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# UPLIFT RATE OF CORAL REEF TERRACES IN THE AREA OF KUPANG, WEST TIMOR: PRELIMINARY RESULTS

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## Abstract

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A Th/U date of 152,000 years obtained from the prominent fifth step, at 44 m elevation, of a flight of 7 well defined raised reef terraces at Cape Namosain, 5 km west of Kupang, allows inference of a preliminary mean uplift rate of 0.3 mm/yr since the last interglacial. Such a slow uplift rate is supported by the observation of numerous large modern reef platforms and of very limited mid-Holocene emergence — if any — throughout the region. Subject to confirmation through further dating, this suggests the existence of a more rapid uplift zone in central West Timor, by contrast with the area of Kupang to the west and of northern East Timor and Atauro Island to the east, possibly in relation with the NW–SE seismic tear zone which has been recently pointed out within the subducting plate north of West Timor.

One of the main interests in the terraces of Cape Namosain, apart from its neotectonic aspect, resides in the fact that there may be an opportunity to define the 180,000 year old paleo-sea level (terrace VIII of Huon Peninsula): based on the geomorphological interpretation of the series, it could correspond here to the fourth or the sixth terrace. Field investigation and dating in that regard are currently in progress.

Another Th/U date of 124,000 years, obtained on the lowest emerged terrace (7 m above low tide) in the southeast of the nearby island of Semau, indicates that this second area has been uplifting little during the last 125,000 years. This, together with the observation of tilts and other structural features, leads to the conclusion that the area to the southwest of Kupang is affected by differential uplifts and block-faulting.

## Introduction

The island of Timor is located on the non-volcanic, fore-arc type, outer ridge of the Eastern Sunda/Banda island arc, in Southeastern Indonesia (Fig.1).

To the west, the Indo-Australian oceanic lithosphere underthrusts the southwestern Indonesian islands (which form the south-facing Sunda Arc) along the Java Trench northwards, with a relative velocity in the order of 7–7.5 cm/yr (e.g. Moore et al., 1980).

To the east, the subduction of the Indo-Australian Plate beneath the Banda Sea is quite active all along the U-shaped eastern tip of the Banda Arc (e.g. Cardwell and Isacks, 1978): this unusual feature appears to be related to the interaction of the huge, northwestward moving Pacific Plate, whose westward component pushes ahead parts of New

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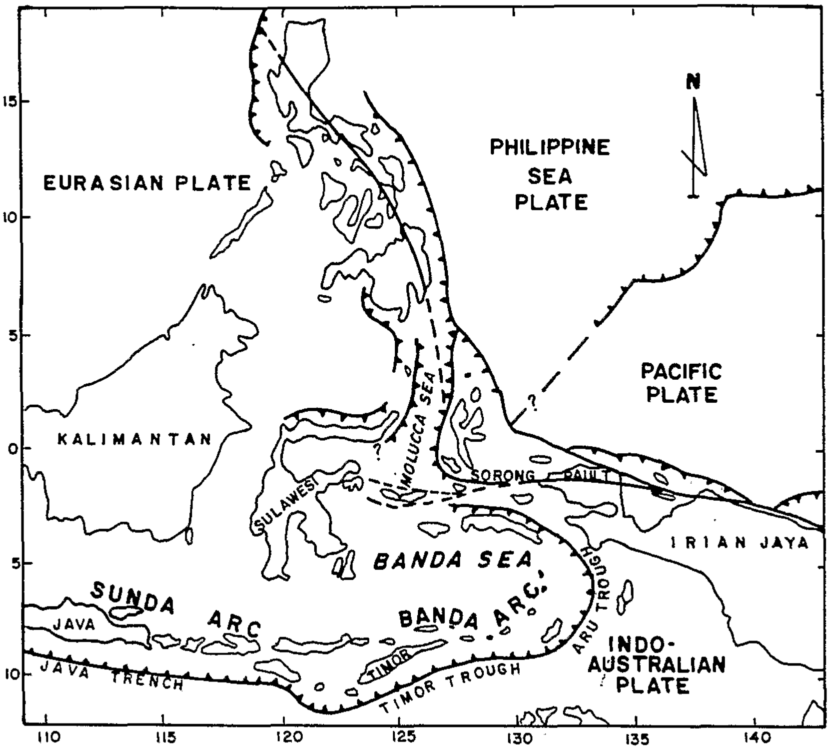


Fig.1. Modified from Silver and Moore (1981): Eastern Indonesia in the convergence zone of the three major Eurasian, Indo-Australian and Pacific Plates. In addition, interaction of the Philippine Sea Plate to the north.

Guinean continental crust along the major Sorong left lateral transform fault system and gives to the northern extremity of the Banda Arc its inversed north-facing direction (Fig.1).

Between the classical Java Trench/Sunda Arc subduction system to the west and the unusual U-shaped Aru Trough/Banda Arc subduction system to the east, lies the region of Timor, where typical subduction appears to have been perturbed at least since the mid-Pliocene period. This corresponds to the area where the northwesternmost part of the Australian continental crust first approached the Banda Sea and commenced to subduct, led by the dipping oceanic lithosphere of the Indo-Australian Plate. Interpretation of seismic reflection and refraction data (e.g. Hamilton, 1979; Jacobson et al., 1979; Bowin et al., 1980) and of gravity data (Chamalaun et al., 1976) shows that continental crust and even shallow water strata of the Australian continental shelf are overthrust by the accretionary wedge of the outer arc ridge, on which rests Timor.

But, owing to the weak capacity of continental crust to subduct (buoyancy effect), in particular beneath the denser oceanic crust of the Banda Sea, the further convergence of the Australian continental crust with the Banda Arc led the normal subduction process to alter, at least in part, as suggested by the pronounced quiescence of shallow and intermediate seismicity north of East Timor (e.g. McCaffrey et al., 1985), or the lack of volcanic activity since 3 M yrs in the corresponding part of the volcanic inner arc (e.g. Abbott and Chamalaun, 1981).

Horizontal shortening is still actively occurring (Karig et al., 1987) at the foot of the inner slope of the Timor Trough, which corresponds to the present plate boundary. Nevertheless, part of the convergence is being accommodated in the area by back-arc thrustings (e.g. Silver et al., 1983; McCaffrey and Nabelek, 1984), severe foldings within the fore-arc associated with thrusts (e.g. Barber et al., 1977) or with metamorphism (Berry and Grady, 1981), major vertical displacements (e.g. Chappell and Veeh, 1978; Hamilton, 1979), etc., which constitute various mechanisms of an on-going arc–continent collision process.

Major vertical movements, in particular, are well documented in the long term by the stratigraphic record (e.g. Barber, 1981). More recently, continuing uplifts are observed in numerous flights of Quaternary raised coral reef terraces on Timor or the neighbouring islands. In north East Timor and, to the north of it, in the nearby island of Atauro, Chappell and Veeh (1978) could show that the area has been uplifted at a mean rate of about 0.5 mm/yr at least for the last 125,000 years and probably for the last 700,000 years. In West Timor, uplifted reef terraces are also extensively developed, especially at the western tip (Fig.2) of the island (area of Kupang, including the nearby islands of Semau and Roti) and in the SW–NE trending Central Graben (Camplong, Soe, Kapan), where they rise up to near 1300 m in altitude (Tjokrosapoetro, 1979). However, to date, available data on raised coral reefs, especially radiometric age determinations, remain more scarce in the western part of Timor than in the eastern part: Tjia (1981) published 4 radiocarbon dates on the low terraces near Kupang, Tjokrosapoetro (1979), citing Kenyon and Berggren, reported a fossil assemblage age of N23 for an elevated unit in the Central Graben, and Prijantono and Tjokrosapoetro (1986), essentially based on geomorphological data, made an attempt to a global interpretation of the whole reefal series in the area.

Within the overall framework of a joint LIPI/ORSTOM/CNRS research programme on the uplifted reef terraces along the Eastern Sunda/Banda Arc, a detailed study of the

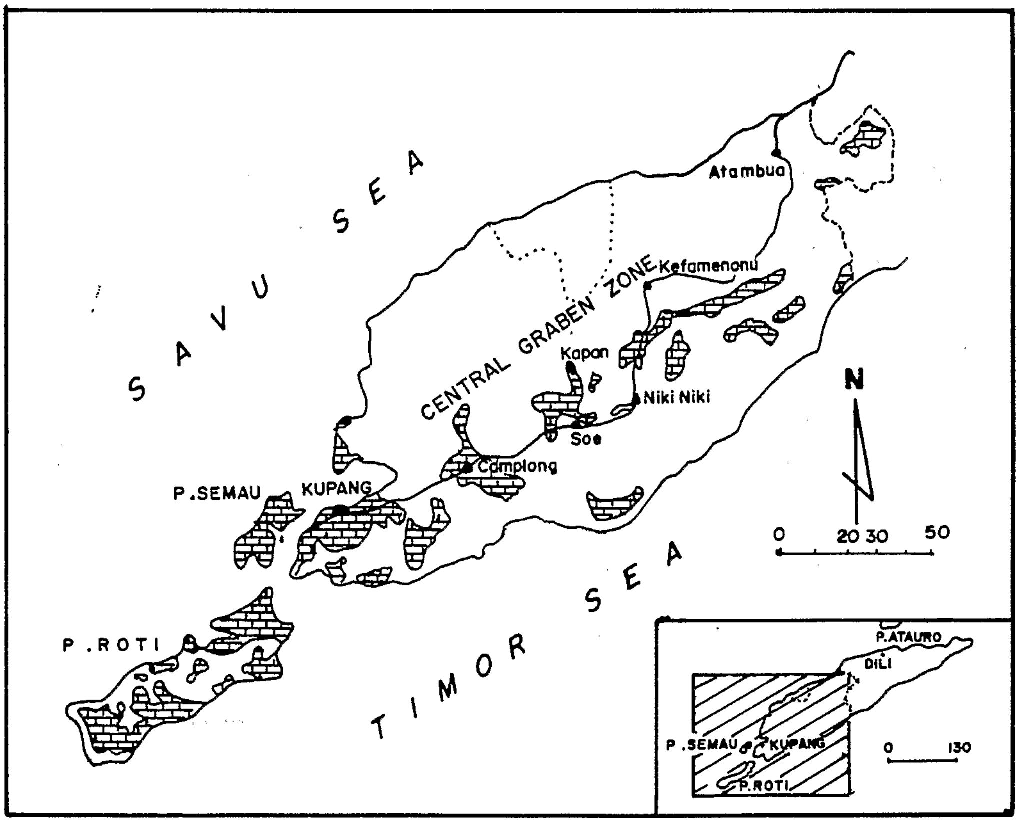


Fig.2. Slightly modified from Tjokrosapoetro (1979): location of the major flights of Quaternary reef terraces in West Timor.

emerged coral terraces in the area of Kupang and neighbouring islands is currently being carried out. Two Th/U dates constitute the first results of that study: they are reported first here and interpreted in relation to their geomorphological environment. Although two such isolated dates remain to be confirmed, they may provide a preliminary idea of the order of magnitude, obviously needed in the area (Karig et al., 1987), of the vertical movements which today affect the western region of West Timor; correspondingly, they suggest potential valuable information towards the general knowledge of the glacioeustatic oscillations of sea level during the Late Quaternary period, concerning particularly the penultimate glacial/interglacial period.

## First two $^{230}Th/^{234}U$ dates obtained in the area of Kupang

Coral heads abound within the emerged reef terraces of the area of Kupang. However, they are mostly recrystallised, even in the lowest terraces, and during a short preliminary visit in the field in September 1984, very few coral samples were collected. Of these samples, two only proved to be suitable for $^{230}Th/^{234}U$ dating, with minor relative abundance of calcite, from 2 to 3%.

The analytical procedures which have been used here are described in Montaggioni and Hoang (1988). Results are presented in Table I. The two analysed samples display uranium content within the range that is usually observed in fossil corals, i.e. from 2 to 4 p.p.m. In these samples, $^{232}Th$ is below the limit of detection of the instruments under experimental conditions of measurement: this indicates that, if there has been incorporation of $^{230}Th$ of external origin into the samples, it remains negligible. The $^{234}U/^{238}U$ ratios, when corrected for decay of $^{234}U$ and for their $^{230}Th$ ages, yield initial $(^{234}U/^{238}U)_0$ values of $1.14 \pm 0.03$ and $1.15 \pm 0.03$ respectively, which are consistent with the present-day sea water value of $1.15 \pm 0.03$.

Further fieldwork has been recently carried out, and additional samples were found, apparently unrecrystallised: if suitable, they will be dated in the near future.

## Geomorphological environment of the dated samples

### *The tract of 7 raised reef terraces at Cape Namosain*

Sample TM-TNU-5-1, dated at 152 ka $\pm 10$, corresponds to a coral head found in growth position in the upper part of the prominent fifth step, reaching +44 m, of a tract of seven geomorphologically fairly well-defined emerged reef terraces, which extend for about 4 km all around Cape Namosain, between the

TABLE I

Analytical data and ages of corals from the area of Kupang, West Timor

| Samples[a] | Elevations[b] (m ALT) | Calcite % | U (p.p.m) | $^{234}U/^{238}U$ | $^{230}Th/^{234}U$ | $(^{234}U/^{238}U)_0^c$ | Age[d] ($10^3$ yr) |
|---|---|---|---|---|---|---|---|
| TM-TNU-5-1 | 44 | 3 | $2.82 \pm 0.08$ | $1.09 \pm 0.02$ | $0.764 \pm 0.021$ | $1.14 \pm 0.03$ | $152 \pm 10$ |
| TM-OLM-1-A-1 | 7 | 2 | $2.46 \pm 0.07$ | $1.11 \pm 0.02$ | $0.692 \pm 0.021$ | $1.15 \pm 0.03$ | $124^{+8}_{-7}$ |

[a]Both samples are coral heads in growth position, most likely in situ.
[b]Elevations which are given here, in meters above low tide (ALT), are the ones of the front crest of the terraces in which the samples have been collected.
[c]Initial $^{234}U/^{238}U$ ratio corrected for $^{230}Th$ age.
[d]Calculated using Kaufman and Broecker (1965) equation and half-lives of $^{230}Th$ and $^{234}U$ of 75,200 and 248,000 yr respectively. The uncertainties quoted are deduced from $1\sigma$ counting errors.

localities of Namosain and Tenau Harbour (the cape itself is situated about 5 km west of Kupang) (Fig.3).

Terraces around Cape Namosain, in particular the seventh one, which corresponds to the plateau on top of the series, are sub-horizontal, yet affected by small NW–SE faults slightly downgrading the series to the south as far as Tenau Harbour. Beyond Tenau Harbour, the series becomes markedly tilted to the south, down to the very flat but lower plateau of Lelendo Peninsula (Fig.3).

The most representative transect of the series is observed about 1 km north of Tenau Harbour, on the west-facing edge of Cape Namosain: in that place, the series is complete and most terraces are defined by scarps on their front crest (Figs.4, 5).

Altitudes, which do not exceed 70 m here, were measured in the field by hand levelling. Because coral reef platforms develop upwards in relation to sea level at low tide, altitudes are here reported above low tide (ALT).

Along the reference section, from sea level

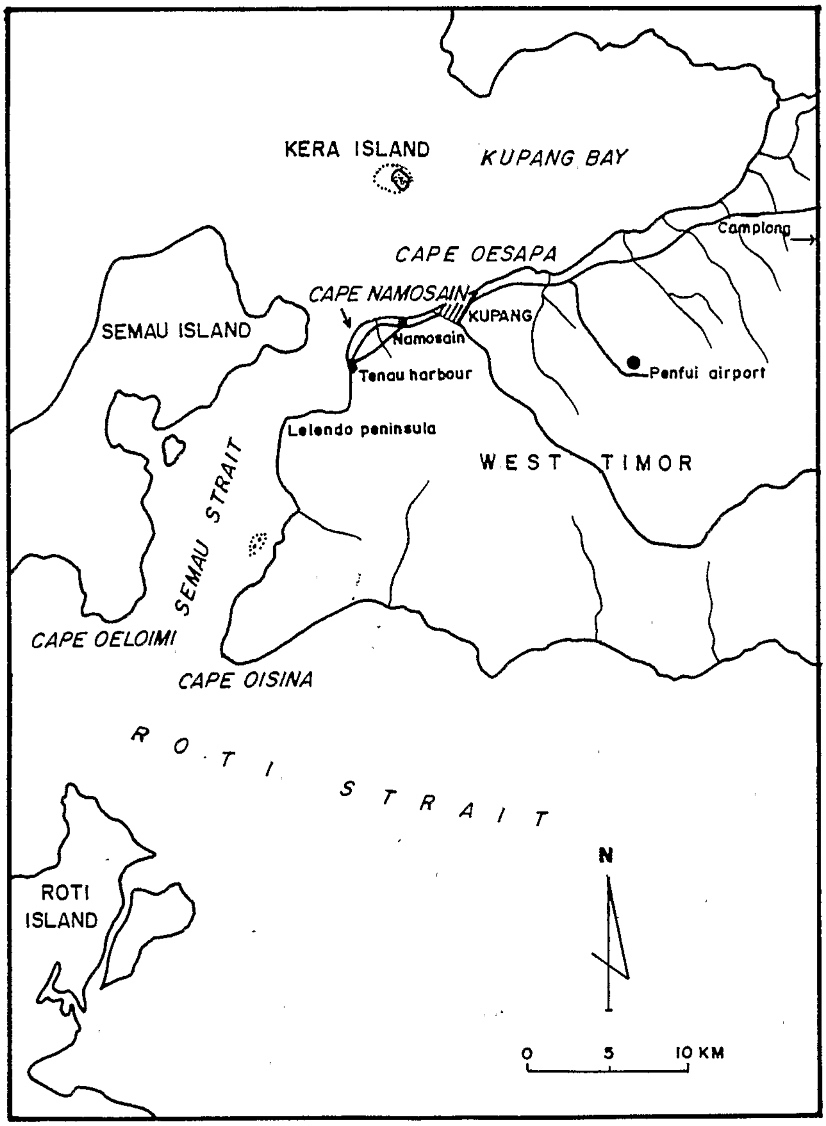


Fig.3. The area of Kupang.

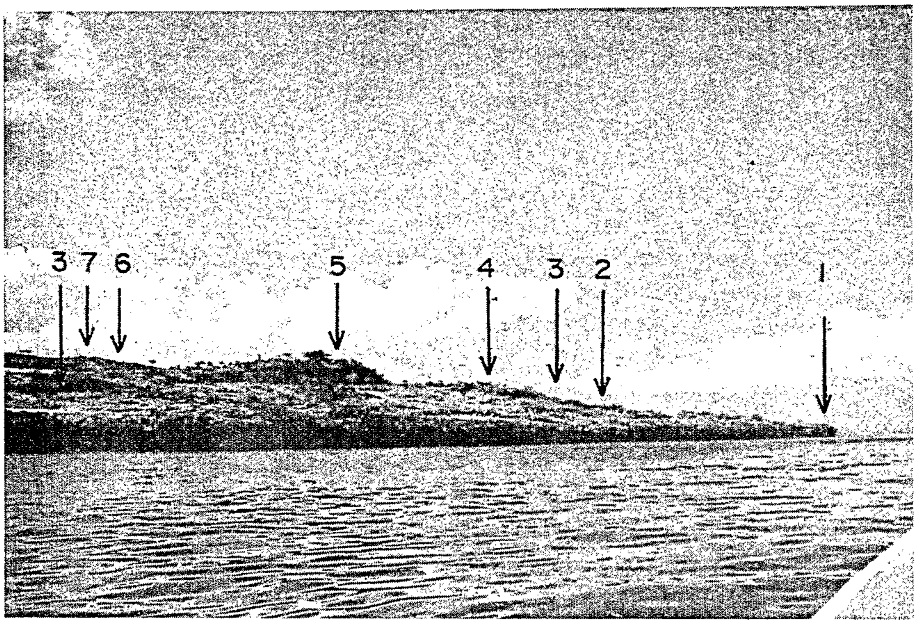


Fig.4. Profile of the terraces at Cape Namosain, observed from the north: terraces *1* (on the sea-side), *4* (at the foot of the main scarp), *5* (the main scarp and its top) and *7* (on top, to the left) are quite visible on this picture. Terrace *3* does not appear clearly on the profile, but shows a considerable extension towards the left of the picture (the scarp immediately below the roof belongs to it) and, further on, all along the north-facing edge of the cape.

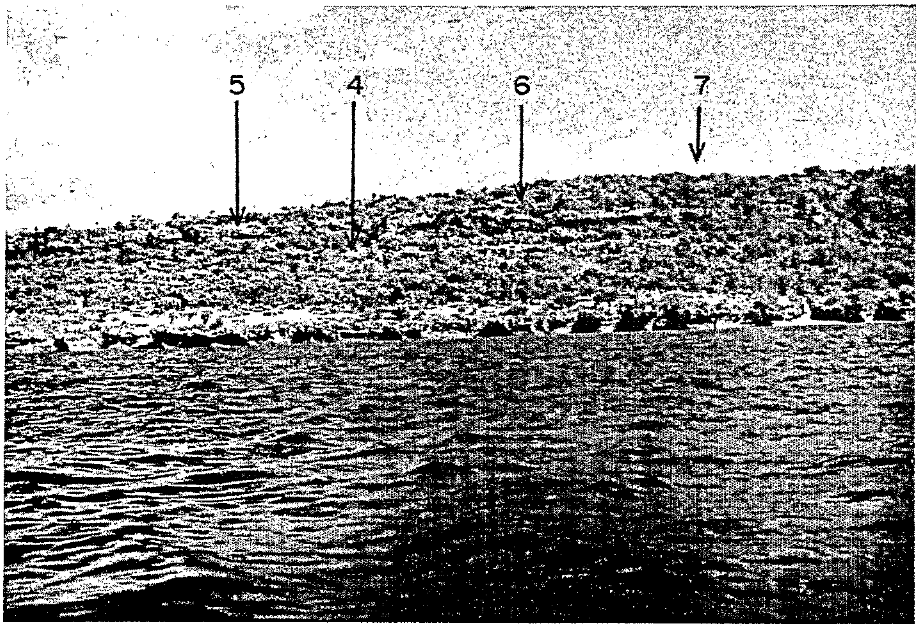


Fig.5. The tract of terraces of Cape Namosain at the reference transect location, 1 km south of the cape, i.e. along its west-facing edge. Terraces *1* (on the sea-side), *4* (intermediary), *5* (the continuous prominent one) and *7* (the rounded top, 64 m ALT) are clearly visible on the picture. Terrace *6* can be distinguished through the vegetation (where terrace *7* looks highest).

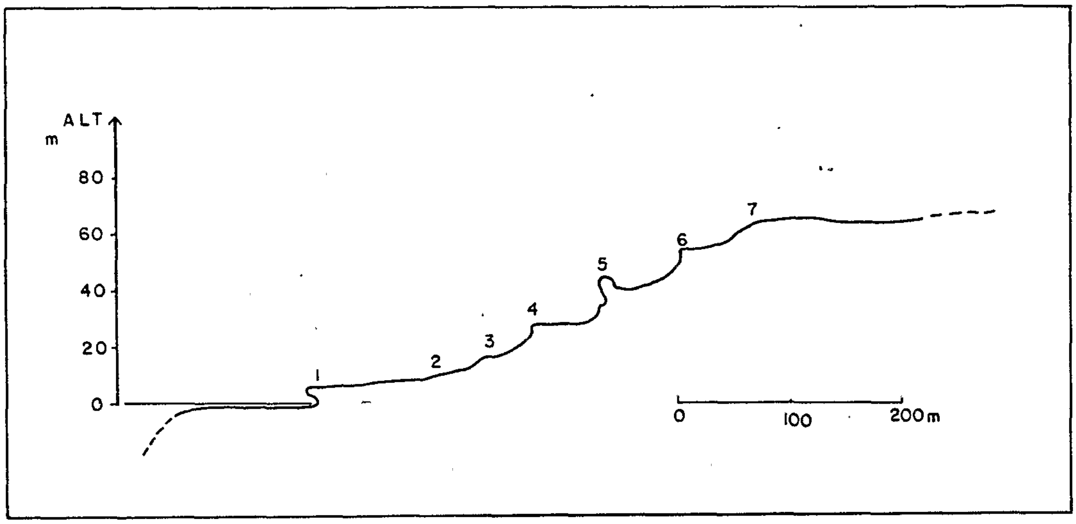


Fig.6. The reference profile, half way between Cape Namosain and Tenau Harbour. All heights surveyed by handlevelling and given in meters above low tide (*m ALT*).

to the top of the flight, one can observe (Fig.6):

— a well developed modern fringing reef, about 100–200 m broad, quite rich in living coral heads over all of its surface, due to the fact that the platform remains slightly submerged, by 1 or 2 m, at low tide;

— a first emerged terrace, terrace 1, about 100 m wide, whose front crest, 5–6 m ALT, is abruptly edged by a modern sea cliff, itself incised by a notch, 2–3 m deep. Towards the rear, terrace 1 is rising up to 9 m ALT. The matrix of terrace 1 is well cemented and rich in coral heads, which look relatively fresh but are mostly recrystallised.

It is on an equivalent low terrace (1 m AHT, i.e. 3 m ALT), located some 2 km east of Kupang, and correlated on geomorphological grounds with terrace 1 of Cape Namosain, that Tjia (1981) reported a $^{14}C$ date of 29,380 yr ±2140 (together with three other radiocarbon dates in the same area: one of 34,930 yr ±3640 for a terrace about 14 m ALT, and two other ones older than 40,000 years for two terraces respectively 36 and 49 m ALT).

— Terrace 2, 10 m ALT and 30–40 m wide, on this reference transect corresponds to a slope break rather than to a real terrace; in fact, terrace 2 is the most poorly defined of the series, narrowing or often disappearing laterally, but clearly visible in a few sections around the cape.

— Terrace 3, 18–19 m ALT at its front crest, is 50 m wide on this reference traverse, but broadens up to 200 m further east: terrace 3 constitutes one of the major terraces of the tract.

— Terrace 4, 28 m ALT, fairly flat, is 50–60 m wide over a long distance, widens eastwards up to 100 m and then disappears.

— Terrace 5, about 50 m wide on the transect, widens laterally up to 100 m; terrace 5 is the most distinctive terrace of the flight due to a prominent scarp up to 10–15 m high, itself incised by a deep notch (Fig.7). At the very Cape Namosain, where it reaches its maximum width, the terrace shows an internal lagoonal morphology. The front reef, which can then be compared to an external barrier reef, culminates at 44 m ALT, while the flat internal lagoon-like depression has an altitude of 40 m ALT (Fig.8).

— Terrace 6, 54 m ALT, is 60–70 m wide along the main transect, but gradually disappears eastwards.

— Terrace 7, which, unlike the other steps, does not exhibit any scarp on its front crest, but is still well-defined as a distinctive step in

Fig.7. The scarp of terrace 5 observed from lower, but perhaps older (see text) terrace 4, on which is constructed the road. The scarp, 10–15 m high, clearly exhibits a notch in the middle of the picture.

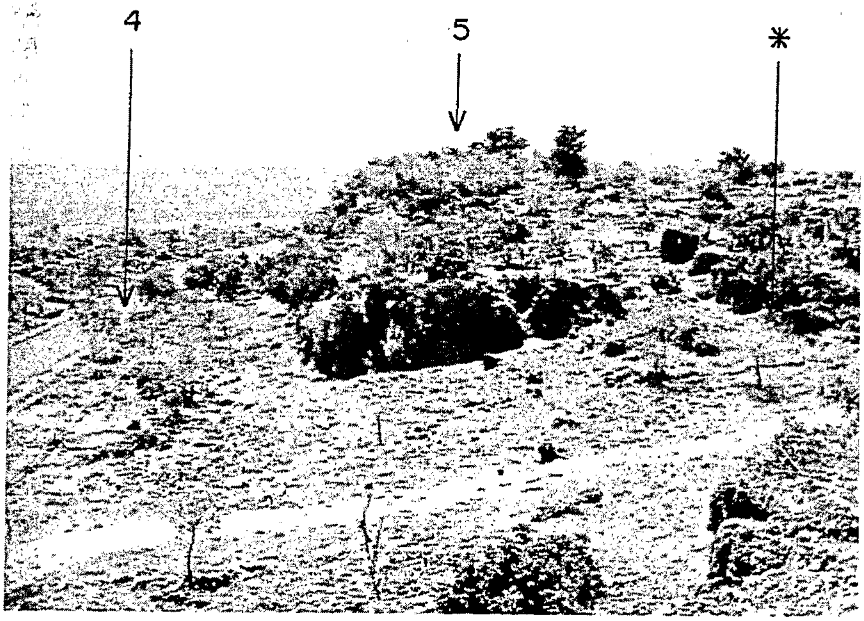


Fig.8. Another view of the barrier reef-like front scarp of terrace *5*, at Cape Namosain, overhanging terrace *4* to the left. A flat, internal lagoon-like depression starts on the right. The trail in the foreground may very well occupy an ancient pass across the barrier. Sample TM-TNU-5-1 (see Table I) was collected in a small cave within the half cliff to the right of the picture, beyond the trail (shown by an asterisk).

the landscape, culminates in 64 m ALT on the reference transect; terrace 7 is indeed a very important terrace as it corresponds to the main surface of the plateau which extends for several kilometers from Namosain to Tenau Harbour. Its surface, sub-horizontal as a whole, is affected in the detail by irregularities that essentially seem to be related to erosion by draining.

*Cape Oeloimi, in the southeast of the island of Semau*

The second $^{230}Th/^{234}U$ date, of 124 ka ±8 (TM-OLM-1-A-1, see Table I), was obtained on a coral head collected in growth position on top of the youngest of four terraces at Cape Oeloimi, in the southeastern tip of the nearby island of Semau (Fig.3). Unlike the sub-horizontal series of Cape Namosain, the four terraces here are markedly tilted to the west, so that they successively intersect the south-facing coast of the cape, getting respectively older towards the west: the youngest reef rims the east-facing shoreline of Cape Oeloimi, with a maximum altitude of 7 m ALT in the south-easternmost part of the peninsula. Below this lowest emerged terrace, a very luxuriant modern platform is growing sub-horizontally, remaining submerged at low tide, like at Cape Namosain, but a little deeper (3–4 m deep).

*Extensive modern reef platforms throughout the region*

Mention must be made of the observation of the large modern reef platforms which fringe most of the shorelines of the area of Kupang and of Semau Island, or develop quite extensively offshore as flat-topped patch-reefs, the best examples of the latter being located in the Semau Strait (south of Lelendo Peninsula) or around Kera Island (this tiny island, that lies in the middle of the entrance of Kupang Bay, represents in fact a sandy cay supported by such a quite broad patch-reef).

These platforms all appear to be controlled by present sea level at low tide, i.e. they are not emerged. The only trace of emersion which has been observed so far occurs on a few tens of square meters on the northern edge of the islet of Kera, where a few fossil coral heads *in situ* (in particular branching corals) are visible 0.5 m above low tide. In fact, in some cases, modern reef platforms remain slightly submerged at low tide, as in the front of Capes Namosain and Oeloimi (see above).

## Interpretation

*Vertical neotectonics in the area of Kupang*

Terrace 5 of Cape Namosain, owing to its outstanding geomorphological development, must have formed during a major Late Pleistocene high paleo-sea level. The age of 152 ka ±10 obtained on a coral head in growth position within the terrace, if referred to the fundamental series of Huon Peninsula (Bloom et al., 1974; Chappell, 1974), is compatible with the age of terrace VIIa of Huon, 140,000 years, given the error limits. Ages of 150–160 ka have already been reported from samples coming from reef complexes corresponding to the last interglacial, for instance on Atauro Island (Chappell and Veeh, 1978).

Terrace 5 of Cape Namosain is therefore interpreted here as having formed during the last interglacial period, 140–125,000 years ago: this is compatible with the major geomorphological development of the terrace. From the present altitude of terrace 5, 44 m, and the paleo-sea level of 5–6 m above present sea level that is generally accepted for the last interglacial period, a total uplift of about 39 m and a mean uplift rate of 0.3 mm/yr are inferred at Cape Namosain for the last 140,000 years.

The second date, of 124 ka ±8, clearly correlates the low terrace of Cape Oeloimi (SE of Semau Island) with the last interglacial period. As the reef is emerged at 7 m only at its front crest, this age indicates that the terrace has been little uplifted during the last 125,000 years. Additionally, the entire peninsula of Cape Oeloimi is markedly tilted to the west: the island of Semau, at least for its southeastern part, is therefore responding differently than the area of Kupang to the tectonic uplifting tendency of the region. The structures which are observed south of Tenau Harbour (tilts, the lower plateau of Lelendo, etc...) suggests that in fact large parts of the region lying south or SW of the area of Kupang and Cape Namosain are affected by differential uplift and block-faulting.

Along the southern shoreline of the bay of Kupang, the structural environment looks quieter, and the city of Kupang is surrounded on either side by extensive subhorizontal plateaux: although correlations remain to be established between these eastern and western plateaux, the uplift rate of 0.3 mm/yr obtained at Cape Namosain provides a preliminary order of magnitude for the area immediately south of the bay of Kupang, to be compared with the one of 0.5 mm/yr inferred in East Timor and Atauro Island by Chappell and Veeh (1978).

Between these two regions lies the Central Graben Zone: Tjokrosapoetro (1979) estimates the elevation of the reefal terraces in the Central Graben from 600 to 1300 m above sea level, and reports a fossil assemblage age of N23 (i.e. about 700,000 years) for one of the units of this Central Graben (however, the exact altitude of that unit is not mentioned). In agreement with Karig et al. (1987), a mean uplift rate ranging from 0.8 to 1.9 mm/yr is required for the last 700,000 years in the Central Graben area (depending on the altitude of the dated unit), which is in any case fairly higher than to the west, in the area of Kupang, or to the east, in the area of Dili and Atauro Island. Therefore, either the uplift rate in West Timor was significantly higher in the Middle Pleistocene times than since the last interglacial, or, more probably, as Prijantono and Tjokrosapoetro (1986) conclude themselves, the central part of West Timor has been more rapidly uplifted than to the east or to the west. This second solution could be related to the NW–SE highly seismic tear zone that McCaffrey et al. (1985) have pointed out, which appears to separate normal subduction to the west from collision to the east, and whose SE root in the subducting slab passes beneath the region of Soe and Kapan in central West Timor, where reefs are the most elevated: uplift would be most active in that sensitive area, while on both sides, East Timor and western West Timor, uplift, though existing, would be slower.

The presence throughout the region of large, non-emerged modern reef platforms strongly supports the low value of the uplift rate (0.3 mm/yr) inferred in the area of Kupang. In a continuously (i.e. very active) uplifting area, such large platforms could not exist, because newly formed reefs would emerge progressively. The area of Kupang, including Semau Island, therefore appears not to have been raised for a certain period of time, to allow the observed platforms to develop relatively widely in relation to present sea level: in other words, the uplift which characterises the area of Kupang is intermittent. Further, one may even consider the possibility of recent subsidence, either affecting the region as a whole, or more restricted areas. This would explain the slight immersion of the modern platform at low tide that is observed at Cape Namosain or Cape Oeloimi; the large platforms today in equilibrium with present sea level at low tide may also be interpreted as slightly subsiding platforms which keep up with sea level by upward growth.

This leads to the question of the existence or not of an emerged mid-Holocene reef level in the area of Kupang. At a rate of 0.3 mm/yr, tectonic uplift could have elevated a 5000 year old terrace to 1.5 m ALT, and possible additional isostatic movements to the observed 5–6 m front reef altitude of terrace 1 at Cape Namosain. But terrace 1 is likely to be older than Holocene, owing to the widespread cementation which affects the whole terrace, to the high degree of recrystallisation of most of its coral heads, to the deep notch (2–3 m) which marks the terrace on its seaward edge, and mainly to published (Tjia, 1981) and unpublished (A. Prijantono, pers. comm., 1986) $^{14}C$ ages. Tjia's radiocarbon date of 29,380 yr ±2140 on a terrace, 3 m ALT, 2 km east of

Kupang, even if it does not directly date the terrace (such a $^{14}C$ date should be crossed-checked by the Th/U method prior to being taken into account, see for instance Chappell et al., 1978), at least strongly suggests that the main low terrace in the area of Kupang is older than Holocene.

Holocene emergence may be restricted in the area to very limited rises such as the one (0.5 m ALT) which affects the modern reef platform on the northern edge of Kera Island. However, one can observe on the flanks of the main low terrace (or terrace 1 at Cape Namosain) remnants of a minor terrace that could be interpreted as evidence of mid-Holocene emergence (for example, between Kupang and Namosain, or near Cape Oesapa, 4–5 km east of Kupang) (Fig.3). Alternatively, this minor terrace, where coral heads are often recrystallised, may correspond to an erosional wave-cut sub-terrace of the main low terrace. In either case, Holocene emergence appears to remain quite restricted in space and vertical amplitude in the area of Kupang, which, again, supports the conclusion that tectonic uplift has not been very active in recent times here.

*The tract of reef terraces at Cape Namosain acts as a record of the Late Quaternary glacio-eustatic oscillations of sea level.*

Based on an age of 140–125 ka for terrace 5 at Cape Namosain and assuming that the subsequent uplift rate of 0.3 mm/yr has remained approximately constant during at least the last 140,000 years, maybe even the last 250,000 years, one can attempt to identify the other terraces of the series at Cape Namosain by comparing them with the ones at Huon Peninsula (Bloom et al., 1974; Chappell, 1974).

Table II shows the calculated altitudes of the terraces corresponding to the high paleo-sea levels of the Late Quaternary period together with the altitudes of the terraces as they are observed along the reference transect at Cape Namosain.

Downwards from terrace 5, Table II shows that terrace 3 can easily be correlated with the 103 ka old paleo-sea level: this is compatible with the continuous and important geomorphological expression of the terrace (in particular along the northfacing edge of Cape Namosain).

Below, terrace 2, 10 m ALT, correlates well

TABLE II

Comparison between measured and calculated terrace heights at Cape Namosain, using a mean uplift rate of 0.3 mm/yr and paleo-sea-level data established elsewhere (see text)

| High paleo-sea-level ages as in Bloom et al., (1974) and Chappell (1974) (yr) | Calculated uplifts (m) | Paleo sea-level positions related to present sea-level (m) | Terrace altitudes at Cape Namosain in m ALT | |
|---|---|---|---|---|
| | | | calculated | measured in field |
| 220,000 | 66 | 0 | 66 | 64(7) |
| 180,000 | 54 | 0(?) | 54 | 54(6) |
| 140–125,000 | 39 | +5 | 44 | 44(5) |
| 180,000 | 54 | −25(?) | 29 | 28(4) |
| 103,000 | 31 | −15 | 16 | 18(3) |
| | | | | 10(2) |
| 82,000 | 25 | −13 | 12 | 5–6(1) |
| 60,000 | 18 | −28 | −10 | ? |
| 40,000 | 12 | −38 | −26 | ? |
| 28,000 | 8 | −41 | −33 | ? |
| 5,000 | 1.5 | 0 | +1.5 | −1(?) |

with the 12 m ALT theoretically required by a 82 ka event, based on the position of the 82 ka sea level, some 13 m below present sea level, which has been inferred from the Barbados data (Broecker et al., 1968) and retained with consistency at Huon (Bloom et al., 1974) and elsewhere. However, terrace 2 at Cape Namosain is largely discontinuous and rather poorly developed for a terrace that would correspond to such an event as the 82 ka one. Moreover, it has been stressed earlier in this report that terrace 1 is most likely to be older than Holocene; but Table II shows that terrace 1 cannot be correlated with the 60 ka event either, because the corresponding terrace should still be submerged by some 10 m below present sea level. For these reasons, and also owing to its major, very continuous development along the shores of the area of Kupang, and to the fact that it gradually rises towards the back up to 9 m ALT, terrace 1 is interpreted as having formed during the 82 ka old event. Terrace 2 may be interpreted as representing a higher — but shorter — sub-event of the same high sea level period. Chappell and Veeh (1978) conclude that the 82 ka paleo-sea level in Atauro Island has a depth of 20 m relative to present sea level. If one uses a paleo-sea level of −20 m in Table II, one infers a theoretical altitude of +5 m for the 82 ka terrace (instead of +12 m), which correlates closely with the 5–6 m elevation of the front crest of terrace 1. Terrace 1 of Cape Namosain, being 82 ka old, supports Chappell and Veeh's datum.

Upwards in the series (Table II), if one assumes that contemporaneous positions of sea level were close to present conditions, terraces 6 and 7 of Cape Namosain can easily be correlated with the 180–190 ka and the 220–230 ka events respectively (terraces VIII and IX of Huon Peninsula, Chappell, 1974).

Terrace 7, corresponding to the 220–230 ka event, i.e. to the penultimate interglacial, constitutes a quite plausible solution, for, indeed, the extensive plateaux west (and east) of Kupang must have developed during a long and very favourable climatic period, such as an interglacial period.

Terrace 6, corresponding to the 180–190 ka event (terrace VIII of Huon), constitutes a more problematic solution in the sense that Chappell (1974) concludes in Huon Peninsula to a 180–190 ka paleo-sea level of 25 m below present sea level. Furthermore, Chappell and Veeh (1978) use a paleo-sea level of that order (−20 to −30 m) to confer, consistently with the rest of the series, an age of 180 ka on reef 2-lower of Atauro Island. If one applies a paleo-sea level of −25 m to the series of Cape Namosain, a theoretical 180 ka terrace should occur at about 29 m ALT, which correlates well with terrace 4 altitude. Both terraces 4 and 6 are geomorphologically well developed, and underlined by continuous scarps at their front crest along the west-facing edge of the cape. Both disappear along the north-facing edge of the cape, terrace 6, however, more rapidly than terrace 4. If terrace 4 is 180–190 ka old, one must admit that it has not been completely buried by the growth of younger (but upper and major) terrace 5. On the other hand, the eventual presence of a former (but lower) flat terrace 4 may explain the setting of the major, 10–15 m high, scarp of terrace 5 (from 140,000 to 125,000 years ago, a hypothetical 180 ka old terrace 4 would have been progressively uplifted — at a rate of 0.3 mm/yr — from 12 to 16 m above its −25 m original level, and thus would have been situated from some 18–14 m below the last interglacial sea level, itself at +5 m). Coral samples recently collected within both terraces (4 and 6), if suitable for dating, should allow resolution of the question.

## Conclusion

The principal conclusions obtained in this paper are (1) a mean uplift rate of 0.3 mm/yr for the last 250,000 years in the area of Kupang, together with little uplift — if any — in the recent times, (2) the existence of a more rapidly uplifted area in central West Timor, possibly related to the NW–SE seismic tear zone of McCaffrey et al. (1985) in the subducting slab beneath the region, (3) the development of the extensive reefal plateaux west of Kupang — and perhaps to the east — during the penultimate interglacial period, 220,000–230,000 years ago, and (4) differential uplifts and block-faulting to the southwest of Kupang.

Although these conclusions are in good agreement with the main geomorphological features of the region, they rest, at least for the first three, essentially on one Th/U date of 152 ka ± 10 within the fifth step of a tract of 7 raised coral reef terraces, 5 km west of Kupang. Furthermore, the slow uplift rate which is inferred to have affected the series at Cape Namosain (0.3 mm/yr) yields emerged terraces that are not well resolved, so that small variations in the observed elevations of the terraces may easily lead to misinterpretations.

For these reasons, the present conclusions remain fragile and thus provisional. Further dating is obviously needed, aimed in particular at confirming that terrace 5 corresponds to the last interglacial period, determining which of terraces 4 or 6 — if any — is 180,000 years old, and establishing the true age of terrace 1.

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