 27.0°C and 30.0°C, and below this layer the thermocline layer is found and it is characterized by a rapid decrease of temperature from around 25°C at 100 m depth to around 15°C at 200 m depth. In the greater depth the temperature still continue to decrease downwards, but only slowly, and at about 800 m depth it attains 6°C.

Salinity (fig.31)

The salinity between 33.9 and 34.4°/oo occupies the surface layer. The maximum salinity of more than 34.7°/oo is recorded in the layer between 180 m and 225 m depths, and it can be observed in the northern part of the cross-section. This maximum salinity can also be considered as an indication of the presence of the Southern Subtropical Lower Water in the area. Its presence here, however, is not so clearly marked as in the case along the Ambon-Buru cross-section. In the greater depths the salinity differs only slightly from 34.6°/₀₀ and below 600 m depth, particularly in the northern part of the section, it is less than 34.6°/₀₀ .

Oxygen (fig.32)

In the surface layer the oxygen content is normally high, it varies between 4.0 and 4.5 ml/l. In the discontinuity layer, i.e. in the layer between 100 m and 250 m depths the oxygen content is low ranging between 2.6 and 3.5 ml/l and in the depths of more than 500 m it is generally less than 2.5 ml/l.

Phosphate (fig.33)

The phosphate content in the surface layer shows a slight variation, it varies from less than 0.3 to 0.6 µmol/l. It will then increase with depth and in the continuity layer it is recorded between 0.6 and 2.0 µmol/l and from 300 m to the greater depth it is always more than 2.0 µmol/l.

Nitrate (fig.34)

The nitrate content, especially in the surface layer, shows a wide range of variation. The zero value is found in the northern part of the section, the value of less than 0.1 µmol/l in the middle part of the section, and the higher value of more than 0.1 µmol/l in the southern part of the section. Below the surface layer the nitrate content increases quite rapidly with depth as it is shown by a value of 1.0 µmol/l at about 80 m depth, it will increase rapidly downwards and becomes 5.0 µmol/l just at about 100 m depth. Below 100 m depth, however, the distribution of the nitrate content is rather unique. The values of stations 20 and 27 are always much higher than those of stations 26 and 28 at the same depths.

Nitrite (fig.35)

In the surface layer the nitrite content is everywhere less than 0.1 μmol/l. The maximum value between 0.2 and 0.3 μmol/l is recorded in a thin layer between 70 m and 100 m depths, and from about 100 m depth downwards the value decreases again and in the deeper layers the uniform value of less than 0.1 μmol/l (around 0.08 μmol/l) is observed.

Silicate (fig.36)

The silicate content in the surface layer ranges between less than 1.0 and 6.0 μmol/l, and shows the low value, (even zero value), in the middle part of the cross-section. At about 100 m depth the silicate content is only around 8.0 μmol/l, and from this depth downwards it increases very rapidly and at about 600 m depth it reaches a value greater than 60.0 μmol/l.

Chlorophyll (fig.37)

From the surface down to 50 m depth the chlorophyll content is less than 0.05 μg/l, except at station 20 (near to Ambon) a higher value between 0.05 and 0.1 μg/l is found. The maximum value between 0.1 and 0.2 μg/l is recorded in the layer between 50 m and 100 m depths, and from 100 m depth downwards it decreases again and below 150 m depth it is generally less than 0.05 μg/l.

It seems interesting to note the station 20 of CORINDON-IV. This station occupied exactly the station 231 of the SNELLIUS Expedition which had been conducted half century age in the Eastern Part of the Archipelago. The vertical distributions of temperature and salinity of the two observations are compared and shown in figure 43. It shows that the vertical profiles of temperature and salinity of the two observations are quite similar, especially in deep layers, from about 400 m depth downwards. This fact suggests that in the surface layer the variations of water properties will happen due to the climatological changes, while in the greater depths the water layers are stable and the horizontal motion or exchanges of water masses may take place very slowly.

2.2. - *Currents*

2.2.1. - *Surface measurements (fig. 38 & 39)*

The currents measured using the GEK are presented in figures 38 and 39. The currents measurements where made on April 9 from 00h to 06h between Buru and Ambon and on April 10th from 00h to 06h for the south leg.

Figure 38 illustrates the currents component perpendicular to the vessel's route, as it is the rough result obtained by GEK. In figure 39 are presented the currents computed at points where perpendicular loops were achieved.

As can be seen, the general pattern observed leads to a westward transport for surface waters in the Banda Sea and a weak southward flow through the strait between Ambon and Buru corresponding probably to water exchange from the Ceram Sea to the Banda Sea. Individual currents (fig.39) look rather irregular, partly due to tidal influence (the wind was very weak and its effect on surface circulation can be considered as negligible). The strongest currents (75 cm/s) were observed near the southwestern edge of Ambon island.

2.2.2. - *Current profiles (fig. 18,40,41 & 42)*

The current profiles are illustrated in fig 18 and 40 to 42 (station 20 to 30). They reveal the complexity of the structure of deep-currents. In general there is no obvious association between the surface mixed layer (fig. 44 to 47, bathythermograms) and a layer of constant current, though there seems to exist a current discontinuity between 100 and 150 meters. These results combined with works from previous authors enhance the probable main role of short term baroclinic waves in the vertical structure of currents in this area.

2.2.3. - *Geostrophic currents*

The geostrophic currents have been computed with the data issued from hydrocasts. The results are not presented here on account of their lack of signification. No reasonable pattern of currents can be deduced from this type of calculation. Once more the reason is presumably the presence of large short term baroclinics variability combined with the proximity of the equator wich enhances the effects of small variation of dynamic depths on the computation of geostrophic currents.

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