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WATERS OF THE WESTERN PACIFIC AT 170°E, BETWEEN 20°S AND 4°N

by

the Oceanographic Section of the Centre ORSTOM de NOUMEA

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INTRODUCTION

In the intertropical oceans, the equatorial zone is a region of high productivity in waters which are generally poor. That of the Pacific ocean differs nevertheless from those of the other oceans. First by its dimension. It extends from 80°W to 130°E, over a distance of more than 9,000 miles, about 17,000 km. Second, the mecanisms of superficial enrichment, equatorial upwelling, westward advection of surface water derived from the Peru upwelling, turbulent vertical mixing in the upper homogeneous layer seem to be extremely active. Finally, the equatorial undercurrent or Cromwell current, which was the first subsuperficial equatorial current to be studied in detail, if one lets aside the observations of Buchanan and the remarks of Puls (Montgomery 1962, Stroup and Montgomery 1963) is very well developped.

Since the end of the last world war considerable efforts have been aimed at its study. In 1965, there were no less than 84 american transequatorial sections, numerous japanese measurements of the equatorial currents in the western Pacific and many russian transequatorial sections of the R.V. Vityaz and other ships. These studies have greatly contributed to the detailed knowledge of the equatorial circulation west of 140°W, and of the north-equatorial countercurrent, but when the R.V. Coriolis of the Centre ORSTOM of Noumea reached the Pacific in 1965, little was known of the equatorial circulation in its western part and many questions were still pending concerning the westward extension of the equatorial upwelling and of the Cromwell current, two fundamental characteristics of the equatorial circulation in the eastern and central Pacific.

As far as the equatorial upwelling proper is concerned, that is to say the upward movement, towards surface waters impoverished by photosynthesis, of richer subsuperficial waters, it is bound to a surface divergence of the wind-driven drift induced by the dominant tradewind. All year around, the equatorial waters of the central Pacific are richer than the adjacent ones and the enrichment in nutrients by westward advection of the upwelled waters off Peru cannot explain alone their relatively high productivity. Thus, there must be an active equatorial upwelling, the probability of it being increased by the fact that the strongest tradewinds are precisely met in this region. Nevertheless, some models of meridional equatorial circulation tie the Cromwell current to an equatorial divergence and consequently to an upwelling without sorting the cause from the effect. Thus, the equatorial upwelling might well be an indication of a divergence of the surface current induced by the wind, as well as of the Cromwell current. In the western equatorial Pacific the tradewind tension seems to be too weak to cause a permanent and important equatorial upwelling. Nevertheless, the surface equatorial cooling due to upwelling had been occasionally met.

At the start of the cruises of the N.O. Coriolis, the westward extension of the equatorial upwelling was very little known. It can vary with the seasons and its importance as an enrichment mecanism of superficial waters relative to the westward advection of richer waters formed eastwards was still to be determined. Further its possible tie with the Cromwell current gave some doubts on the westward extent of the former since the disappearance of any one of them implied the disappearance of the other, the causes of the observed fluctuations of the Cromwell current being unclear.

On the other side, Montgomery (1962) has noted than in the western Pacific the velocity cores of the Cromwell current and of the north equatorial countercurrent are generally tied together by a continuous zone of eastward flow. Other eastward flows have been evidenced in the southern hemisphere (Reid 1959) both at the surface and at the subsurface (isopycne 26.81 g/l or isanostere 125 cl/t) and one must not reject a priori the hypothesis of some kind of continuity between themselves and the Cromwell current. Finally, Burkov (1968) has suggested that the Cromwell current and the north equatorial countercurrent converge through the whole Pacific. The eastward circulation, both superficial and subsuperficial appears thus like a juxtaposition of flows which are distinct from each other in the central and eastern Pacific and which could have a common part in the western Pacific where they are formed.

During three years, the cruises of the R.V. Coriolis were devoted to these problems. The studies limited to the upper 1,500 metres have been devoted to the equatorial and tropical waters at 170°E, between 20°S and 4°N, from the point of view of the movements of the water masses, their hydrological properties, their primary productivity, the distribution of the biomasses of zooplankton and micronekton and the time variations of all these factors.

The present work gives the observed distributions of the main dynamical and hydrological parameters. As far as the biological studies are concerned only the distribution of the micronekton and of the macroplankton during the cruises "Bora" have been included together with comments on the main features of the distributions with regards to the general circulation, exclusively of any detailed study of the fine structures.

The raw data of the various cruises have been published in the local scientific reports of the Centre ORSTOM de Noumea, Section Oceanographie, and are also available at the World Data Centers A and B.

THE CRUISES

From november 1965 to may 1968, 11 cruises entirely or partially devoted to the oceanography of the meridian 170°E were made in two series. The trimestrial cruises "Bora" have defined the general oceanographical frame and indicated time variations much greater than expected. The monthly cruises "Cyclone" have studied the average term variations and in some cases the shorter term variations of the equatorial currents system. The date of these cruises and that of their equatorial station are given table 1 :

Table 1

List and dates of the cruises and of the equatorial stations at 170°E of the R.V. Coriolis

Cruises		Dates	Equatorial stations
BORA	1	26.11.65 - 22.12.65	7 .12.65
BORA	2	3. 3.66 - 5. 4.66	15. 3.66
BORA	3	9. 6.66 - 15. 7.66	22. 6.66
BORA	4	19. 9.66 - 17.10.66	2. 10. and 10.10.66
CYCLONE	1	14.11.66 - 7.12.66	22. 11. - 30.11.66
CYCLONE	2	14. 3.67 - 5. 4.67	22. 3.67
CYCLONE	3	18. 4.67 - 10. 5.67	26. 4.67
CYCLONE	4	29. 5.67 - 20. 6.67	6. 6.67
CYCLONE	5	4. 7.67 - 26. 7.67	12. 7.67
CYCLONE	6	17. 8.67 - 9. 9.67	25. 8.67
CYCLONE	7	9. 4.68 - 10. 5.68	18. 4, 24.4 and 8.5.68

On the whole, 102 stations have been occupied between 20°S and 5°S and 228 between 5°S and 4°N.

Methods

The one cast hydrological stations used 20 to 24 reversing Nansen type bottles internally plastified (T S K) during the first cruises and then all PVC (General Oceanics) Niskin type during the last cruises. The sampling depths were choosen according to a BT cast prior to each station so that the transition layer in the tropical zone and the Cromwell current in the equatorial region were best described. At some stations the distance between successive samples was 10 m. Most of the casts were made with an hydrological cable close to verticality. The distance between stations was 60 to 80 miles from 20°S to 4°S and 30 miles north of 4°S.

The reversing thermometers were almost all japanese (Yoshino). Pairs of protected thermometers were mounted on the reversing bottles used above 200 m depth; below, the thermometers frame contained alternatively two protected and one unprotected thermometers and then one protected and two unprotected thermometers. The accuracy of the temperature measurements, at the probability level of 0.05 is ± 0.02°C . For a thermometric depth less than 1,000 m the accuracy of the depth determination is ± 5 m. A recording thermometer (Pyrometrie Industrielle, accuracy ± 0.2°C) gave a continuous reading of the surface temperature. A BT cast with a 300 m type BT (Thermarine Recorder) was made before each station, at 30 miles intervals in tropical zone and at 10 miles intervals in equatorial waters.

The salinity was measured with an inductive salinometer (Auto-Lab Mark III), with an accuracy of ± 0.003 ‰ (Brown and Hamon 1961). In the studies of the Equatorial Pacific it is common use to express densities (sigma-t) in terms of thermosteric anomally Δ st (Montgomery and Wooster 1954) which has been defined as :

$$\Delta_{st} = 0{,}02736 - \frac{10^{-3}\,\sigma_t}{1 + 10^{-3}\,\sigma_t} \qquad \text{(La Fond 1951)}$$

The correspondence between Δ_{st} and σ_t is given table 2 :

Table 2

Correspondence between σ_t and Δ_{st}

Δ_{st}	σ_t
100	27.070
200	26.017
300	24.964
400	23.915
500	22.868
600	21.823

Oxygen has been measured by the Winkler method modified by Green (1965) and Carritt and Carpenter (1966). The titration was made with an automatic titrator (Beckman Model K) coupled to an electric burette (Metrohm) and modified to obtain a complete automatism of the titration (Rual and Voituriez 1969). The accuracy of the determination is $\pm$ 0.05 ml/l.

Phosphate, measured by the method of Murphy and Riley (1962) on a Beckman Model D U spectrophotocolorimeter, is known with an accuracy of $\pm$ 0.02 mat-g/m^3.

Nitrate, measured on the same colorimeter by the method of Morris and Riley (1963) modified by Wood, Armstrong and Richards (1967), is known with an accuracy which varies according to the concentration between $\pm$ 0.1 mat-g/m^3 and 0.7 mat-g/m^3. The nitrite was measured by the method of Bendschneider and Robinson (1952) with an accuracy of $\pm$ 0.02 mat-g/m^3.

All colorimetric measurements made on the Beckman Model D U spectrophotocolorimeter used 10 cm or 1 cm cells according to the intensity of the color.

No direct current measurements were made during the cruises "Bora". During the cruises "Cyclone" current measurements were made with 1, 2 or 3 (according to the cruise) recording currentmeters (Hydro-Products model 501) with Savonius rotors. The measurements were made from the drifting ship, the meters being attached to the hydrological cable maintained as close as possible to verticality, the direction and the speed of the ship being kept constant during the station. The currents are expressed relative to a depth of 500 m supposed to be motionless. The accuracy of the measurements is $\pm$ 5 cm/s on the intensity of the E-W component and $\pm$ 5° on the direction.

The chlorophyll a was determined by the method of Richards and Thompson (1952) slightly modified to adapt it to oligotrophic tropical waters : filtration of big volumes of water 10 to 20 litres and, for the colorimetric measurements, use of special cells with a long optical path (10 cm) and a small capacity (5 ml). The concentration has been computed by the formulas of Parsons and Strickland (1963) with an accuracy of $\pm$ 7 % for a range of concentrations of 0.05 - 0.20 mg/m^3.

The rate of photosynthesis has been measured during the cruises "Bora" only, by the method of Steeman-Nielsen (1952) with in situ incubation of the samples between 0700 and 1200 local time. In the range 0.05 - 0.90 mg/m^3/h the relative error is $\pm$ 40 %.

The distribution of micronekton and macroplankton has been systematically studied only during the cruises "Bora" with a 10 feet Isaacs-Kidd midwater-trawl, of 4 mm mesh. Its cod end was a 50 cm diameter ordinary conical net, of 000 mesh size (mesh aperture between 0.9 and 1.0 mm). A flowmeter (TSK) and a bathykimograph (Marine Advisers) were mounted on the gear. All the samplings were made nightly, between 0800 and 1100 p.m. local time with oblique hauls the depth of which varied according to the cruises. The biomasses are expressed as humid weights. The small plankton fraction has been separated from the rest of the catch by filtration in water with sieve having circular holes of a diameter of 3.4 mm.

HYDROLOGICAL SECTIONS AND MERIDIONAL DISTRIBUTIONS

The sections present the vertical distribution to a depth of 500 m, of the currents measured between 4°S and 4°N, of the geostrophic currents between 20°S and 5°S and, between 20°S and 4°N, of temperature, salinity, thermosteric anomaly, dissolved oxygen, nitrate, reactive phosphorus, with the identification numbers given in table 3.

Besides, various meridional distributions of biological parameters are given. They are chlorophyll a in the layers 0-50 m, 0-100 m and 0-200 m (Fig. 9), the photosynthetic rate in the layers 0-50 m and 0-100 m (Fig. 10), various biomasses (Fig. 11) : total biomass and that of the small plankton, bathypelagic copepods and thecosoma pteropods, chaetognats and gelatinous organisms, mysids and amphipods, peneids and euphausids, carids and sergestids, cephalopods, fishes and fish larvae.

Table 3

List of illustrations

	Measured currents	geostrophic currents	T°C	S ‰	st cl/t	O_2 ml/l	NO_3 mat-g/m^3	PO_4-P mat-g/m^3
N° of identification of the figure	1	2	3	4	5	6	7	8
Identification of the section								
B 1		a	a	a	a	a	a	
B 2		b	b	b	b	b	b	
B 3		c	c	c	c	c	c	
B 4		d	d	d	d	d	d	
B 4 (return)			e	e	e			
C 2	f	f	f	f	f	f		f
C 3	g	g	g	g	g	g	g	g
C 4	h	h	h	h	h	h	h	h
C 5	i	i	i	i	i	i	i	i
C 6	j	j	j	j	j	j	j	j
C 7_1	k	k	k	k	k	k	k	k
C 7_2	l		l	l	l	l	l	l
C 7_3	m		m	m	m	m	m	m
C 7 (20°S-5°S)	n							

Figure 9 : Distribution of chlorophyll a

Figure 10 : Distribution of primary production

Figure 11 : Distribution of various biomasses of micronekton and macroplankton.

A rapid survey of the various cross-sections shows that the vertical distributions are strongly determined by the zonal and meridional circulation such as they appear from the direct measurements and considerations on continuity and mass conservation.

Currents

The measured currents (Fig. 1, f - m) indicate three main zonal equatorial flows. At the surface, the westward equatorial current is usually divided in two cores. One core is centered at about 2°30S, has a thickness of the order of 200 m and its maximum speed is close to 50 cm/s. The second is located near 2°30 N. Its thickness is smaller and its maximum speed which is also smaller varies more. Quite often there is a third superficial small maximum at the equator.

Below this westward equatorial surface current and between its two north and south extensions there is the equatorial undercurrent or Cromwell current approximately centered at the equator. It has two velocity cores, one at about 100 m depth, the other at about 200 m depth, separated at about 150 m by a maximum of the southward component of the current. The upper limit of the upper core is close to 50 m and it flows thus in the lower part of the surface layer. The average velocity in the upper core is 30-40 cm/sec and it is 50 cm/sec in the lower core. This general scheme of surface and subsurface equatorial circulation is not always observed. In april 1967 (Fig. 1 g) at the equator, the surface current was eastwards. The upper cell of the Cromwell current was then replaced by a westward current bound to the two north and south branches of the equatorial westward current. At depths greater than 200 m the currents were unchanged and the lower core of the Cromwell current was found at this depth. This change of surface circulation followed a strong north-west wind which blew west of the zone under study some days before the cruise. It underlines the strong dependency of the currents in the upper layers of the equatorial region over the dominant winds system and the independency of the deep flows towards the same winds. North and south of the equator the Cromwell current is tied to two other eastward flows. North, it is the southern part of the surface north equatorial countercurrent which dives obliquely equatorwards and extends in depth to at least 500 m; this flow joins the Cromwell current through a "bridge" located at about 200 m at 2°30 N in which the velocity varies greatly. The thickness of this "bridge" is also highly variable and the meridional component of the velocity indicates a tendancy of the water at this level to diverge. The continuity of the flow between the north equatorial countercurrent and the Cromwell current indicated by Montgomery (1962) in the western Pacific is thus confirmed. Similarly, it appears that these two currents have a common origin, likely to the north of New-Guinea. However, they seem to separate east of 170°E. South of the equator, there is also an eastward flow with a core at about 2°S and 200-300 m depth and a velocity of the order of 30 cm/sec. This stable current reaches a depth of 1,500 m at least and could be the current described by Reid (1965) between 3°S and 7°S on the isanosteric surface 125 cl/t.

In these two deep north and south extensions of the Cromwell current is embedded a westward flow, the upper limit of which is near 300 m, where the velocity can be as high as 20 cm/sec, which is extremely thick since it has been found to extend to at least 1,500 m, and which is likely to be very important in the balance of flows in the equatorial region. It is proposed to call this newly discovered current the intermediate equatorial current.

The geostrophic currents between 20°S and 5°S (Fig. 2, a - k) indicate, in a general westward flow, the permanence of two eastward countercurrents, the south equatorial countercurrent and the south tropical countercurrent. The velocity core of the former is near 10°S with a maximum speed of the order of 20 cm/s. Its width varies considerably from 300 km to 900 km and it seems to reach great depth. However, velocities greater than 10 cm/sec are generally limited to the upper 300 m. The latter is more sluggish, thinner and its meridional extend smaller. It flows south of 15°S and its southern limit is difficult to define because the observations have been limited to 20° S. However its existence at 170°E is ascertained by direct current measurements with current meters and with GEK which were made on board of the R.V. Coriolis and by a drift bottle observation giving at 23°S a westward current between the longitude of the Fiji Islands and that of New Caledonia with an average velocity of 0.5 knots. Thus, it cannot be considered as part of the westward south Pacific current pertaining to the big anticyclonic gyre which includes the Peru current, the south equatorial current and the east australian current and located south of the south subtropical convergence (Burkov, 1968).

To sum up, at the surface, the circulation in the western Pacific appears to be quite different from the simple scheme based on the existence, over the greatest part of the south Pacific of one simple anticyclonic gyre. At the equator, when the dominant wind is the tradewind the current is westwards and it reverses when the wind reverses. This equatorial current is wind induced. At 10°S there is the south equatorial counter current which flows at the latitude where is located the wind convergence during the southern summer, (november-april); it coresponds to the similar current existing between 5°N and 10°N, called equatorial countercurrent and which should be named north equatorial countercurrent. At 20°S there is the south tropical countercurrent having also its counterpart in the northern hemisphere (Yoshida and Kidokoro, 1967), which has been called the subtropical countercurrent.

In subsurface, besides the equatorial undercurrent or Cromwell current there is a deep equatorial westward flow which we propose to call equatorial intermediate current. Because of its existence the term equatorial undercurrent used for the Cromwell current is ambiguous and it is proposed to use only for it the name Cromwell current.

Temperature (Fig. 3, a-m)

Three main features appear in the temperature distribution. An equatorial spreading of the isotherms of the thermocline is present between 3°S and 3°N, in a water layer extending from at least 100 m depth to 300 m depth. It affects also a large range of temperatures, from 25°C to 10°C. This spreading is much more marked than that described by Knauss (1960) at 140°W and associated to the Cromwell current. It suggests that the latter at 170°E is larger and thicker than at 140°W, what is confirmed by the direct measurements. Such a spreading is typical of the southern hemisphere winter time (april-november). During the summer, (Fig. 3, a and g) the bulging of the isotherms is limited to the lower ones whereas the upper ones remain horizontal. Nevertheless, at all seasons, below a depth of about 300-400m, the equatorward slope of the isotherms reverses in the vicinity of the equator. They slope upwards equatorwards. In terms of geostrophy this means that a westward current, the equatorial intermediate current is flowing in an eastward flow indicated by the downward slope equatorwards of the isotherms deeper than 300 m.

Generally the upward bulging of the upper isotherms results in a cooling of the equatorial surface water relatively to the adjacent waters. It is the equatorial upwelling. Usually, this upwelling is not symetrical to the equator as it should be if it were due only to the equatorial divergence of the equatorial westward surface current. It is displaced either northwards or southwards depending on the dominant wind during the cruise. When the wind has a north component the upwelling is displaced northwards, the reverse when the wind is from the southeast. These facts confirm the model of meridional circulation proposed by Cromwell (1953) to explain the thermal fronts which he met in the central Pacific. Again, the equatorial upwelling does exist only in southern hemisphere winter time. In summer december 1965 (Fig. 3 a) and april 1967 (Fig. 3 g) the wind induced surface current is eastwards because the wind is blowing from the north-west, the surface divergence is replaced by a convergence resulting in an increase of the thickness of the isothermal layer at the equator and there is no cooling of the surface water.

Finally in the tropical waters the thermocline gets thicker south of 5°S. Its deeper isotherms slope downwards southwards whereas the upper ones indicate at some locations very marked changes of slope. In the northern hemisphere an upward slope polewards is associated either to the north equatorial countercurrent (Kendall 1966) or to the north tropical countercurrent (Robinson 1969), that is to say, to a geostrophic eastward current. In the southern hemisphere, at 170°E, it coincides respectively with the south equatorial countercurrent near 10°S and with the south tropical countercurrent south of 15°S. Further, the thermal structure indicates clearly that the location and the strength of these countercurrents vary greatly with time. It must also be noted that the upper part of the thermocline presents at various latitudes a ridge due to an upward movement of the lower water at the southern limit of an eastward countercurrent; such a movement fulfills the continuity equation. On the contrary, the troughs are due to a downward movement which is associated to a surface convergence.

Salinity

The distribution of salinity (Fig. 4, a-m) is more complicated and gives more indications on the influence of the zonal circulation over the hydrological properties. There are interesting features at the surface as well as in subsurface.

At the surface, north of 3°N there is a low salinity water ($S°/_{oo}$ lower than $35°/_{oo}$) quite close to the northern limit of the westward equatorial current and likely to be bound to the north equatorial countercurrent. In the central and eastern Pacific this equatorial water is mostly formed by the advection of the upwelled Peru and equatorial water. The surface salinity maps show that in the western Pacific this waters cormes from the extreme western end of the equatorial Pacific where there is a great excess of rain over evaporation.

The subtropical surface water of the south Pacific extends south of 3°N and has a salinity higher than $35°/_{oo}$. It is separated from the formed by a well marked salinity front. In the equatorial region the distribution of the salinity gives evidences of the upwelling. Close to 10°S there is a core of low salinity water, partly entrained by the south equatorial countercurrent. It originates in the western equatorial Pacific, near New Guinea where can be found the only source of low salinity water in this part of the south Pacific. There is a salinity front between the subtropical surface water and the low salinity water of the south equatorial countercurrent and this front as well as the others which can be noticed at various latitudes might be indications of surface convergence and of downward movement in the upper layer. Some of them are in fact associated to throughs of the thermocline and of the pycnocline.

Near 10°S and 200 m depth, there is a core of saline water with a salinity higher than $36°/_{oo}$. It is the subtropical water of the south Pacific formed at the surface to the southeast of Polynesia. As indicated by the location of the $35.50°/_{oo}$ isohaline its equatorward extent varies greatly. This water participates to the formation of the Cromwell current and, close to the equator, its core is very near and generally sligthly above that of the Cromwell current. In the central Pacific there is always, south of the equator but at the level of the velocity core of the Cromwell current an isolated core of salinity, trace of the subtropical water of the south Pacific integrated into the current in the western Pacific (Montgomery and Stroup 1962, Knauss 1966, Wyrtki 1967). On some sections at 170°E there is a similar isolated core which suggests that this longitude is close to the eastern limit of integration of the subtropical water of the south Pacific into the Cromwell current. Further it is another indication of the greater width of the latter in the western Pacific since the salinity core is further south. The subtropical south Pacific water formed in the central Pacific, south of 20°S, between 110°W and 140°W extends westwards and northward, along several paths as indicated by secondary isolated maxima both north and south of the main core.

At the equator in subsurface the salinity structure is extremely complicated by the presence of numerous maxima derived from the southern hemisphere and minima formed of northern hemisphere water. These two waters converge equatorwards and participate to the formation of the Cromwell current. North of the equator, at about 200 m depth, there is a low salinity water which is the north Pacific intermediate water. It extends southwards and reaches almost the equator where it forms with the saline water of southern origin a well marked salinity front. The intensity of this front depends on the equatorward extent of the subsurface waters and it can be seen that it varies greatly. In december 1965 (Fig. 4 a) and in april 1967 (Fig. 4 g) the equatorial surface water was desalted. The westward equatorial current was then replaced by an eastward current formed north of New Guinea and transporting the low salinity water formed in this region.

Ridges and troughs in the upper part of the halocline are also indications of vertical ascending or descending motions in the upper layer.

Density or thermosteric anomaly

The vertical distribution of thermosteric anomaly (Fig. 5, a-m) reflects that of temperature. The vertical spreading, between 3°S and 3°N of the isanosteric surfaces locates the Cromwell current and confirms that it is wider and thicker at 170°E than at 140°W. If this current is geostrophic the vertical shear of the zonal current, both sides of the equator, is given by.

$$f \frac{\partial u}{\partial z} = - \rho g \frac{\partial \delta}{\partial y} \quad (1)$$

whereas at the equator it is given by

$$\frac{\partial u}{\partial z} = - \rho g \frac{\frac{\partial^2 \delta}{\partial y^2}}{\beta} \quad (2)$$

in which g is gravity, δ anomaly of specific volume, f Coriolis force and $\beta = df/dy$. Both equations indicate that the zonal component of the current is maximum at the level where an isanosteric surface is horizontal. This fact had been pointed out by Montgomery and Stroup (1962) at 150°W and is confirmed at 170°E where the depth of the horizontal isanostere, of the order of 200 m, is that of the velocity core of the Cromwell current. It must also be pointed out that the surface conditions do not affect the depth of the core of the Cromwell current as it appears from the density distribution, whatever the surface current is eastwards or westwards. At 150°W it was found that the core of the Cromwell current was at a depth of 125 m on the 300 cl/t isanosteric surface. Flowing west to east it gets thus lighter and closer to the surface.

The lower limit of the Cromwell current seems to be associated to a thermosteric anomaly of the order of 180-140 cl/t because at this level there is a reversal of the descending slope equatorwards of the isanosteres. In terms of geostrophy, an ascending slope equatorwards of these surfaces implies a westward current which is the equatorial intermediate current embedded in the eastward flow of the deep extensions of the Cromwell current; the depth of the limit between these two currents is 300-400 m.

The upper limit of the Cromwell current is not clear at all because the ascending slope equatorwards of the upper isanosteres of the pycnocline is due to the generally westward surface current. Further, in an homogeneous layer in which there are two opposite flows only one of them can be geostrophic. This is more or less the case of the surface current which is somewhat reflected by the density distribution. Consequently the upper core of the Cromwell current does not show on the density distribution. The latter indicate nervertheless an equatorial upwelling which is not necessarily symetrical to the equator, its latitude depends on the meridional component of the dominant wind (cf supra, temperature). This upwelling which brings to the surface water heavier than the adjacent one disappears when the wind reverses and blows from the north-west. This shows in december 1965 (Fig. 5 a) and in april 1967 (Fig. 5 g) when the surface current being eastwards the surface divergence is replaced by a convergence. The equatorial water is then warmer, less saline and lighter than north and south.

In the tropical region the upward slope polewards of the upper isanosteres of the pycnocline points out the location of the geostrophic south equatorial countercurrent near 10°S and of the southtropical countercurrent south of 15°S. But there are also, at the top of the pycnocline, troughs and ridges marking the limits of the geostrophic currents and indicating ascending or descending motions at the bottom of the homogeneous layer.

Oxygen nutrient salts and biological properties

The vertical oxygen distribution (Fig. 6 a-m) suggests also an equatorial upwelling (Fig. 6b,d.and j) and is typical in case of convergence (Fig. 6 a and g). Nevertheless, one of the most important features of the oxygen distribution is the homogeneous core, associated to the Cromwell current (Knauss 1960) wider and thicker at 170°E than at 140°W. The concentration at 170°E being also higher than at 140°W there is consumption of oxygen while the current is flowing eastwards either by remineralization of organic matter, either by diffusion into the less oxygenated water which frame it or by the two processes. Knauss attributed the oxygen homogeneity to a strong vertical mixing within the core of the Cromwell current. It has been shown later (Rotschi and Wauthy 1969) that it is due to the superposition of different water masses having very similar oxygen content. The upper water is a mixture of subtropical water of the south Pacific and of water of the north equatorial countercurrent. The lower water is from the Coral sea.

Below the Cromwell current, at depth greater than 300 m, the equatorial intermediate flow transports water with a relatively small concentration of oxygen reflecting the oxygen minimum formed along the coast of Peru (Reid 1965). Both sides of this oxygen minimum this current is embedded in various waters with different oxygen concentrations. First, there is oxygenated water which prolongs in depth the Cromwell current and made either from Coral sea water in the southern hemisphere (Tsuchiya 1968) either from north Pacific water in the northern hemisphere. Then it is low oxygen content water from the oxygen minima formed along the central american coast in the northern hemisphere and off Peru south of the equator.

In the southern part of the sections a highly oxygenated water at more than 4 ml/l appears. It results from the transport equatorwards of antarctic intermediate water formed at the surface near 60°S where it gains an oxygen content higher than 6 ml/l. The contact region between this antarctic water rich in oxygen and the poor intertropical water of Peru is located between 10°S and 20°S and its meridional extend varies much. The latitude of the 3 ml/l isopleth associated to a strong meridional gradient of oxygen and which can be considered as the limit of the southward extent of the peruvian water being relatively stable, it is the northward extent of the antarctic intermediate water which varies most.

The distribution of nutrients, nitrate (Fig. 7, a-m) and phosphate (Fig. 8, f-m) reflects that of the main hydrological and dynamical features described above. The enrichment of the equatorial surface layer is a permanent mechanism except when there is a surface convergence of the eastward wind-induced surface current during the north-west wind period (Fig. 7 a and g, Fig. 8 g). In subsurface, coinciding with the Cromwell current as defined by the spreading of the thermocline, of the pycnocline, and by the oxygen homogeneous core, there is a layer in which the vertical gradient of phosphate and nitrate is not negligible. This confirms that within the core of the Cromwell current there is no strong vertical mixing and that waters of different origins but with similar oxygen content and different phosphate and nitrate concentrations superpose. Below 300 m, there is a core of water richer than the adjacent one and poor in oxygen. It is embedded by two tongues of water relatively poor corresponding to water flowing eastward. Further poleward there are waters relatively richer of the oxygen minima off central America and Peru.

At intermediate depths of the intertropical zone of the southern hemisphere appears dearly a core of high concentration of phosphate and nitrate directly tied to the low oxygen water. Besides the antarctique intermediate water is much poorer in nutrients salts so that there is a strong meridional gradient between this water and the peruvian water.

The high time variations of the phytoplanktonic biomasses makes it extremely difficult to give a picture of their distribution. The observations have thus been grouped in order to give the average concentration of chlorophyll <u>a</u> in the layers 0-50 m, 0-100 m and 0-200 m (Fig. 9) and of daily primary production in gC/m^2/day in the layer 0-50 m and 0-100 m (Fig. 10). The chlorophyll <u>a</u> expressed as active chlorophyll plus phaeophytin shows a typical equatorial maximum in the layer 0-200 m. In the layer 0-100 m there is a secondary maximum between 12°S and 16°S. In the layer 0-50 m another secondary maximum appears between 5°S and 6°S. This distribution illustrate quite well the geostrophic zonal circulation implying a divergence at the northern limit of the south equatorial countercurrent and of the south tropical countercurrent and a convergence at their southern limit. The distribution of primary productivity shows only one region of high productivity, the equator.

The same problems of presentation of the results were raised by the biomasses of micronekton and macroplankton. Great time variations and changes in the sampling technique complicate the interpreation of the results. The results of all the hauls made during the cruises "Bora" have thus been cumulated at the level of the sorted groups (Fig. 11) : small plankton, bathypelagic copepods, thecosoma pteropods, chaetognats gelatinous organisms, mysids, amphipods, peneids,euphausids, carids, sergestids, cephalopods, fishes and fish larvae. Besides, a cumulated curve gives also the total biomass. Each of these curves gives thus a fictive distribution looking like an average distribution. The total biomass (A) shows an equatorial and an intertropical maximum; the latter corresponds to the tropical maximum of chlorophyll a in the layer 0-100 m. Other distributions give similar maxima : mysids (G), cephalopods (M), fishes (N), fish larvae (O). Some show an equatorial maximum more or less displaced : bathypelagic copepods (C), thecosoma pteropods (D) euphausids (F) carids (K) sergestids (L). Othershave a uniform distribution gelatinous organisms (F) peneids (I). Some have only an intertropical maximum well marked at about 5°S chaetognats (E) amphipods (G). These distributions confirms the gross feature of the zonal circulation and of the surface convergences and divergences that it implies. The relative displacements of the peak regions could be due to the patchiness distribution of some groups which have thus been badly sampled, but also to the duration of the biological cycles of the various components of the micronekton, to lateral transports and to vertical migration the amplitude of which varies from one species to the other.

CONCLUSION AND SUMMARY

Taking into account the currents both measured and computed and the hydrological and biological observations, it appears that the western equatorial and south tropical Pacific has a circulation which is more complicated than indicated by the accepted schemes, that this circulation strongly determines the hydrological "climate" of the region and has also a strong impact on the fertility of this region.

As far as the circulation is concerned, the new facts concern the two cells structure of the Cromwell current in the western Pacific, the very thick westward equatorial intermediate current giving some ambiguity to the name equatorial undercurrent used for the Cromwell current and requiring a reconsideration of the balance of flows of the currents in the equatorial region, the deep extensions of the Cromwell current and the permanence of the south equatorial and south tropical geostrophic currents.

The hydrological factors permit an easy identification of :

- the equatorial upwelling the axis of which seems to depend on the meridional component of the wind; it disappears when the surface current reverses,
- the Cromwell current broader and tkicker than in the central and eastern Pacific with a lower limit clearly visible at about 300 m,
- the westward intermediate current embedded in the deep north and south extensions of the Cromwell current and transporting water with specific oxygen, phosphate and nitrate contents,
- the south equatorial and south tropical countercurrents,
- the subtropical subsurface water mass of the south Pacific converging equatorwards, whereas the north Pacific intermediate water flows southwards,
- the northward extent of the antarctic intermediate water,
- the water of the oxygen minima formed off Peru and the central american coast.

They also show that some hydrological characteristics of the Cromwell current are gained further west, north of New Guinea, that the core of the Cromwell current is homogeneous in oxygen because it is formed by the superposition of different water masses with the same original content but different by their origin and their nutrient salts content.

Finally these data give strong evidences of enrichment mechanisms of surface waters by deeper waters from the upper part of the discontinuity layer at the equator where the upwelling is present during the tradewind season (april-november) and in tropical waters where upward and downward movements are permanent and located respectively at the southern and northern limit of eastward countercurrents. These vertical movements are part of a general cell like circulation in the homogeneous layer creating regions of greater productivity characterized by a greater biomass of micronektonic or macroplanktonic organisms.

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