Supplementary files for the article "The influence of rock uplift rate on the formation and preservation of individual marine terraces during multiple sea level stands"

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1 Code to generate the occupation plot

The Python code used to plot Fig. 2 and 3 and is available in the Zenodo repository doi:10.5281/zenodo.5233650 (`https://zenodo.org/record/5233650`)

Note that the binder links in the read me file allow to run the jupyter notebook, or only the interactive figure directly in a browser.

Summary of the code

The code can be summarized as following.

```
Import eustatic curves
Compute eustatic curve at different rock uplift rates
Calculate kernel distribution of sea level occupation time along elevation
Store kernel distribution in a matrix for each uplift rate
Represent the distribution as a heat map in elevation vs.  rock uplift space
```

2 Sea level occupation since 600 ka

Figure 1 takes the last 600 kyr into account instead of the 300 kyr presented in the main manuscript. The longer record yields additional loci of repeated occupation and spans a greater vertical

3 Plots with alternative sea level curves

Figure 2 shows alternative versions of the illustration of total sea level occupation time as a function of rock uplift rate (Figure 3 in the main manuscript) with the sea level curves of Lea et al. (2002), Lisiecki and Raymo (2005), Spratt and Lisiecki (2016), and Westerhold et al. (2020). Additional plots can be generated using the Python code available in Section 1.

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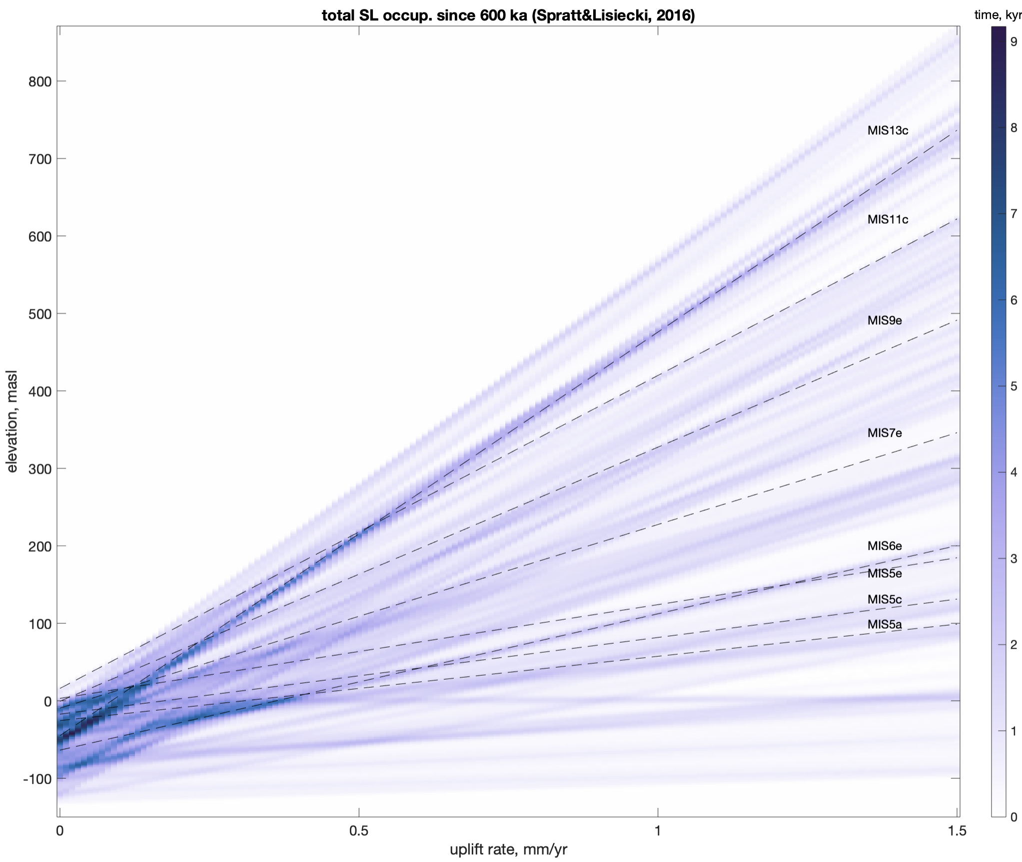

Figure 1: Total occupation time of sea level from 600 ka over a range of rock uplift rate of 0 to 1.5 mm/yr using the sea level curves of Spratt and Lisiecki (2016).

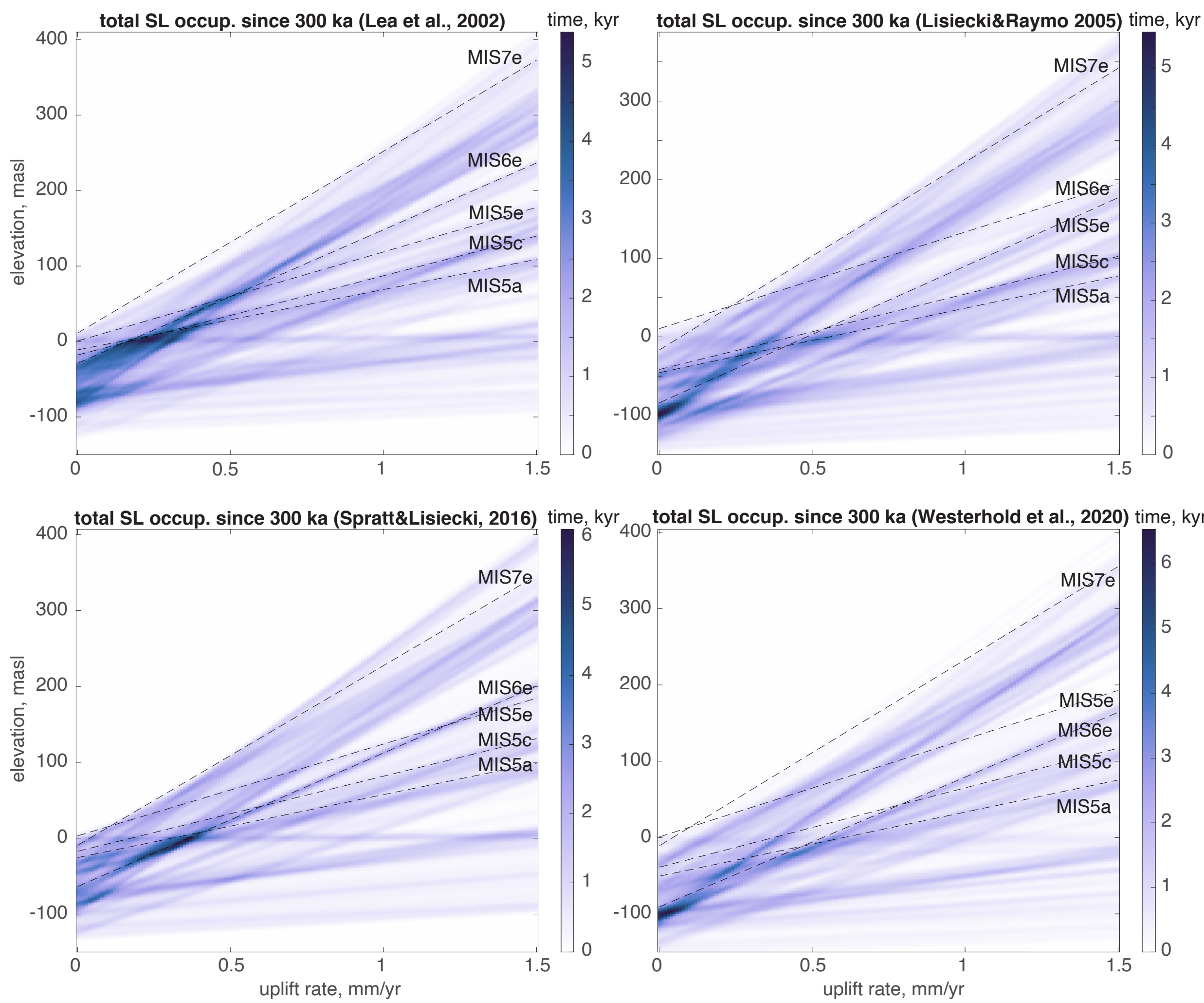

Figure 2: Alternative display of total occupation time over a range of uplift (Figure 3 in manuscript) using the sea level curves of Lea et al. (2002), Lisiecki and Raymo (2005), Spratt and Lisiecki (2016), and Westerhold et al. (2020).

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土佐湾北東岸の海岸段丘と地殻変動

Mode of crustal movement in the late Quaternary on the southeast coast of Shikoku. Southwestern Japan

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1964 年度日本地理学会春季大会において発表した内容を補足訂正したものである._研究費の一部は 1962, 63 年度文部省科学研究費による. Geographical Review of Japan, 1964, Volume 37, Issue 12, p. 627-648

[translation using Google Translate by Luca C. Malatesta, Shigeru Sueoka, and Sumiko Tsukamoto]

摘要

土佐湾北東岸に発達する海岸段丘は,上 位より羽根岬面,室 戸岬面,およびﾞ 沖積低地に分けられ,いずﾞ れも南東より北西に低 くなる.室 戸岬面の高さは南海地震の際の隆起量 と正の相 関を不し,地 震 前の沈降 量 とは負 の相 関を示す.約 120 年を周期としておこった大地震 の際の室戸 岬付近の隆起 は,その間の沈降 よ りも大きく,段 丘面の高度分布はこのような隆起沈降を差引した結果てﾞ ある南東より北西への傾動隆起によって決定されたと考えられる.こ のような隆起地域てﾞ あるにもかかわらずﾞ ,各 段丘面の形成過程に沈水期かﾞ 挟まれているのは,氷 期後の海面上昇速度かﾞ 地盤の隆起速度を上回つたからに他ならない.

室戸岬面は,その地形発達の過程より判断して,約 9 万年前にはじまる Riss-Wurm 間氷期に形成されたと考えられる.室 戸岬付近の大地震 1 周 期の問における地盤隆起の平均速度は約 2mm/年 と算定され,もし Riss-Wurm 間 氷期以後かかる性質の地殻変動が一様に継続したとすれば,室戸岬面は室戸岬付近において約 180m の高さにあるはずであるが,これは事実と一致する.また水準測量の結果によると,安田の 水準点を基準とした吉良川の水準点の高度は,大地震 1 周 期の間に平均 1.2mm/年 の割合で増大している が,もし Riss-Wurm 間氷期以後このような地殻変動がつづいてきたのであれば,室戸岬面は吉良川において安田よりも約 110m 高いはずであるが,これも事実とほぼ一致する.したがって, Riss-Wurm 間氷期以後,室戸岬付近は現在と同じく平均 2mm/年の速さで北西へ傾動しつつ隆起してきたと考えられる.

Abstract

The marine terraces that develop on the northeastern coast of Tosa Bay — Shikoku, Japan — are divided into Cape Hane (Hanemisaki) terrace, the Cape Muroto (Murotomisaki) terrace, and the alluvial lowland. All of them are lower in the northwest than the southeast. The height of Cape Muroto terrace has a positive relationship with the amount of uplift during the Nankai earthquake, and shows a negative relationship with the amount of subsidence before the earthquake. Near Cape Muroto, the uplift of a large earthquake with a period of about 120 years is greater than the subsidence during that period, and the altitude distribution of the terrace surface is considered to be set by the southeast to northwest tilting resulting from a combination of uplift and subsidence. Although this area is uplifted, the formation process of each terrace involves a period of submergence. It is because the rate of sea level rise after the glacial period has exceeded the rate of ground uplift.

Considering landscape building processes, the surface of Cape Muroto is thought to have been formed during the Riss-Wurm interglacial period, which began about 90,000 years ago. The average uplift rate during a mega-earthquake cycle is calculated to be about 2 mm/year, and if the crustal deformation that occurred after the Riss-Wurm interglacial period has continued uniformly, the Cape Muroto surface should be about 180-m-high near the Cape Muroto, which is consistent with the observations. Also, according to the results of leveling, the altitude of the Kira River level point has increased at an average rate of 1.2 mm/year during a mega-earthquake cycle, relative to the Yasuda level point. If that deformation was ongoing since the Riss-Wurm glacial period, the surface of Cape Muroto at the Kira River should be about 110m higher than Yasuda, which is consistent with observations. Therefore, after the Riss-Wurm interglacial period, the area around Cape Muroto has risen while tilting northwest at an average speed of 2 mm/year, as it does now.

このような地殻変動と第四紀における海面変化とを複合した結果は,この海岸の地形発達の過程とよく一致す るので,この地域 の海岸段丘の分化を生じたのは,地 殻変動の緩急ではなく,海 面変化の結果であり,その間地殻変動はほぼ一様に推 移したと考えられる.

The combined result of such crustal movements and sea level changes in the Quaternary is in good agreement with the landscape building processes on this coast. The differentiation of the marine terraces in this region is derived not from fluctuation of the deformation rate, but the result of sea level change. It is considered that the crustal deformation continued almost uniformly during that period.

まえがき

この研究の目的を分けて述べると,次の 2 つ になる.

(1) わが国の地形の特色の 1 つは,地殻変動が激しいことを反映している点にある,といわれている.第三紀以 降の地質時代ならびに現在における日本島の地殻変動の形式や速さは,層 位学的方法,地形学的方法,測地学的方法などによって,かなり明らかになっていて,日本島は世界的にみて地殻変動がはげしいところである.しかし,地形学的方法が地殻 変動の研究に適用できる時代,すなわち,ほぼ 10^3 ~10^6 年 の地殻変動の量についての研究は,十 分に多いとはいえない.

とに,地 殻変動の速さが時とともにどのように変ってきたのかは,ほとんど知られていないといってよい.地形学的方法が適用できる時代の地殻変動の速さを明ちかにすることは,測地学的方法で明らかにされている現在の地殻変動が,過去の地質時代も同じように進行していたかどうかを検証するという意義をもっている。

ここに報告する四国南東部の,高知平野から室戸岬に至る海岸(第 1 図)は,幾 段かの海岸段丘が発達し,地 形学的方法 による地殻変動 の研究には都合がよい.このことは,いままでに,この海岸段丘に関する三野与吉 [1],渡 辺光 [2],今 村学郎 [3],土隆一 [4]ら多くの研究によって明らかである.また,この地 域には測地学的資料も少なくない.

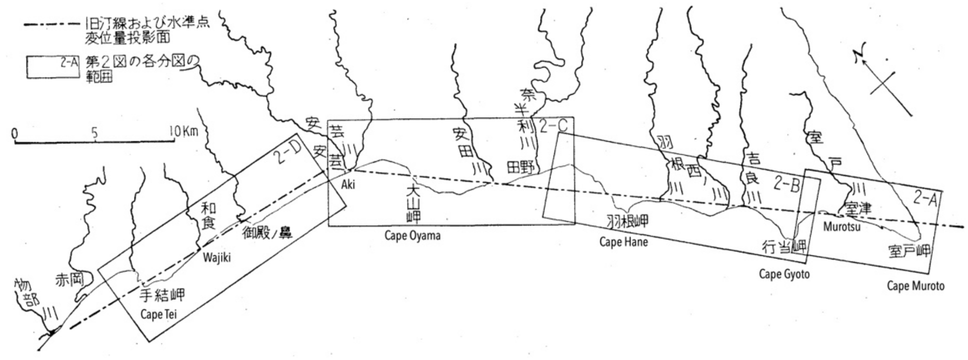
Introduction

The purpose of this research can be divided into the following two parts.

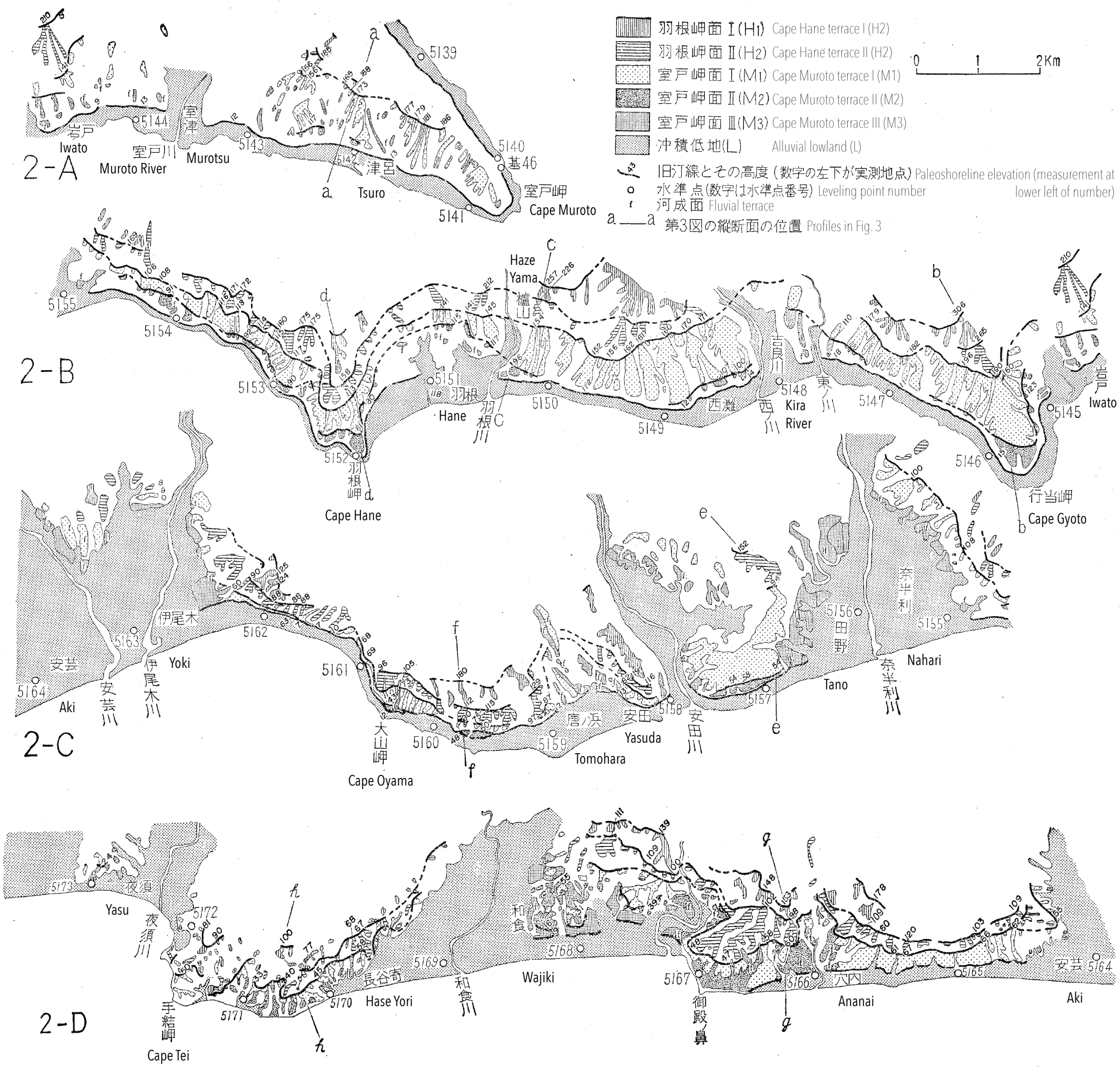
(1) It is said that one of the characteristics of Japan's topography is that it reflects severe crustal motion. In the geological ages of the Tertiary and later eras, it is now present. The pattern and rate of crustal movements on the island of Japan have been investigated by various geological methods, and earthquakes on the Japan Islands are observed worldwide. However, there are not enough studies constraining crustal deformation between 1Ma and 1ka when most geological methods cannot be applied.

In addition, changes in crustal deformation rates over time are poorly constrained. The rate of crustal deformation can be defined in the era when geological methods can be applied. It is important to verify whether the current crustal deformation has evolved in the same way in the past geological ages.

On the coast from the Kochi Plain to Cape Muroto (Murotomisaki, Fig. 1) in the southeastern part of Shikoku reported here, several marine terraces have been visited for the survey of crustal movements by geological methods. Conveniently, this has been clarified by many studies such as Yokichi Mino[1], Mitsuru Watanabe[2], Shiro Imamura[3], Ryuichi Do[4] regarding these marine terraces. In addition, there are many geological data in this area.



第 1 図研究地域索引図　　　　Fig. 1: Map of the research area



第 2 図海岸段丘分布図　　　　Fig. 2: Map of the marine terraces

すなわち,南 海 道沖に震源をもつ大地震のたびごとに,室戸岬が隆起し,高知付近が沈降すること,ならびに地震と地震の間には地震時とは逆むきの地殻変動が進行することが,今村明恒の研究[5]によって明らかにされていたし,1947 年の南海地震に関連して多くの測地学的研究がなされている.

したがつて,この地域は,現在の地殻変動と第四紀の地殻変動を比較するのに好都合である.この比較も,すでに渡 辺光[2)b]や今村学郎[6]によって試みられているが,本研究では,旧汀線の測定を従来おこなわれたよりも一層くわしくおこなうとともに,次の問題との関連において,海 岸段丘の時代を考え,旧汀線の示す地殻変動と現在の地殻変動との比較を試みた.

(2) これまでになされた世界の各地での多数の研究によると,氷河の消長に原因があると考えられる海面変化は,海 岸地形の形成に重要な役割を演じてきたとみられる.

それでは,この土佐湾北東岸の海岸段丘のように,旧汀線の傾きが大きく,またその上昇側にあたる室戸岬のように隆起の速さが大きいと考えられるところでは,海面変化の影響があるとすれば,どのような形であらわれるであろうか.そのあらわれ方は,いくつかの仮定のもとに論理的に考えられるが,それと現実の地形とは一致するであろうか.この問題の検討は,この地域を例にひいて渡辺光によつて論ぜられている段丘地形から地殻変動の形式を知る方法[2)ab7)]の検証にも,つながるであろう.

この報告は,このような 2 つの目的のもとにおこったものである[8].

Footnote 8: 野外調査は,1962 年 10 月と 1963 年 12 月の 2 回にわたり,延 約 40 日をかけて行つた.調査にあたっては,まず重点地域を共同で調査し,調査方法を統一したのち,地域を分担して調査した.その間たえず調査結果について討論を行ない,対比その他について見解の違いを生じた場合には,現地において十分討論を行なって,結論を出した.

Cape Muroto rises and the area around Kochi subsides with each major earthquake on the Nankai subduction megathrust. The meaning and implications of interseismic crustal motion opposed to coseismic displacement have been clarified by Akitsune Imamura's research[5]. Much geological research has been done in connection with the 1947 Nankai Earthquake.

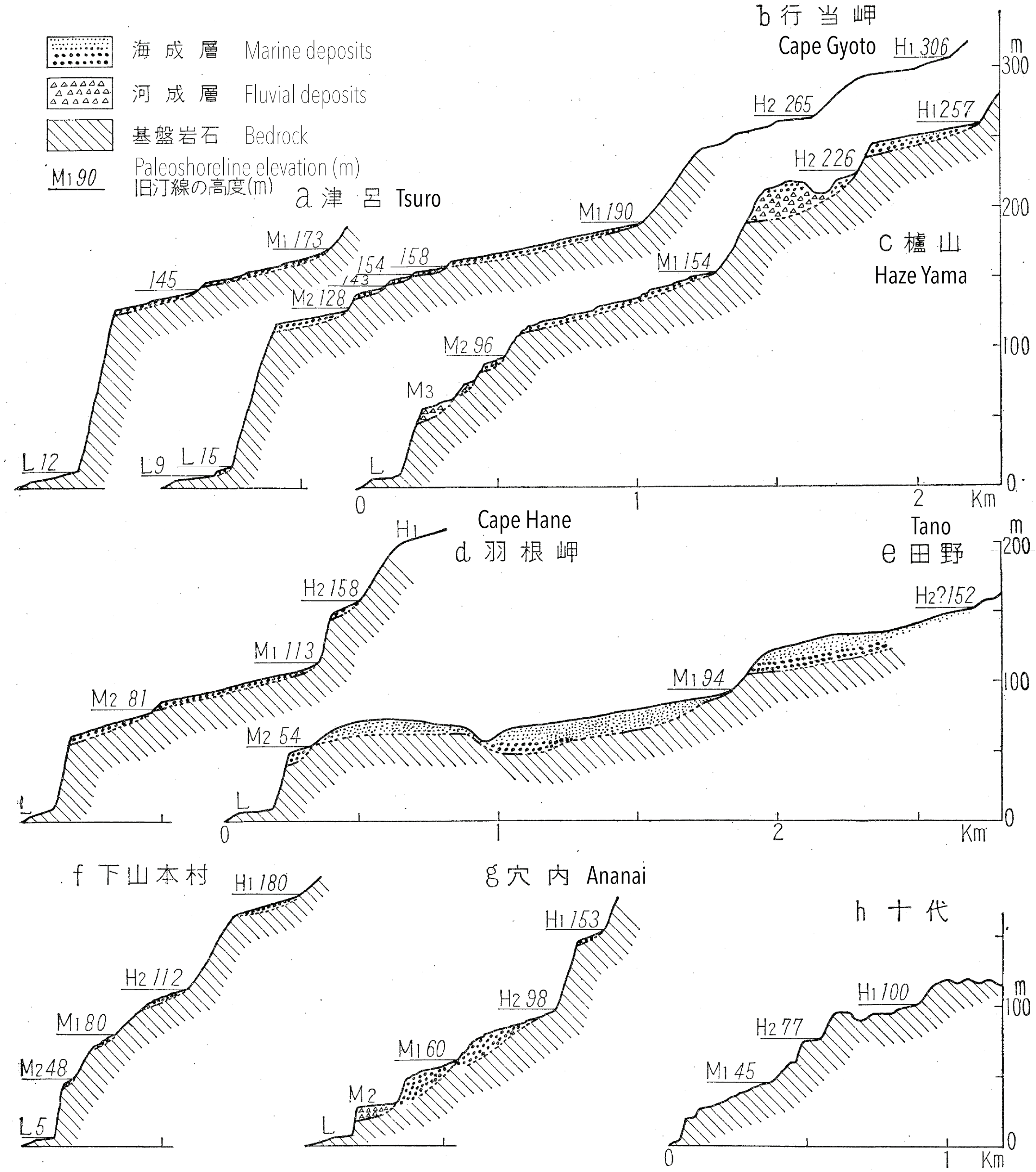
Therefore, this area is convenient for comparing the current crustal strain with Quaternary deformation. This comparison was already done by Mitsuru Watanabe[2)b] and Gaku Imamura[6], but in this study, we survey the old shoreline in more detail than the conventional one, and consider the age of the marine terrace in relation to the following problems. We attempted to compare the crustal movements recorded by the old shoreline with current crustal motion.

(2) Numerous studies around the world conducted so far suggest that sea level changes, which may be due to glacial cycles, have played an important role in the formation of coastal topography.

Then, it is thought that the slope of the old shoreline is steep like the coastal terrace on the northeastern coast of Tosa Bay, and the rate of uplift is fast like at Cape Muroto, which is on the uplifted side of the old shoreline. If there is any influence by sea level changes, what effect will it have? The way it appears can be logically considered under some assumptions, but will it be consistent with the actual topography? The examination of this issue is also linked to the verification of the method[2)ab7)] to derive the patterns of crustal deformation from terrace topography discussed by Watanabe Hikaru, taking this area as an example.

This report was made for these two purposes[8].

Footnote 8: The field survey was conducted twice, in October 1962 and December 1963, over a total of about 40 days. First, important areas were surveyed together to ensure a unified methodology. After that, individual areas were surveyed by individual member. During that time, the results of the survey were discussed, and if there were any differences in views regarding comparisons and other matters, sufficient discussions were held at the site and conclusions were reached.



第 3 図海岸段丘縦断面図(縦断面の位置は第 2 図に示す)

Fig. 3: Profiles of the marine terraces (see Fig. 2 for location)

海岸段丘の記載

II–1 調査の方法 上にのべた目的にそうように,この調査でていねいにおこなったのは,段 丘の旧汀線高度の測定と段丘の対比であるが,これとともに,段丘の縦断面形ならびに段丘堆積物の層相や厚さについても調査した.

調査には約 1/15,000 と約 1/25,000 の空中写真を用いた.段丘分布図は,これにもとづき,1/25,000 のスケールで作成した.第 2 図はそれをやや簡略化したものである.

旧汀線をはじめ,高度の測定には,American Paulin System のバロメーターTERRA MT2 型を用いて,1m 単位で測定した(目盛は 2m).気 圧変化に対する補正は,2~4 時間おきに水準点・三角点・海浜など高度既知の地点でのバロメーターの読みにもとづいておこなった.温度の補正はおこなっていない.3 台のバロメーターを用いいたが,同一地点の測定における器差は最大 4m であった.測定値の誤差はほとんどが±5m の内に入るであろう.

旧汀線の測定位置としては,旧海蝕崖下で,海浜堆積物がある場合にはその上限付近の,傾斜が急から緩に変るところを選んだ.下記の室戸岬面の旧汀 線についていうと,測 点地点は,と ころによっては,2~3m の高度の幅の中で誰にも明瞭であったが,まれにはその位置のえらび方によっては 10m 以内の個人差を生ずることはやむをえないと思われるところもあった.室戸岬面より高位の段丘ほど,旧汀線の位置の選定はむずかしかった.沖積低地の旧汀線については,その高度が低いので,測定の精度を上げる必要があるが,今回は上記の方法である程度測定をおこなった.

II–2 段丘面の分類 調査地域には,高度や開析の程度を異にする数段の段丘面があるが,行当岬から羽根岬に至る地域ではことに段丘の発達がよいので,この地域の段丘を基準として段丘面の分類を おこなった.

Description of the marine terraces

II–1 Survey method. For the purposes mentioned above, the height of the paleoshoreline was carefully surveyed and compared across terraces. We also investigated the vertical cross-sectional shape of terraces and the facies and thickness of terrace deposits.

The survey used aerial photographs of about 1/15,000 and about 1/25,000. The resulting terrace distribution map was created on a scale of 1/25,000. Figure 2 is a slightly simplified version of it.

Altitudes, including the old shoreline, were measured in 1m increments using the American Paulin System barometer TERRA MT2 (resolution is 2 m). Correction for changes in air pressure is a benchmark every 2 to 4 hours. It was performed based on the reading of the barometer at a point with known altitude such as a triangulation point or a beach. The reading was not corrected for temperature. Three barometers were used, but the maximum difference in the measurement of the same point was only 4 m. Most of the measured values should be within ± 5 m.

To measure the old shoreline, we chose a place under the old sea cliff, near the upper limit of the beach sediment, where the slope changes from steep to gentle. Regarding the old shoreline of the Cape Muroto surface, the elevation of the shoreline was obvious to everyone and within a range of altitudes of 2 to 3 m, depending on the location, but in rare cases, it was within 10 m depending on how the position was selected. The higher the hills above Cape Muroto, the more difficult it was to select the location of the old shoreline. For the old shoreline in the offshore lowlands, it is necessary to improve the accuracy of the measurement, since the altitude is low.

II–2 Classification of terraces. There are several terraces in the survey area with different degrees of elevation and erosion, but in the area from Cape Gyoto (Gyotomisaki) to Cape Hane (Hanemisaki), terraces are particularly well developed. Given that quality, the terraces were classified based on this area.

第 3 図 b は行当岬付近の地形の縦断面である.これによると,10 以上の段があるが,比高 3~5m 前後の低い崖は連続性も悪いので,段丘面の分類.対比の際には一まとめにして扱う.そうすると,主な段丘面としては,高位から順に旧汀線高度がそれぞれ 306, 265, 190, 128, 15m の 5 段の面が識別される.この中で,高い 2 つの段丘面は,開析が進んでまるみをおびており,段丘崖も傾斜が緩い.その下の 2 つの段丘面は,平坦面の保存がよい.開析谷はかなりあるが,段丘面と谷壁との境は明瞭で,段丘崖の勾配も急である.最下位の面は,その上の面と比高の著しく大きい崖で区別され,幅は狭いが,海岸に沿ってよく連続する.この段丘には,過去の岩礁・砂丘・砂州などの微地形がよく保存されている点で,より上位の段丘面と性格を異にしている.

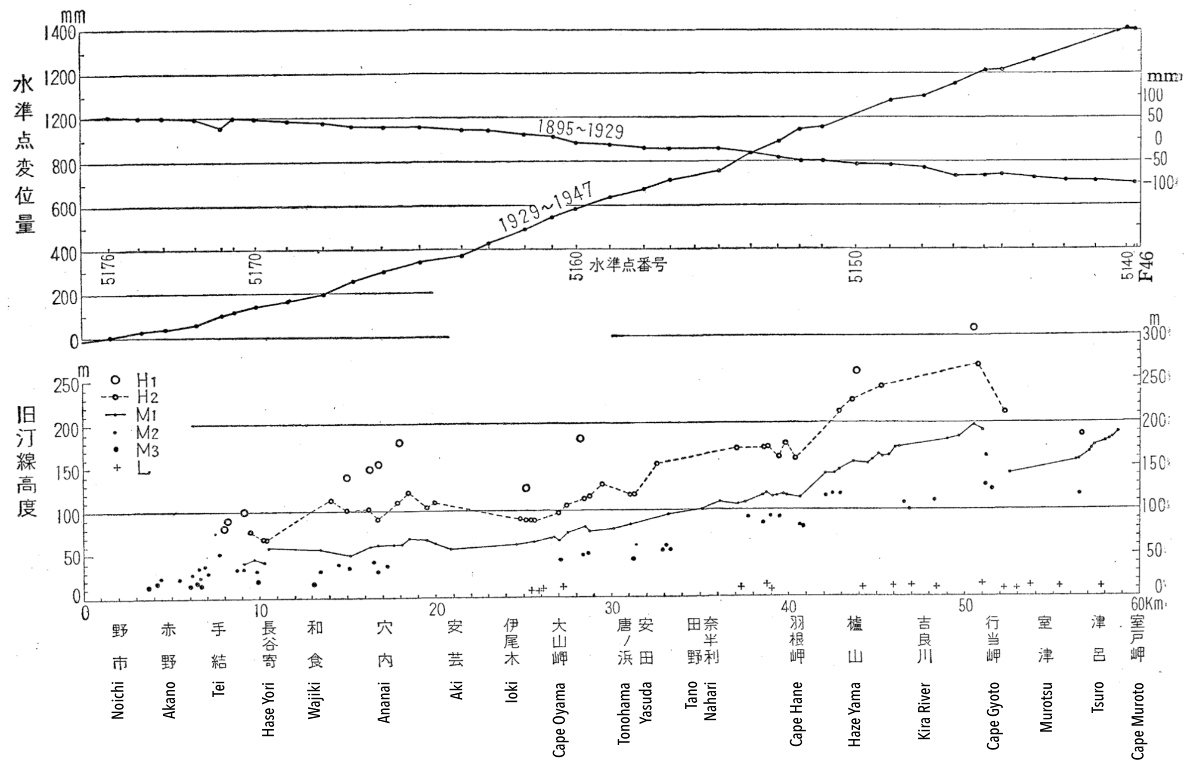
以上のように,行 当岬付近の段丘は,上・中・下の 3 段に大別できるが,この 3 大別は,旧汀線高度こそ異なっても,調 査地域に広く共通してみとめられる.そこで,この地域の段丘を模式的に発達する地域の名称に基づいて,上位を羽根岬面(略号 H),中位を室戸岬面(略号 M),下位を沖積低地(略号 L)とよぶ.さらに,羽根岬面は,行当岬でみられるように,2 段に分れることが多いので,高位を羽根岬面 I(H1 面),低位を同 II(H2 面)とする。室戸岬面はかなり明瞭な海蝕崖を以て,3 段にわけられるので,高い方から順に室戸岬面 I(M1 面),同 II(M2 面),同 III(M3 面)と名づけた[9].

Footnote 9: なお,この毅丘面の分類を従来の分類とくらべると,つぎのようになる.羽根岬面は渡辺の上位段丘,今村の上部汀線,土の上西山段丘にあたり,室戸岬面は渡辺の中位段丘,今村の下部汀線,土の室戸岬段丘に,また沖積低地は渡辺の下位段丘にあたる.もちろんこれは大まかな比較であって,段丘面の分類,分布,対比などの詳細については,筆者らの見解には従来の結果とは異なる点がある.

Fig. 3b is a topographic cross section near Cape Gyoto. According to this, there are 10 or more terraces, but some cliffs are only 3 to 5 m high making a clear distinction difficult such that they are often lumped in a group. Then, for the five main terraces, the altitudes are 306, 265, 190, 128, and 15m, respectively. Among the identified terraces, the two high surfaces are rounded by erosion and the cliffs also slope gently. The two lower flat surfaces are well preserved. There are quite a few valleys, but the boundary between the terrace surface and the valley wall is clear, and the slope of the terrace edge is steep. The lowest surface is distinguished from the upper surface by a cliff with a large height, and although narrow, it is continuous along the coast. On this terrace, microtopography such as past reefs, sand dunes, and sand bars is well preserved. The surface characteristics are different from the higher terrace surface.

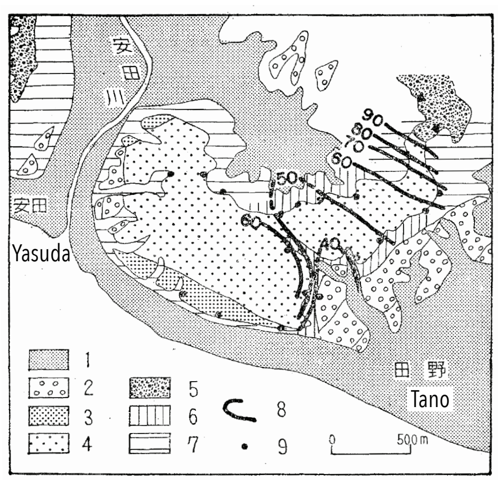
As described above, the terraces near Cape Gyoto can be roughly divided into three steps: upper, middle, and lower, but these three major categories are widely common to the survey area even if the altitude of the old shoreline is different. Here, based on the name of the area where the terraces of this area are schematically developed, the upper part is the Hane Cape surface (abbreviation H), the middle is the Cape Muroto (abbreviation M), and the lower part is called the alluvial lowland (abbreviation L). In addition, the Hane Cape surface is often divided into two terraces, as seen at Cape Muroto, so the higher rank is the Hane Cape surface I (H1). Surface), the lower rank is the Hane Cape II (H2 surface). The surface of Cape Muroto is divided into three levels with a fairly clear sea cliff, so we named it Cape Muroto I (M1 surface), II (M2 surface), and III (M3 surface) from highest to lowest[9].

Footnote 9: If the classification of this Kouki hill surface is compared with the conventional classification, it looks like as below. The Cape Hane surface corresponds to the upper terraces of Watanabe, the upper terrace of Imamura, the Kaminishi mountain terrace of the soil, and the Cape Muroto surface. Watanabe's middle terrace, Imamura's lower shoreline, soil-mantled Cape Muroto terrace, and alluvial lowlands correspond to Watanabe's lower terrace. Of course, this is a rough comparison, and the classification and distribution of the terrace surface. Regarding details such as comparisons, the authors' views differ from the conventional results.



第 4 図旧汀線高度(下)と水準点変位量(上)の投影図水準点変位量の目盛のうち,右側は 1895〜1929 年の絶対変位量,左側は 1929〜1947 年の相対変位量を示す.

Fig. 4 Projection view of the paleoshoreline elevation (bottom) and levelling displacement (top). For the levelling, the right side is the absolute displacement from 1895 to 1929, and the left side is the relative displacement amount from 1929 to 1947



第 5 図田野付近の地質略図. 1. 沖積層 2. M3 段丘砂礫層 3. M2 段丘砂礫層 4. M1 段丘砂礫層 5. H 段丘砂礫層 6.唐ノ浜層 7.奈半利川層群 8. M1 段丘砂礫層の基底等高線(m) 9. M1 段丘砂礫層の基底高度測定点

Fig. 5 Geological outline near Tano. 1. Alluvium 2. M3 terrace gravel 3. M2 terrace gravel 4. M1 terrace gravel 5. H terrace gravel 6. Karanohama layer 7. Nahanrigawa Group 8. M1 terrace gravel base contour (m) 9. measurement point of M1 terrace strath elevation.

II–3 段 丘面 の対比 空中写真の判読お よ び野 外調査によって,段 丘面の対比をおこなった。段丘面の対比に当っては,段 丘面の広がりと連続性,上 述の H, M, L 各 段丘面の形態上の特色や開析の程 度などに注目した.な お,室 戸岬面を構成する堆積 物 は,一 般 に比較的新鮮 であ るのに対し,羽 根岬面 構成物はかなり風化が進み,赤 褐色をおびたり,赤 色の表土をのせることが多いことも,対 比の目安とした.第 2 図 には この ように して分類,対 比 した段 丘面の分布ならびに測定した汀線高度をあらわしてある.

II–4 段丘の旧汀線高度の概観 各段 丘 の 旧 汀線高度の実測値を海岸線の一般方向(第 1 図の鎖線)に投影したものが第 4 図 である.この図に基づいて,各段丘の旧汀線高度 を高位から順 に室戸岬から北西に向って記述する.

〔羽根岬面 I(H1 面)〕 津呂付近では確実に H1 面とみなされるものはない.行当岬では約 300m,櫨山付近で約 260m,大山岬付近で 180m,伊尾木付近 125m と,北西に向って低くなる.穴内付近で再び高度をまして約 150m となるが,ここからはまた手結付近の 80m までしだいに低くなっている.H1 面は断片的に分布するだけなので,対 比も困難であり,高度変化の細かい状態を知り難い.しかし,全体として北西ほど低くなる傾向を示すようである.

〔羽根岬面 II(H2 面)〕 津呂付近で 185m あるが,行当岬で 265m に達し,そこから北西に向っては,多少の不規則はあるが,次第に低くなって,伊尾木付近では約 80m となる.安芸から西では,安芸付近の 110~120m から長谷寄付近の約 70m に至るまで,やはり北西ほど低くなるが,高 度の不規則さは安芸以南よりも大きい.全 体的には,津 呂付近をのぞいて,行 当岬から北西に向って低くなることは,H1 面と同様である.

II–3 Correlation of terrace surface. The terrace surfaces were compared by reading aerial photographs and conducting field surveys. We focused on the extent and continuity of the terrace surface, the morphological characteristics of each of the H, M, and L terrace surfaces and the degree of erosion. The deposits that make up the cape surface are generally relatively fresh, whereas the terrace surface composition is considerably weathered and can be reddish-brown or covered with red-colored surface soil. The fact that there are many is also used as a guideline for comparison. Fig. 2 shows the distribution of terraces classified and compared in this way and the measured shoreline height.

II–4 Overview of the terrace paleo shoreline elevation. Fig. 4 is a projection of the measured values of the old shoreline altitudes of each terrace in the general direction of the coastline (dashed line in Fig. 1). The following description starts in Cape Muroto (right in Fig. 4) and moves northwest (left in fig. 4).

[Cape Hane surface I (H1 surface)] Nothing is definitely considered to be the H1 surface near Tsuro. The altitude is ~300m at Gyoto Cape, ~260m at Hazeyama, ~180m at Oyama Cape (Oyamamisaki), and ~125m at Ioki, becoming lower toward the northwest. The altitude becomes about 150m again near the Ananai, but it gradually becomes lower up to 80m near the Tei. H1 surface Since only fragments of H1 are preserved, it is difficult to compare them, and it is difficult to know the detailed state of the altitude change. However, it seems that the overall tendency is lower toward the northwest.

[Cape Hane surface II (H2 surface)] It is 185m near Tsuro, but it reaches 265m at Gyoto Cape (km 51). From there altitude of the terrace surface lowers gradually, with displaying some irregularities, to the northwest, and reaches about 80m near Ioki (km 27). Further west, it will lower northwestward from 110 to 120m near Aki (km 18) to about 70m near Haseyori (km 10). The degree of irregularity is greater than that south of Aki. Overall, except for the vicinity of Tsuro, the elevation drop from Cape Gyoto to the northwest is similar to that of the H1 surface.

〔室戸 岬面 I(M1 面)〕この面はもつとも分布が広く,段丘面も明瞭であるので,多くの地点で旧汀線高度を測定できた.室戸岬付近では 188m で,そこから北に向って低 くなり,岩戸付近で 141m となる.この地域での汀線の傾きは 1.3×10^{-2} と大きく,遠望してもその傾きがわかるほどである.行当岬では急に高度をまして 190~195m となるが [10],ここから北西に向ってはほぼ一様 な割合で低くなって,伊尾木付近で 60m となる.安芸から手結の間では,全体的には西ほど低くなるが,その低下の割合は伊尾木以南よりはるかに小さく,また不規則性も著しい.以上のように,M1 面の旧汀線高度は H2 面のそれとほぼ平行している.なお,行当岬~室津間での M1 面高度の急変は,この付近における M1 面形成後の変位-断 層あるいは撓曲運動-を予想させる.

Footnote: 10) 行当岬付近では,旧汀線高度 190m の地点のすぐ東側に 160m の旧汀線高度が記入されているが,これは第 3 図 b に示したような M1 面をさらに細分した場合の高さ 158m の面に続くもので あって,M1 面の旧汀線高度を代表するものではない.

〔室戸岬面 II(M2 面)〕行当岬の 125m 前後から北西に向って低くなり,大山岬で約 40m になる.安芸以西では,上 位の面と同様に高度変化がやや不規則であるが,西に向っての高度の減少は認められ,赤岡付近で 25m となる.M2 面は全般的に分布が断片的で,高 度の変化も不規則である.

〔室戸岬面 III(M3 面)〕これに含めた段丘面は,おもに河口付近に分布する河成面であって,海 成面は和食以西にみられるだけである.旧汀線高度は和 食で 15m,長谷寄で 20m,手結,赤岡で 15m 内外である.

〔沖積低地(L 面)〕この面は高度が低いので,その汀線高度の変化を厳密にとらえるためには,今後レベルなどを使用して測定する必要がある。大まかにみると,津呂~吉良川付近で 9~15m,大山岬付近で 7~10m,夜 須付近で 5m となり,北西に向って低くなる傾向はいくらか認められる.

[Cape Muroto surface I (M1 surface)] Since this surface is extensive and the terrace surface is clear, the altitude of the old shoreline could be measured at many points. It is 188 m high near Cape Muroto (km 51). From there, it drops toward the north and is 141 m high near Iwato (km 40). The slope of the shoreline in this area is as steep as 1.3%, and the gradient is noticeable from a distance. At Cape Muroto, the altitude suddenly rises to 190-195m[10], but from here to the northwest it progressively loses elevation sown to 60m in the vicinity of Ioki. From Aki to Muroto, the overall elevation will be lower in the west, but the rate of decrease will be much smaller than that in the south of Ioki, and it will be irregular. As mentioned above, the altitude of the old shoreline on the M1 plane is almost parallel to that of the H2 plane. The sudden change in the altitude of the M1 plane between Cape Muroto and Muroto suggests faulting after the formation of M1.

Footnote 10) In the vicinity of Cape Gyoto, the altitude of the old shoreline of 160m is identified on the east side of the point where the altitude of the old shoreline is 190m. It follows the 158m plane and does not represent the old shoreline altitude of the M1 plane.

[Cape Muroto surface II (M2 surface)] From 125 m before and after Gyodo Cape, it becomes lower toward the northwest, and it becomes about 40 m at Oyama Cape. Although it is irregular, a high decrease toward the west is observed, and it is 25 m near Akaoka. The distribution of the M2 plane is generally fragmented, and the high change is also irregular. is there.

[Cape Muroto surface III (M3 surface)] The terrace surface included in this is the river surface mainly distributed near the river mouth, and the marine surface is only found west of Wajiki. Old shoreline altitude Is 15m for Wajiki, 20m for Hase-yori, hand-knot, and 15m for Akaoka.

[Alluvial lowland (L plane)] Since this plane has a low altitude, it is necessary to measure it using a level in order to accurately grasp the change in the shoreline altitude. Roughly speaking, it is 9 to 15 m near Tsuro-Kira River, 7 to 10 m near Cape Oyama, and 5 m near Yasu, and there is some tendency for it to decrease toward the northwest.

II–5 段丘の地域別の記載この項では,記述の便宜上,いくつかの地域にわけ,地 域毎に段丘の分布や堆積物の状態をのべる.

〔室戸岬 ~ 行当岬間〕(第 2 図 A 参照)H1 面(?)は尾垂山北方, H2 面は尾垂山の西および北,岩戸北方に,著しく開析された断片的な段丘面としてのこされている.

M1 面 は全域に広く分布している.しかし,他地域の M1 面とくらべると,開析が進んでいて,平行する細長い平頂な尾根となっている。室津川沿岸では孤立した尾根となり,旧汀線を知ることはできないが,その他の場所では背後の海蝕崖と旧汀線の位置は明瞭である.段丘面は比高 3~5m の小段丘崖によって 2~3 段に細分されていることが多い.段丘堆積層は厚さ 3m 以下の砂礫である(第 3 図 a).最大礫は 30~50cm に達することもあるが,一般に 5~10cm 前後の亜円礫,円 礫を主とする海浜堆積 物であり,表土はほとんどなく,地 表面に砂礫層が露出していることが多い.

M2 面は,津呂~菜生間,岩戸,上の内付近などに断片的に分布する.面の幅は狭いが,地 形,堆積 物 の状態は M1 面とほとんどかわらない.なお,この面の状態は河成面として谷の中に入りこんでいることがある.

M3 面は,高度 60~70m 前後で,谷の出口だけに分布し,淘 汰の悪い亜角礫からなる河成面である.

L 面は,幅は狭いが,海岸沿いに連続しており,2 面に細分できることが多い.上 位の面は厚さ 2m 前後の海浜礫層をのせていることもあるが,下位の面はほとんど堆積物がない海蝕面で,かつての岩礁の高まりものこっている.室戸川沿岸には L 面に続く谷底平野がかなり上流まで分布する.室戸川河口では基盤岩石が露出しているから,この谷底平野の沖積層の厚さは薄いと考えられるが,確かなことは知られていない.

〔行当岬 ~奈半利川間〕(第 2 図 B 照)この地区は段丘面の連続性がもっともよい.

II–5 Description of terraces in different areas. In this section, the distribution of terraces and the characteristics of sediments are described for each region, divided into several regions for the sake of convenience.

[Between Cape Muroto and Cape Gyoto] (Refer to Fig. 2 A) The H1 plane (?) to the north of Mt. is weathered as a typical terrace surface.

The M1 plane is widely distributed over the entire area. However, compared to the M1 plane in other regions, the M1 plane is more incised and has a flat, elongated ridge. On the bank of the Murotsu River, it becomes an isolated ridge, and it is not possible to identify the old shoreline, but in other places, the sea cliff and the old shoreline are clear. The terrace is often subdivided into 2 to 3 steps by terraced cliffs with a relative height of 3 to 5 m. The terrace sedimentary cover is gravel with a thickness of 3 m or less (Fig. 3a). The maximum gravel is 30 to 50 cm, but it is generally 5 to 10 cm with subrounded gravel with almost no surface soil, and a gravel layer often exposed on the ground surface.

The remnants of the M2 surface are scattered between Tsuro, Nabae, Iwato, and near Uenouchi (or Kaminouchi). The width of the terrace is narrow, but the shape and deposits are almost the same as the M1 surface. The terrace may have entered the valley as a river terrace.

The M3 surface is a river terrace with an elevation of 60 to 70 m distributed only at the exit of the valley and consists of poorly sorted subrounded-clasts.

The L surface is narrow, but it is continuous along the coast and can often be subdivided into two surfaces. The upper surface may have a beach gravel layer with a thickness of about 2 m, but the lower surface is a wave erosion surface with almost no sediment, and high topography of the old reefs is preserved. On the coast of the Muroto River, the valley bottom plain following the L surface is distributed upstream. Since the rocks are exposed, it is considered that the thickness of the offshore sedimentation on the valley floor is thin, but the exact thickness is unknown.

[Gyodo Cape-Nahanri River] (See Fig. 2 B) This area has the best terrace surface continuity.

H1 面も,H2 面も,ともに開析は進んでいるが,旧汀線は明瞭である.露頭が悪くて構成物質の詳細は知り難いが,大部分の場所は厚さ 3~4m 以下の薄い海浜堆積物からなるようである.しかし,櫨山付近には第 3 図 C に示すように,かなり厚い堆積層がある.すなわち,H1 面は外縁部で厚さが 8m の海成層からなる.この層の下部は径 10~20cm の粗い円礫からなるが,上部に向って次第に細粒となり,最上部ではややシルト質の砂層となる.全体として赤く風化している.H2 面では厚さ 30m に達する堆積物があり,その中・下部の 20m は淘汰の悪い亜 角礫で径 50~70cm の ものが多く,扇状地礫層のようにみえる.上部の 10m は,成層し淘汰のよい円礫層で,海 成層と判断される.この円礫層の礫径は上部で 20~30cm,中部で 3~5cm,下部で 10~20 cm のものが多く,層位によりかなり異なるが,いずれもよく水磨されている.また,風化が著しく,とくに最上部の礫層は赤福色を呈している.羽根川河目付近におけるこの厚い堆 積層とその下底の示す谷地形の存在は,一つの下刻期とそれに続く扇状地 礫層および海成層の堆積期をあらわすものとして注意される.

M1 面は,幅の広い明瞭な平坦面である.行 当岬をはじめとして,3m 前後の小崖で細分される小段丘面の集合,すなわち渡辺光 [2)ab7)]の 多生的海岸段丘の形態を示すところが,この海岸の多くの地点で見られる.この段丘面はどこでも堆積物の厚さは薄く,内 縁で 1~2m,外 縁で 3~5m 以下であり,とくに著しい堆積地域はみられない.堆 積物は層理のある円礫 層で,粟おこし状の海浜堆積 物である下部で粗く,上 部で細かくなる傾向がある。一般に礫は風化がすすまず,表 面に赤色土はみられない.なお,羽 根川~羽根岬間では,現 在の海岸線と平行して旧汀線も内側へ彎曲しており,面の開析も進んでいる.これは,この地域の基盤が新第三系であるため,他 の古第三系一中生界よりなる地域より侵蝕が進んだものであろう.

Although the H1 and H2 surfaces are being progressively eroded, the old shoreline is clear. The details of the sediments are difficult to know due to poor exposure, but most of the locations seem to consist of 3 to 4 m thick beach sediments. However, there is a thicker sedimentary layer near Hashiyama, as shown in Fig. 3C. The H1 surface consists of a layer of marine sediments with a thickness of 8 m at the outer edge. The lower part of this layer consists of coarse gravel with a diameter of 10 to 20 cm, but gradually fines to sand and silt in the upper section. It is weathered red as a whole. On the H2 surface, there is a deposit with a thickness of 30 m, and the middle and lower 20 m is made of poorly sorted subangular blocks with a diameter of 50 to 70 cm. This looks like a fan-shaped gravel layer. The upper 10 m is a well-sorted rounded gravel layer, which is assumed to be a marine layer. The gravel diameter of this circular gravel layer in the upper part is 20 to 30 cm, 3 to 5 cm in the middle, and 10 to 20 cm in the lower part, and although they vary depending on the stratum, they are well water-polished. In particular, the uppermost gravel layer has a reddish color. The existence of this thick sediment near the Hanegawa river and the valley terrain indicated by its lower bottom is the presence of one lower period and the subsequent fan-shaped gravel. It is noted that it represents the sedimentary period of the strata and marine strata.

The M1 surface is a wide and clear flat surface. A set of small terraces subdivided by small cliffs 3 m before and after Cape Gyoto, according to Watanabe Hikaru [2) ab 7)]. The morphology of the coastal terraces can be seen at many points on this coast. The surface of this terrace is thin everywhere, 1–2 m at the inner edge and 3–5 m at the outer edge. The deposit is a stratified gravel layer, which is a beach deposit with an awaokoshi-like texture (puffed millet or rice cake), fining upward trend. In general, gravel is not weathered and red soil is not seen on the surface. Between Hanegawa and Hane Cape, the old shoreline is curved inward in parallel with the existing coastline. The dissected plateau is also progressing. This is probably because the basement of this area is the Neogene, so the erosion is more advanced than the other areas consisting of the Paleogene and Mesozoic.

また,吉良川の北西,磯原の東の広い段丘面は,海浜礫をのせる M1 面と考えられる面であるが,磯原の M1 面よりは 10~20m 低く,高度分布が異常である.この異常の原因をつきとめることはできなかった.

M2 面は,行当岬,吉良川~西灘,羽根川以北などにみられる.岬の先端では M1 面との境は明瞭で,幅も広いが(第 3 図 d),その他の地域では M1 面との境が不明瞭で,幅も狭いことが多い.地 形や構成層の性質は M1 面とほぼ似ている.

M3 面は,行当岬東方,羽根川河口付近,奈 半利川河口付近など,主として大きな河川の河口付近にだけ分布する.いずれも淘汰の悪い亜角礫を主とする礫層からなる河成面である.高 度は場所によって異なり,行当岬東方で約 40m,羽 根川河口付近で 60~70m,奈半利川河口付近で 30~40m 前後である

L 面は,狭いけれども,海岸沿いによく連続し,2 面に細分することができる.この面は海浜堆積物からなる所と,海蝕面そのものからなる所とある.またこの面は行当岬東方,羽根川河口付近などではかなり幅が広く,過去の浜堤や砂州,それらをおおう砂丘などの堆積地形がのこされていることがある.また L 面は主要河川に沿ってかなり上流まで谷底平野として追跡できるが,この地域の沖積層の厚さについての資料はない.

〔奈半利川-安 芸川間〕(第 2 図 C 参 照)田 野北方の丘陵は,南西に緩斜する唐ノ浜層の砂礫層よりなり,崩 壊地が多い.ここでは,H1 面の存在は明らかでない.安田町背後の尾根では,160~170m と 200~220m の平坦面をともに H1 面とした.ここでの段丘堆積物は薄く,チャートの多い円礫である.

田野北方の 120~150m の平らな尾根を H2 面とした.この段丘面は厚さ 20m をこえる礫まじりの砂からなるが,その一部はあるいは唐ノ浜層かもしれない.安田以西の H2 面の堆積物は赤褐色をおびた海浜砂礫である.

The wide terrace surface northwest of Kira River and east of Isohara is considered to be the M1 surface on which beach gravel is placed, but it is 10 to 20 m lower than the M1 surface of Isohara and the elevation is unusual. The cause of this anomaly could not be determined.

The M2 terrace is found in Cape Gyoto, Kira River-Nishinada, and north of the Hane River. At the tip of the cape, the boundary with the M1 plane is clear and wide (Fig. 3d). In other areas, the boundary with M1 is unclear and M2 is often narrow. The shape and the properties of the surface material are almost similar to the M1 terrace.

The M3 terrace is distributed only near the mouth of a large river, such as the eastern part of Cape Gyoto, near the mouth of the Hanene River, and near the mouth of the Nahanri River. The altitude of this fluvial terrace varies depending on the location, about 40 m to the east of Cape Gyoto, 60 to 70 m near the mouth of the Hanene River, and 30 to 40 m before and after the mouth of the Nahanri River.

Although the L-terrace is narrow, it is continuous along the coast and can be subdivided into two surfaces. This plane consists of beach sediments and the erosion surface itself. This surface is quite wide in the eastern part of Cape Gyoto and near the mouth of the Hanene River. It is occasionally covered with sedimentary deposits such as beach banks, sandbars, and sand dunes. The L terrace can be traced as a valley bottom plain along the main river to a considerable distance upstream, but there is no data on the thickness of the offshore sediments in this area.

[Between Nahari River and Aki River] (Refer to Fig. 2 C) The hills to the north of Tano are more collapsed than the gravel layer of the Karanohama Formation, which slopes gently to the south and west. The existence of the H1 surface is not clear. At the ridge behind Yasuda Town, both the flat surfaces of 160 to 170 m and 200 to 220 m were designated as the H1 surface. The terrace deposits here are thin, chert-rich pebbles.

The flat ridge of 120 to 150 m north of Tano was designated as the H2 surface. This terrace surface is composed of gravel-rich sand with a thickness of more than 20 m, but part of it may be the Karanohama Formation. The sediment on the H2 surface west of Yasuda is reddish-brown beach gravel.

M1 面は田野町北西方の台地でもっとも広く,安田以西では,幅はせまいが,よく連続する.段丘堆積物は,田野北西の大野・北張の台地では,厚さ約 20m の砂礫よりなる.この砂礫層は,第 3 図 e に示すように,下部の 4~5m は径 10~20cm の円礫よりなり,その上に砂を主とする砂礫がのる.この段丘砂礫層の基底の不整合面の高度分布を第 5 図に示す.これからわかるように,この段丘堆積物の下には,北西-南東にのびる谷状地形がある.また,この図は,谷状地形のところの基盤は唐ノ浜層の泥岩で,その他は奈半利川層群の砂岩よりなること,さらに,大野・北張の台地の北西に彎入している沖積地は,段丘堆積物および基盤の唐ノ浜層が侵蝕されやすいためにできた谷であることを推測させる.

唐ノ浜西北(地 名)の M1 面の堆積物は,厚さ約 20m の海成砂礫よりなるが,その上流の遠山の M1 面は河成礫をのせている.大山岬付近(第 3 図 f)より伊尾木までの M1 面は,幅はせまいが,よく連続する.この段丘堆積物はふつう厚さ 3~4m 以下の海浜礫で,よく円磨されており,赤 褐色を呈するところがある.

なお,安芸川沿いの僧津付近には,M1 および H2 面に対比されそうな河成段丘がある.

田野西方大野の高 さ 70~80m の台地の南縁には,それより 20m ぐらい低い平坦面がつらなる.この平坦面を M2 面とみなす.この面は厚さ 5~10m の海浜性の砂礫層の堆積面である.この砂礫の基底部には径 30cm をこえる巨礫が含まれている.なお,小礫からなるやや固結した礫層がこの M2 面構成層と基盤岩石との間にあり,これを M1 面の堆積物と考えた.大山岬の M2 面には,厚さ約 10m の海浜礫がある.

M3 面は奈半利川,安田川,伊尾木川および安芸川の沿岸,ならびに唐ノ浜の北に,M2 段丘より低い河成段丘として分布し,海 成段丘と認められるものはない.田野付近では M3 面の発達がもっともよく,少くとも 4 段に細分できる.これらの M3 面の堆積物は,ふつう厚さ 3~10m の分級度の悪い扇状地性の砂礫層である.

The M1 side is very wide on the plateau northwest of Tano-cho, and the width is narrow but continuous well west of Yasuda. It consists of about 20 m of gravel. As shown in Fig. 3e, the lower 4 to 5 m consists of rounded gravel with a diameter of 10 to 20 cm, overlain by sandy gravel. Fig. 5 shows the altitude distribution of the irregular surface of the base of this terraced gravel layer. The northwest area is covered by the terrace deposit. There is a valley-like terrain extending to the southwest. In this figure, the base of the valley floor is the mud rocks of the Karanohama Formation, and the others are composed of the sand rocks of the Nahanri River Group. It is speculated that the Karanohama Formation favors the localization of the valley because it is easily eroded.

The deposits on the M1 surface of the northwestern part of Karanohama (place name) consist of marine gravel with a thickness of about 20 m, but upstream, the M1 surface of the Toyama is covered with river gravel. From Cape Oyama to Ioki, the M1 surface from (Fig. 3f) is narrow but continuous. The deposit on this landscape ledge is usually a well-rounded beach gravel with a thickness of 3 to 4 m or less. It has been polished and has a reddish brown color.

There is a river terrace near Souzu along the Aki River, which is comparable to the M1 and H2 surfaces.

On the southern edge of the 70-80 m high plateau west of Tano, there is a flat surface set 20 m below. This flat surface is regarded as the M2 terrace. This surface has a 5 to 10 m thick deposit. It is the sedimentary surface of the beach gravel layer. The base of this gravel contains boulder with a diameter of more than 30 cm. a slightly solidified gravel layer consisting of small gravel is interbedded between the terrace deposits and basement rock of M2 surface, which is considered to be the M1 surface deposit. On the M2 terrace of Cape Oyama, there is beach gravel with a thickness of about 10 m.

The M3 surface is distributed as a river terrace lower than the M2 terrace on the coasts of the Nahari, Yasuda, Ioki and Aki rivers, and north of Karanohama. No marine terrace is identified. The development of the M3 surface is best near the fields, and it can be subdivided into at least 4 fluvial terraces. These M3 surface deposits are usually poorly sorted fan-shaped gravels with a thickness of 3 to 10 m.

田野,唐ノ浜,伊尾木付近のL面には,浜堤ないし砂州があり,砂礫よりなるが,沖 積層の厚さは明らかでない.

〔安芸川~手結間〕(第 2 図 D)全般的に段丘面の開析がすすみ,その幅も狭い.

御殿ノ鼻より東でH1面のやや広くのこっているのは,八丁北方だけであって,基 盤の露出した平坦な尾根をなし,外縁近くにところどころ厚さ 2m 内外の海成礫がみられる.穴内から和食の間にも H1 面は分布するが,きわめて狭く,山麓に点在する.これらの段丘面の中には,厚さ 15mn 内外の海成礫よりなるものもある.和 食川より西では,山麓につらなるいちじるしく開析された狭い平頂な尾根を H1 面と考えた(第 3 図 h).

H2 面 は安芸平野に面するところにやや幅広くみられるが,相当開析されている.厚い河成礫層よりなるが,これは段丘堆積物ではなく,基盤の新第三系のようである.H2 面は土 佐電鉄安芸駅西方でいったん狭くなるが,西に向ってしだいにその幅をまし,穴内までかなり連続してみられる.ここではふつう厚さ 10m 内外の海成礫よりなる,穴内から御殿ノ鼻付近では,H2 面の幅は大きくなるが,かなり開析されてまるみをおびた平頂丘陵をなし,細長くひろがっている.不 明瞭な崖によって,さらに細かく分けられる.この段丘面は厚さ 20m あまりの海成礫よりなる.和食付近には,H2 面とみなされる段丘面が山麓に点在するが,低い崖によって細分されるとともに,開 析も相当すすんでいるので,その認定がかなり困難である.和食より西の丘陵では,さらに開析され,基盤のあらわれた平坦な尾根や孤立し丘となって点在する.

On the L terrace near Tano, Tonohama, and Ioki, there are beach ridges, or sandbars, with gravel, but the thickness of the alluvium is not clear.

[Between Aki River and Tei] (Fig. 2D) In general, the terrace surface has been dissected and its width is narrow.

To the east of Gotennohana, the H1 surface is slightly wider north of Haccho, forming a flat ridge with an exposed base. About two meter-thick deposits of well rounded marine gravel outcrop near the outer edge of H1. The H1 surface is distributed between Ananai and Wajiki, but it is extremely narrow and intermittent at the foot of the mountain. Some of these stepped hill surfaces have a ca. 15 m thick marine gravel cover. West of the Wajiki River, the narrow flat ridge that was dissected at the foot of the mountain was considered to be the H1 surface (Fig. 3h).

The H2 surface is rather widespread in the area facing the Aki Plain, but is incised. It consists of a thick layer of fluvial gravel, but this is not a terrace deposit, but part of the Neogene bedrock. The H2 side becomes narrower to the west of Tosa Electric Railway Aki Station, but it gradually widens toward the west and can be seen quite continuously up to Ananai. The width of the H2 surface becomes large from the inside of the mine pit to the vicinity of the Gotennohana, which consists of marine gravel with a thickness of ca. 10 m, but it forms a long and wide flat terrace that is dissected and rounded. It is further subdivided by a diffuse step. This terrace surface is composed of 20 m thick marine gravel. In the vicinity of Wajiki, the terrace surface is considered to be the H2 surface. It is scattered at the foot of the mountain, but it is quite difficult to certify it because it is subdivided by low cliffs and the dissected plateau is considerably eroded. In the hills west of Wajiki, it is further dissected and is scattered as flat ridges and isolated hills cut in the bedrock.

この地域でもっとも広く発達する段丘面は M1 面であり,安 芸から穴内までほとんど連続していて浅い谷に刻まれるだけである.段 丘面は,基 盤をなす新第三系の泥岩または礫岩の上にのる厚さ 10m 以下の海成礫よりなるが,背後の山地の谷口にあたる新城付近では,その上に厚さ 10m たらずの河成礫層がのる.段 丘面はかなり平坦であるが,やはり低い崖によって細分される.御 殿ノ鼻付近では, M1 面はやはり厚さ 10m 内 外の海成礫よりなるが,相 当開析されている.和食付近では,M1 面はさらに狭くなり,丘 陵の頂きに孤立して点在する.長谷寄から手結にかけては,かなり開析されてはいるが,やや連続して分布する.しかし,その表面には基盤があらわれ,段丘堆積物はみられない.

穴内より東では,M2 面は穴内川河口付近の両岸にのみ分布し,いずれも河成段丘面である.御 殿ノ鼻付近には,M2 面がやや連続してみられるが,M1 面の開析谷にそって入りこみ,その一部は河成面のようである.御 殿ノ鼻より西では, M1, M2 両面間の段丘崖が不明瞭となり,ところによっては両者の 識別が困難な場合もある.和 食付近では, M2 面 は多少起伏のある平項な丘陵をなし, M1 面 をとりまいてやや広く分布する.この地域では, M1, M2 両面とも海成円礫よりなるが,この礫層は多少西にかたむき,基 盤の新第三系と考えられる.長谷寄から手結の間では, M1, M2 両面の区分はさらに困難であるが,一般に M1 面より海岸寄りに一段低くつらなる段丘面を M2 面とした.この段丘面にも堆積物はほとんどみられない.

The most widely developed terrace surface in this area is the M1 surface, which is almost continuous from Aki to the inside of the mine pit and is only dissected in a shallow valley. The terrace surface forms the basis. It consists of marine gravel with a thickness of 10 m or less on the new third system of mud or gravel, but in the vicinity of Shinshiro, around the mouth of the valley, it is covered by a 10 m thick layer of fluvial gravel. The terrace surface is fairly flat, but it is subdivided by low cliffs. In the vicinity of Gotennohana, the M1 surface is still composed of marine gravel with a thickness of ca. 10 m. In the vicinity of Wajiki, the M1 surface becomes even narrower and is scattered at the top of the hill. From Hase-yori to Tei, it is nearly continuous despite some erosion. However, the bedrock outcrops at the surface and no terrace deposits are found.

East of Ananai, the M2 plane is only present on both banks near the mouth of the Ananai River, and both are river terraces. The M2 plane is slightly continuous near the Gotennohana. It entered along the dissected valley of the M1 surface, and a part of it seems to be an estuary. To the west of Gotennohana, the terrace cliff between both M1 and M2 surfaces became unclear. Depending on the time, it may be difficult to distinguish between the two. In the vicinity of Wajiki, the M2 surface forms flat terraces with some undulations, and the M1 surface is surrounded by a slightly wider distribution. In this area, the M1 surface is distributed. Both sides of M2 are composed of marine gravel, but this gravel layer is considered to be a new third system of the base, which is slightly westward. Between Haseyori and Tei, it is difficult to discern M1 and M2. Nevertheless, the surface lying one step lower than the M1 surface toward the coast is generally defined as the M2 surface. Almost no deposits are found on this terrace surface.

この地域では,赤 野川河口付近から和食付近にだけ M3 面がみられる.和 食付近では海成段丘面であるが,その他は河成段丘面で,河谷にそって分布している.

L 面は,安芸川および和食川のやや広い沖積平野のほかは,海岸にそってきわめて狭くつらなるにすぎない.安芸川および和食川の沖積平野は,いずれもその山麓に低い沖積段丘があり,少くとも 2 段に分けられる.安芸平野のボーリング資料 11)によると,この平野の沖積統の厚さは 30m 以上もあり,その基底は少なくとも海面下 20m 以下の深さにある.このことは,M3 面形成後に,海退期とそれにひきつづく海進期のあったことを示している.

Footnote 11: （安芸市上水道水源（深さ 30m）、安芸市庁舎（深さ 15m）、安芸督察署庁舎（深さ 12m）などの工事のためのボーリング資料があり、いずれも安芸市街北方、平野の中央部の海抜 10m 以下の地点で行われたものである。一般に、地表から深さ 10m あたりまでは砂傑よりなり、その下に厚さ 5m たらずの粘土があり、さらにその下部は砂傑となるもっとも深い上水道水源でも沖積統の基底に達しない。

In this area, M3 surface can be seen only near the mouth of the Akano River and near Japanese food. Although it is a marine terrace near Wajiki, the rest is a fluvial terrace along the river valley.

The L plane is only very narrow along the shore, except for the slightly wider alluvial plains of the Aki and Wajiki rivers. The alluvial plains of the Aki and Wajiki rivers are all low at the foot of the mountain. There are hills, which can be divided into at least two steps. According to the Aki Plain Boring Material[11), the alluvial plain deposits are more than 30m thick, and the bedrock base is at least 20m below sea level. It is at depth. This indicates that there was a retreat period followed by a marine advance period after the formation of the M3 plane.

Footnote 11: (There are boring materials for construction work such as Aki City Water Supply Source (30m depth), Aki City Hall (15m depth), Aki Administration Office Building (12m depth), all in the north of Aki City, in the central part of the plain. It was carried out at a point less than 10 m above sea level. Generally, from the surface of the earth to a depth of about 10 m, there is sand and gravel, and below that there is clay less than 5 m thick, and the lower part is sand and gravel. Even the deepest tap water source does not reach the base of the Okizumi line.

III 考察

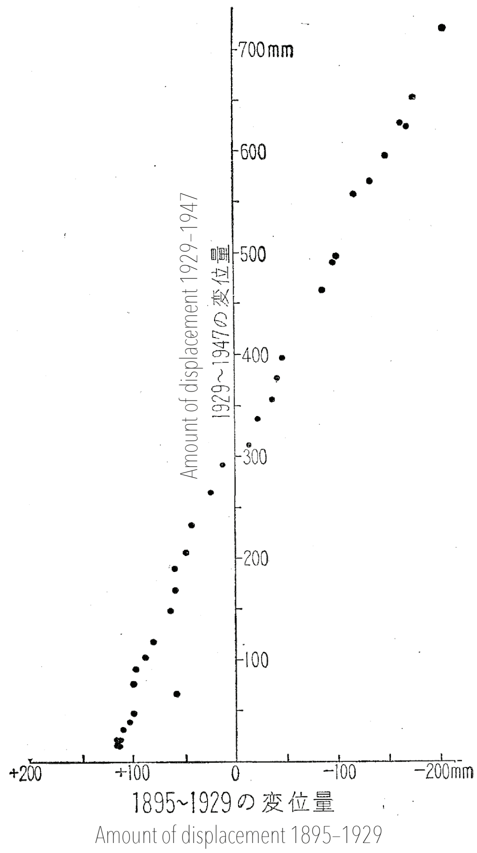
III-1 **海**岸段丘堆積**物**か ら推定 され る沈 水 現 象とその解釈

(a) 地震隆起と海岸段丘との関係すでにのべたように,M 面や L 面は,比高 3~5m 以下の小崖によって分けられた階段状の平坦面の集合よりなる場合が多い.このことはすでに渡辺光によって指摘され,多生的海岸段丘 (coastal terrace of polygenic origin) と呼ばれている 2)ab7).渡辺は,かかる階段状の地形は,南海地震のさいに室戸岬でおこったような小隆起が間歇的にくりかえされて形成されたと考えた.

III Discussion

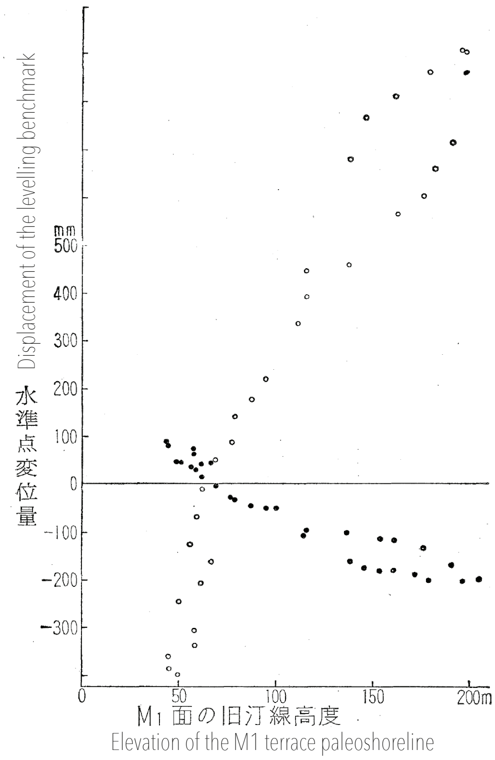
III-1 Submergence episodes identified from marine terrace deposits and their interpretation

(a) Relationship between seismic uplift and marine terraces. As mentioned above, the M and L surfaces are a set of stepped flat surfaces separated by small cliffs with a relative height of 3 to 5 m or less. This is already pointed out by Mitsuru Watanabe, who assigns a polygenic origin to the terrace[2)ab7)]. Watanabe proposed that the stepped terrain at Cape Muroto results from repeated uplift episodes similar to the Nankai earthquake.



第6図南海地震(1946)をはさむ期間の水準点相対変位量と地震前における水準点絶対変位量との関係

Fig. 6 Relationship between the relative displacement of the levelling benchmark during the period immediately preceding the Nankai earthquake (1946) on the y-axis and the absolute displacement of the benchmark before that on the x-axis.



第7図M1面の旧汀線高度と水準点変位量との関係

●1895～1929年の絶対変位量

○1929～1947年の相対変位量

Fig. 7: Relationship between the elevation of the M1 terrace paleoshoreline and the amount of levelling benchmark displacement

● Absolute displacement from 1895 to 1929

○ Relative displacement from 1929 to 1947

一方,南海地震のときの地殻変動は,潮位の変化の観察や,地震をはさんでの水準測量によって知られている.それらによれば,室戸岬付近では 1m 内外隆起したが,北 西へ隆起量を減じ,高知付近では約 0.5m 沈降した.地震をはさんで 2 度の水準測量(1929 年と 1947 年)から知られる水準点の変動量[12)]を,海岸段丘の旧汀線高度と同じく,海岸に沿う断面に投影した結果が,第 4 図上部の図である.

Footnote 12: この変動量は海面を基準とした絶対量ではなく,ある地点を基準とした相対変動量を示すものである.

南海地震前の土佐湾北東岸における地殻変動は,同じく第 4 図に示した 1895 年と 1929 年の問の水準点の変動量 [13)]のグラフでみられるとおり,地震の時とは反対に,高知付近が隆起し,室戸岬に近づくほど沈 降量が大きくなるような性質のものであった.

Footnote 13: この値は,今村明恒 5)によるもので,小松島の検潮記録にもとずいて,海面を基準とする絶対量で示してある.

南海地震をはさむ 1929 年~1947 年の変動量と地震前の 1895~1929 年の変動量 とが負の相 関を示すことは第 6 図 のとおりである.

ところで,南 海地震のような南海道沖の海底に震源を有する大地震には周期性があり,過去の記録によると,大地震時の室戸岬の隆起量は次の大地震までの間の沈降量よりも大きいと考えられる.このようなことから,渡辺光は M 面が室戸岬で高く,北西へ低下するのは,現在のような地殻変動の長期にわたる累積の結果であろうと推定した [14)].ここに, M1 面の旧汀線高度と 1929~1947 年間ならびに 1895~1929 年間の水準点変位量の関係を図示すると [15)],第 7 図のようであり,前者は正の相関,後者は負の相関を示している.ただし点のならび方は直線的ではない.

Footnote 15: 同じグラフは今村学郎に よって作られたことがある.今 回の M1 面の旧汀線高度の測定値は,今村のそれとはかなり違うので,グラフは同一ではないが,本質的な差異はない.なお,水準点変位量と L 面の旧汀 線高度との関係を調べることも興味があるが, L 面の旧汀線高度の測定は精度が低く,測定点も少ないので,今回はおこなわなかった.

On the one hand, crustal movements during the Nankai earthquake are constrained by changes in tide level and leveling around the rupture area. The amount of uplift was ca. 1 m near Cape Muroto and decreased to the northwest, reaching subsidence of about 0.5 m near Kochi. The upper part of Fig. 4 (left hand axis) shows the uplift[12)] projected onto the cross section alongshore. It follows a similar trend to the altitude of the old shoreline of the terrace.

Footnote 12: This amount of fluctuation is not an absolute amount based on the sea level, but a relative amount based on a certain point.

The crustal movement on the northeastern coast of Tosa Bay before the Nankai Earthquake is opposite to that of the coseismic displacement, as can be seen in the plot of leveling fluctuations[13)] between 1895 and 1929 shown in Fig. 4 (right hand axis). In addition, the area around Kochi was uplifted, and the amount of subsidence increased as it approached Cape Muroto.

Footnote 13: This value is based on Akitsune Imamura[5)] and is shown as an absolute quantity relative to sea level based on the tidal gauge record of Komatsushima.

Figure 6 shows the negative relationship between the fluctuations between 1929 and 1947, which sandwich the Nankai earthquake, and the fluctuations between 1895 and 1929 before the earthquake.

Even if large earthquakes with epicenters off the Nankaido coast, such as the Nankai earthquake, are periodic, and according to past records, the amount of uplift at Cape Muroto during a major earthquake is considered to be greater than the amount of subsidence between earthquakes. Therefore, Watanabe Hikaru proposes that the M-surface, high at Cape Muroto and lower to the northwest, is the result of long-term cumulative cycles of crustal deformation[14)]. Here, the relationship between the old shoreline altitude of the M1 plane and the displacement between 1929 and 1947, and between 1895 and 1929 is illustrated[15)] in Figure 7. As shown in the figure, the later period shows a positive correlation and the earlier period shows a negative correlation. However, the points are not arranged linearly.

Footnote 15: The same graph is said to have been made by Gakuro Imamura. The measured values of the old shoreline altitude on the M1 surface this time are different from those of Imamura, so the characteristics are not the same. However, there is no qualitative difference. It is also interesting to investigate the relationship between the displacement of the sea level and the old shoreline altitude of the L plane, but it is also interesting to measure the old shoreline altitude of the L plane. The accuracy is low and there are few measuring points, so I did not do it this time.

なお,M1 面 の旧汀線高度(m_1)と H2 面の旧汀線高度(h_2)との関係は第 8 図のとおりで,正の相関を示し,その回帰方程式は, h_2=1.28m1+18.8 となる.このことは, H2 面はその形成後, M1 面がうけたと同じ形式の地殻変動をこうむってきたことを示している.

以上にのべたのは,要するに,多生的海岸段丘の存在と,この地域の旧汀線高度の分布とが,それぞれ大地震の度ごとの室戸岬の隆起という地 殻変動の様式によく一致しているという事実である.

ところが,ここに 1 つの問題がある.それは,すでに記載したように, H2 面および M1 面は,一般には薄い海成礫層におおわれる海蝕段丘面であるが,谷ぞいのところでは段丘堆積物の厚さが 20~30m に達する部分があり,また安芸川ぞいの沖積層の厚さも 30m 以上あって,その基底は現海面よりかなり低いということである.これらの事実は,H2 面,M1 面および L 面 の形成前にそれぞれ離水・下刻期があり,そ の後に沈水期があったことを示している.これは,先にのべた室戸岬の地殻変動の性質-大地震ごとの隆起の累積-と 一見矛盾するようにみえる.この矛盾とみえるものは,土隆一の指摘 [4]を除くと,論ぜられたことのないものであり,何 等かの説明を要する問題である [16].

Footnote 16: なお,後にのべるように,この沈水期の問題は, H, M, L などの諸段丘面を分ける高い海蝕崖の成 因の問題と深い関係をもっている.

(b) 地盤の隆起と glacial eustasy との関係わが国の海岸地帯において第四紀の glacial eustasy がいかなる形でその地形発達に関与したかは,関東平野や濃尾平野などで,かなりくわしく研究されてきた.しかし,四国南東岸のような著しい隆起地域における glacial eustasy の現われ方については,ほとんど論じられたことがない.上記の土隆一の論文 [4] はこれに言及しているが,具体的な説明は少ない.

The relationship between the old shoreline elevation (m_1) on the M1 plane and the old shoreline elevation (h_2) on the H2 plane is shown in Fig. 8, showing a positive correlation, with the regression $h_2 = 1.28\ m_1 + 18.8$. This indicates that the H_2 plane has undergone the same form of crustal movement as the M1 plane after its formation.

In short, the existence of prolific marine terraces and the distribution of paleo-shoreline elevations in this area result from coseismic uplift of Cape Muroto. This is in good agreement with the pattern of crustal deformation.

However, there is one problem here. As already mentioned, the H2 and M1 planes are marine terraces generally covered with a thin marine gravel layer, but the terrace deposits are thicker in the valleys, reaching up to 20 to 30 m. The alluvium thickness near the Aki River is more than 30 m, and its base is considerably lower than the current sea level. These facts suggest that there was a period of emergence followed by renewed submergence before the formation of the H2, M1 and L surfaces. At first glance, it seems to be inconsistent with the nature of the crustal movement of Cape Muroto where uplift accumulates with each major earthquake. This problem has never been discussed before and requires some explanation[16].

Footnote 16: As will be described later, the problem of this submergence period is closely related to the problem of the formation of high sea cliffs that divide terraces such as H, M, and L.

(b) Relationship between rock uplift and glacial eustasy. The pattern of Quaternary glacial eustasy involved in the topographical development in Japan's coastal areas was studied in detail in the Kanto Plain and Nobi Plain. However, the pattern of glacial eustasy in areas of fast uplift rates such as the southeastern coast of Shikoku has hardly been discussed. Although it is mentioned, there are few concrete explanations.

さて,隆 起地域においては,海 面低下の影響は見掛けの地盤隆起量を増大させる形で現われるはずである.一方,海面上昇の影響は,見掛けの地盤隆起量を減少させたり,時には見掛け上地盤を沈降させたりする形で示されるであろう.この後者の場合を量的に検討しよう.

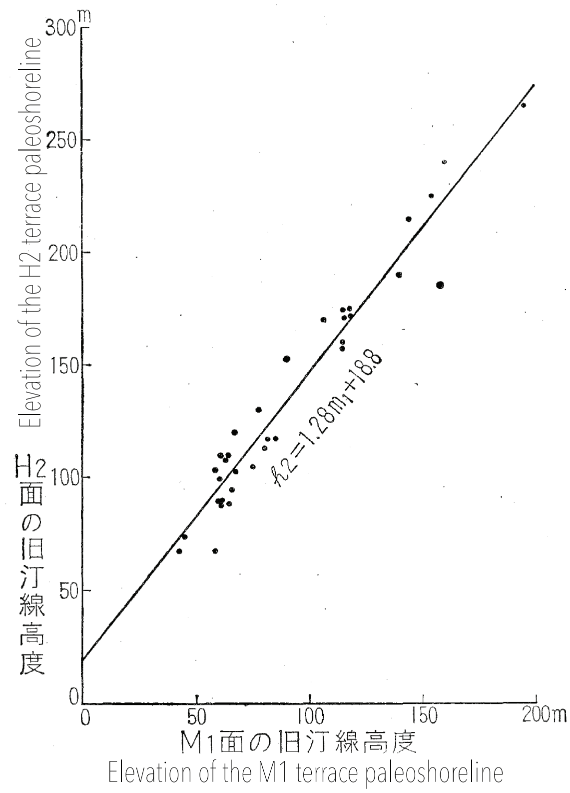
F. P. Shepard (1961)[17] の資料によると,約 18,000 年前から約 6,000 年前までの海面上昇速度の平均値は約 9mm/年である.一方,わが国の沖積世の海岸段丘の中でもとくに隆起量の大きい房総半島南部のものは,野島岬付近で海抜約 20m に達している.この段丘面の時代は,加茂遺跡出土の丸木舟の C^{14} 年代測定により,約 5,000 年前と考えられるので,この段丘の示す平均隆起速度は約 4mm/年である.さらに,杉村新と成瀬洋が推定したように [18],この期間に約 6m の海面低下があったとすれば,地盤隆起の速度はさらに小さく,約 3mm/年となる.すなわち,わが国の著しい隆起地域でも,その隆起速度ば後氷期の海面上昇速度よりずっと小さい.

室戸岬付近の L 面の形成時代については確かなことはわかっていないが,房総南部の沖積段丘の形成期と大差がないであろう.しかし,その高さはせいぜい海抜 15m 程度であるから,地盤の隆起速度は房総南部より小さいと推定される.このことから,室戸岬付近は海岸段丘の高さからみると著しい隆起地域ではあるが,後氷期の海面上昇速度はこの地域の地盤隆起速度を上まわり,その結果沈水海岸が形成されたと考えられる.室戸岬より地盤隆起速度の小さい安芸付近で沖積埋積谷がみられるのは,このような考えからすれば当然であろう.これより類推すれば,M1 面にみられる沈水期は,後氷期海進の前の海進期,すなわち Riss-Wurm 間氷期に対応することとなる.現在のところ,この推測を年代測定あるいは古生物によって直接確かめることはできないが,次に,地 殻変動の速さに関する資料を検討し,その観点からこの年代の問題を考えてみたい.

On the one hand, in uplifting areas, the effect of sea level fall should translate in an apparent increase of the amount of rock uplift. On the other hand, sea level rise reduces the apparent rock uplift. Occasionally, it will be result in apparent rock subsidence. Let us consider this latter case quantitatively.

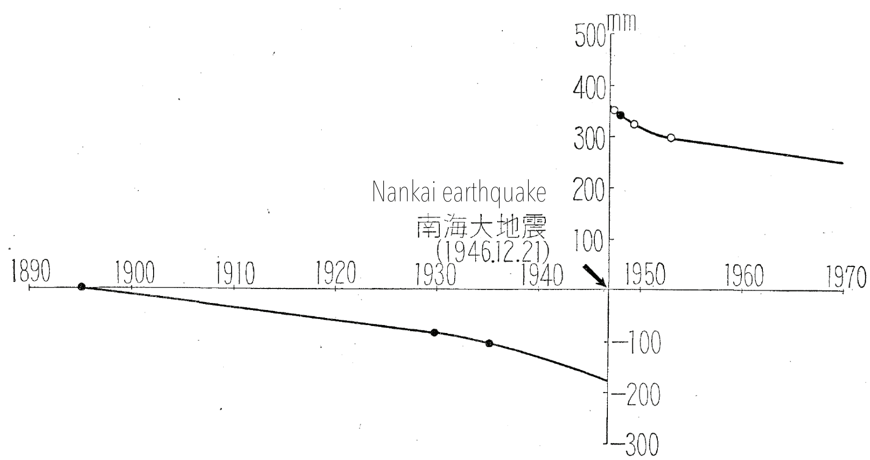
According to the data of Shepard (1961)[17], the average sea level rise rate between 18 and 6 ka is about 9 mm/year. On the other hand, Holocene marine terraces in the southern part of the Kiboso Peninsula, Japan, are raised to 20 m above sea level by fast uplift rates near Cape Nojima. Since these terraces are thought to be about 5 ka, the average local uplift rate is around 4 mm/yr. Furthermore, if sea level dropped by 6 m during theis period, as estimated by Shin Sugimura and Hiroshi Naruse[18], the rate of ground uplift would be even lower with about 3 mm/yr. That is, even in Japan's fast rising areas, the uplift rate would be slower than the Holocene sea level rise.

The formation period of the L-surface near Cape Muroto is not known with certainty, but it may not be much different from the formation period of the alluvial terrace in the southern part of Boso. However, its height is at most ca.15 m above sea level and the local uplift rate should be lower than that of the southern part of Boso. The area near Cape Muroto is a remarkable uplift area considering the height of the coastal terraces. The rate of postglacial sea level rise exceeds ground uplift rate in this area, and it is thought that a submerged coast was formed as a result. It makes sense then that alluvial valleys are buried near Aki where the ground uplift rates are slower than at Cape Muroto. By analogy, submergence of the M1 surface corresponds to the transgression period during the penultimate postglacial, at the beginning of the Riss-Würm interglacial period [T.N. MIS 5e]. At present, it is not possible to directly confirm this speculation by dating or paleontology, but next, I would like to examine evidence about the rates of crustal deformation and consider the problems from that perspective.



第 8 図 M1 面と H2 面の旧汀線高度の関係

Fig. 8: Relationship between the elevation of the M1 and H2 terrace paleoshorelines.



第 9 図水準点 No. 5158(安田)に対する水準点 No. 5148(吉良川)の比高の変化 ●実測値 ○推定値

Fig. 9 Change in the relative height of benchmark No. 5148 (Kira River) with respect to benchmark No. 5158 (Yasuda)
● Measured value ○ Estimated value

III-2 地殻変動の速さの問題

(a) 地殻変動の周期性南海道沖に発生した歴史時代の大地震(マグニチュード約 8 以上)を理科年表からぬきだすと,第 1 表のとおりであって,南海地震程度の大地震が過去約 1,300 年されている.

ところで,この表をみて気づくのは,正平 16 年の地震以降の大地震間隔は大体 100~150 年,平均 117 年でかなり周期性のあることである.さらにそれ以前の大地震の間隔は 200~250 年で,正平 16 年の地震以降の平均間隔の約 2 倍である.古い地震の記録ほど得がたいことを考えると,正平 16 年以前には,上の表の大地震の間に各 1 回づつの大地震があったのかもしれないそうであるとすれば,(天 武)12 年以降の大地震の平均間隔は 105 年となる.

これらの南海道大地震のうち,(天 武)12 年,宝永 4 年,安政元年の地震に伴なう地変は,いずれも南海地震の時の地殻普変と非常によく似たものであることがわかっている [19].すなわち,室戸岬での 1m 程度の隆起と高知平野での沈降がおこっている.また,地震の間の期間には,これと逆むきの地殻変動が慢性的におこったとみられるのも,南海地震以前あるいは以後の慢性的地殻変動と規を一にしている.

そこで,南海地震の時とその前後におこった地殻変動が,100~120 年の周期をもつ過去の大地震の際にもおこったと考え,最 近の地殻変動の平均速度を求めてみよう.

(b) 地殻変動の平均速度この地域の地殻変動の平均速度は,ある地点の,現海面に対する絶対的垂直変位速度と,傾 動速度の両方について求めることができる.

III-2 Problem of rates of crustal deformation

(a) Periodicity of crustal movements. Large historical earthquake (magnitude of ca. 8 and above) similar to the Nankai earthquake are listed in Table 1. The record of major earthquakes covers the last 1,300 years.

By the way, what you notice from this table is that the interval between large earthquakes after year 16 of the Shohei Era (1361 CE), earthquake occur every 100 to 150 years, with an average period 117 years, which is rather periodic. The interval between major earthquakes before that was about twice as long at 200 to 250 years. Considering that it is difficult to obtain the record of an old earthquake, it is possible that, before Shohei 16 (1361 CE), a major earthquake happened between each one listed in Table 1 but was not recorded. If so, the average interval of major earthquakes since (Tenmu) 12th year (684 CE) is 105 years.

Of these major Nankaido earthquakes, the surface changes associated with (Tenmu) 12th year (684 CE), Hoei 4th year (1707 CE), and the 1st year of Ansei (1854 CE) earthquakes are all very similar to the surface changes caused by the Nankai earthquake[19], namely uplift by ~1 m at Cape Muroto and subsidence in the Kochi Plain. The fact that the crust moved in the opposite direction between the earthquakes seems to have occurred repeatedly and is in agreement with crustal movement before and after the Nankai earthquake.

Therefore, let us assume that the crustal movements that occurred before, during, and after the Nankai earthquake also accompanied the past large earthquakes with a period of 100 to 120 years, and let us find the average velocity of the nearest crustal movement.

(b) Average velocity of crustal movement. The average velocity of crustal movement in this area can be calculated for both the absolute vertical displacement rate at a certain point with respect to the current sea level and for the tilt rate.

i) 室戸岬の絶対的隆起速度南海地震の際に室戸岬付近は約 120cm 隆 起した [20].一方,南海地震前の沈降量は, 1895~1929 年の 34 年間に約 180mm であることが,水準測量と小松島の検潮記録とからわかっている.したがって,地震間の慢性的沈降がこの速さで進行したとすれば, 100 年間では約 55cm 沈降したことになる.しかし,岡田惇・永田武 [21]によって室戸岬付近で地震後に繰返しおこなわれた水準測量の結果から,南海地震直後には,地震時に生じた南上りの傾動を回復するむきの傾動が速かに進み,地震後約 6 年間に地震時の変位の約 1/3 を回復し,それ以後は再び平時の沈降速度にもどったことが知られている.そこで,この値を用いれば,地震直後の数年間の沈降量は, 120cm×1/3 で,約 40cm となる.したがって,大地震間の約 110 年における沈降量は合計約 95cm となり, 1 回の大地震を含む 1 周期の間に室戸岬付近は差引約 25cm(地震隆起の約 1/5)の隆起を生ずることなり,平均約 2mm/年の隆起速度となる.これを一応室戸岬の現在の地殻変動の平均速度と考えよう [22].

つぎに,この速度の地盤の隆起が過去の地質時代にもおこっていたと仮定した場合,海岸段丘の旧汀線高度はいくらになるか調べてみる。室戸岬付近の L 面の形成時代は明らかでないが,一応房総南部の沖積段丘と同じく約 5,000 年前とすると,前記の平均隆起速度から,その現在の高さは約 10m となるはずである.これは実際とかなり一致する.

つぎに, Riss-Wurm 間氷期に形成されたと考えた M1 面の旧汀線高度は現在室戸岬で約 180m である. Riss-Wurm 間氷期の絶対年代は, C^{14} 測定の域をこえるために,その信頼度は小さいが, H. E. Suess [23] が深海底コア中の有孔虫の O^{18}/O^{16} による古海水温 度の変化を示した図から推定すると,約 9 万年前となる.

i) Absolute uplift rate of Cape Muroto. The area around Cape Muroto was uplifted by about 120 cm during the Nankai earthquake [20]. While the amount of subsidence before the Nankai earthquake was about 180 mm during the 34 preceding years (1895–1929) according to the leveling and the tidal gauge records of Komatsushima. Therefore, if the chronic subsidence between earthquakes progressed at this rate, it would have subsided about 55 cm in 100 years. However, based on leveling results repeated immediately after the earthquake near Cape Muroto by Atsushi Okada and Takeshi Nagata [21]. The tilting to the south was recovered rapidly, and about 1/3 of the coseismic displacement was recovered within about 6 years after the earthquake and the subsidence rate then returned to that of the pre-earthquake period. Therefore, using this value, the amount of subsidence in the first few years immediately after the earthquake is 120 cm × 1/3, which is about 40 cm. The total amount of subsidence in about 110 years between major earthquakes is about 95 cm (40 cm postseismic subsidence and 55 cm interseismic subsidence), and the uplift is about 25 cm (120 cm coseismic uplift and 95 cm of total post- and interseismic subsidence). Near Cape Muroto (about 1/5 of the coseismic uplift) during one period including one major earthquake. The average uplift rate will then be about 2 mm/yr at Cape Muroto [22].

Next, assuming that uplift rates were similar in the past, let us investigate how high the old shoreline of the marine terrace will be. The age of the formation of the L-plane near Cape Muroto is not clear, but if it is about 5,000 years ago, like the alluvial terrace in the southern part of Boso, the current height should be about 10 m given the above-mentioned average uplift rate. This is inconsistent with the actual situation.

Now, the height of the old shoreline on the M1 surface, which was thought to have been formed during the Riss-Wurm interglacial period (MIS 5e), is currently about 180 m at Cape Muroto. The absolute age of the Riss-Wurm interglacial period is out of the range measured by C^{14}. Therefore, its reliability is low, but it is estimated to be 90,000 years old according to the figure by H. E. Suess [23] showing changes in sea paleotemperature due to O^{18} / O^{16} of the foraminifera in deep sea cores.

R. W. Fairbridge[24)も,堆積速度に関する資料を参照して,Riss-Wurm間氷期は約95, 000年前に始まるとしている.そこで, Riss-Wurm間氷期を約9万年前にはじまるとし,約 2mm/年の隆起速度を用いると, M1 面の旧汀線は現在約 180 m の高さにあるはずで 25),これも実際と合致する.

ii) 室戸岬付近の傾動速度水準測量の成果は,検潮記録と結びつけなければ,平均海面に対する変位量に換算できない.この地域における何回かの水、準測量のなかで,1895~1929 年の期間に関しては,前記のように小松島の検潮記録によって平均海面に対する変位量が求められているが,それ以外は,厳密にいえるのは,水準点間の比高の変化,すなわち傾斜の変化だけである 26).この点では,さきの岡田・永田の資料も同様である.また,前項の隆起速度の算定に用いた室戸岬付近の隆起量の約 120cm という値は,海岸での潮位変化の観察などにもとづくものであるから,求められた隆起速度も精度の高いものではなく,一応の目安を得たというにとどまる.

Footnote 26: 潮位の観察などから不変点を仮定して,おおよその垂直変動量を求めること,あるいは本州の水準測量と結んで,東京湾中等潮位に対する変動量を求めることはおこなわれているが,厳密な変位量にはならない.

そこで,以下には,水準測量にもとづき,大地震を含む 1 周期間の傾斜変化量を求め,またそれと隆起汀線の傾斜とを比較しよう.

この目的のために,水準測量の回数が多く,一方では隆起汀線がほぼ一様な勾配をもつ地域として,吉良川-安田間をえらんだ.そして安田の水準点 No. 5158 に対して吉良川の水準点 No. 5148 の比高がどのように変化したかを,第 9 図のようにプロットした.この図で,4 つの黒点は水準測量による実 測値である.この 4 点だけでは,南 海地震の時の比高の変化がわからないので,次のように地震直前と地震直後の比高変化の曲線を描き,それより地震時の比高変化を求めることにした.

R. W. Fairbridge[24)] also refers to the data on the deposition rate and says that the Riss-Wurm interglacial period begins about 95,000 years ago. Assuming that the Wurm interglacial period begins about 90,000 years ago, and using an uplift rate of about 2 mm/yr, the old shoreline on the M1 surface should now be about 180 m high[25)]. This matches the reality

ii) Tilt rates near Cape Muroto. The results of leveling surveys cannot be converted to displacements with respect to sea level unless they are linked to tide gauge records. Among several leveling surveys in this area, for the period of 1895 to 1929, the amount of displacement with respect to the average sea level was obtained from the tide gauge record of Komatsujima. Without tide gauges, only the change in relative height between survey points, that is, the change in the inclination, can be used[26)]. In this respect, the same applies to the data by Okada and Nagata. In addition, in the calculation of the uplift rate in the previous section. The value of about 120 cm of uplift near Cape Muroto is based on observations of changes in the tide level at the seashore. The resulting uplift rate is not highly accurate but is a rough guide.

Footnote 26: Potentially, one can determine the invariant point of the tide level record, and obtain the amount of vertical fluctuation with respect to the mean tide level in Tokyo Bay to connect it to leveling of the mainland. Although it has been done, it does not result in a precise displacement.

Then, based on the leveling, the amount of change in slope for one earthquake cycle can be found and compared to the slope of the uplifted shoreline.

For this purpose, the Kira River-Yasuda section was selected as an area where the number of levelling surveys was large and the uplifted shoreline had an almost uniform slope. A plot of the relative height of the point No. 5148 of the Kira River changed with respect to Yasuda's leveling station No. 5158 is shown in Fig. 9. In this figure, the four black points are the actual leveling values. Since the change in the relative height at the time of the Nankai earthquake cannot be known from these four points only, we drew the change in height by fitting curves as a function of time with a sudden shift during the earthquake.

一方,地 震直後の 6 年間には,前 記のように,急な南下りの傾動が室戸岬でおこったことが水準測量によって知られているが,その測量は吉良川-安田間には及んでいない.そこで,この区間でも同じ期間に室戸岬と同じ割合で減衰した南下りの傾変を仮定し, 1947 年 12 月の実測値の点をとおる曲線を描いたのである.この曲線は南海地震の時点で+360 mm を示している.したがって,地震の際に,吉良川と安田の 2 地点間では合計 535mm だけ南上りの傾動をおこなったと推定される.

これに対して,地震の間の南下りの傾動の量は,地震直後の 6 年間に 65mm であり,地震直前のや や変化が大きいと思われる 17 年間に 90mm である.また大地震を含む 1 周期のうち,のこる約 95 年間の慢性的な比高変化は,1895~1929 年間の変化と同じ速さであると考えると,235mm となる.したがって,地震間の約 120 年の南下りの傾動による安田-吉良川間の変位量は合計 390mm となる.

以上の推定にもとづき,南海地震をはさむ約 120 年の大地震 1 周期の間に,安田に対して吉良川が差引き 145mm(地 震時の約 1/4)だけ高くなるような傾動がおこると考える.計算の便宜上,これを年平均速度に直すと,約 1.2mm/年となる.

次に,過去の地質時代にも,この速さで南上りの傾動が続いていたと仮定し,また M1 面の隆起汀線が約 9 万年前に形成されたとすれば,吉良川でのM1 面の旧汀線は安田のそれより約 110m 高いはずである.実際には,吉良川のそれは 175m,安田のそれは 85m で,その差は 90m となり,上の予測値とかなり一致する.

以上, (b)の項でのべた検証にもとづいて,III-1 の項で予想した,M1 面は約 9 万年前の Riss-Wurm 間氷期の高い海水準に関して作られたものであること,および III-2 の 項で仮定した,大地震を 1 周期としておこっているシーソー状の傾動がほぼ一様な速さで繰返しおこってきたことは,ともに確からしくなってきた.そこで,室戸岬付近では,2mm/年の一様な速さで隆起が続いてきたものとして,さらに論をすすめよう.

Leveling shows a rapid southward tilt at Cape Muroto in the six years immediately following the earthquake but the survey does not extend between the Kira River and Yasuda. Therefore, in this section, we attempt to estimate the southward tilt — that decayed at a similar rate as Cape Muroto during the same period — using a curve that passes through the point of the actual measurement value in December 1947. This curve shows +360 mm at the time of the Nankai earthquake. Therefore, during the quake, the total tilt was 535 mm between the two points of the Kira River and Yasuda.

On the other hand, the amount of southward tilt during the quake was 65 mm in the 6 years immediately after the quake, and 90 mm in the 17 years immediately before the quake, where the change seems to be large. In addition, the secular relative height change in a ca. 95-year period that includes a large earthquake is 235 mm. The same rate as the change between 1895 and 1929. Therefore, the total displacement between Yasuda and the Kira River due to the southward tilt of about 120 years between the earthquakes is 390 mm.

Based on the above estimation, the Kira River will be lowered 145 mm relative to Yasuda during one period of the 120-year earthquake cycle. This corresponds to about 1/4 of the opposite direction 535 mm coseismic displacement. For convenience, it corresponds to a relative rate of about 1.2 mm/yr.

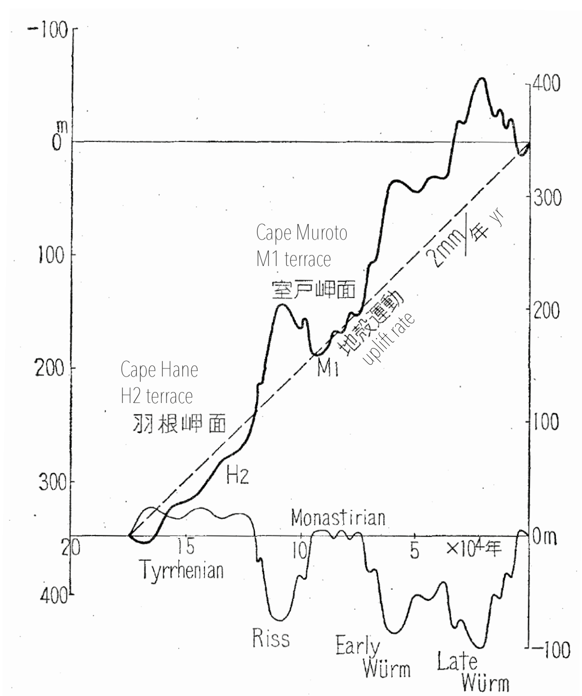
Next, assuming that the southward tilt proceeded at this rate in the past, and that the uplifted shoreline on the M1 surface was formed about 90,000 years ago. The old M1 shoreline at the Kira River side should be about 110 m higher than that of Yasuda. At the Kira River it is 175 m and 90 m lower with 85 m at Yasuda. It is in good agreement with the predicted value.

Based on the verification above, the M1 terrace (Section III-1) was created during the high stand of the Riss-Wurm interglacial period about 90,000 years ago. The seesaw-like tilt that occurred in the first period of the large earthquake (Section III-2) was repeated at almost constant rate. Therefore, it is assumed that the uplift has proceeded at a rate of 2 mm/yr near Cape Muroto.

Japanese regnal calendar 日本暦	年	月	日	western calendar 西暦(年)	interseismic interval 間隔(年)	earthquake magnitude マグニチュード
(天武)	12	10	4	684		8.4
仁和	3	7	30	887	203	8.6
永長	1	11	24	1096	209	8.4
正平	16	6	24	1361	265	8.4
明応	7	8	25	1498	137	8.6
慶長	9	12	16	1605	107	7.9
宝永	4	10	4	1707	102	8.4
安政	1	11	5	1854	147	8.4
昭和	21	12	21	1946	92	8.1

第 1 表 南海道大地震年表(理科年表による)

Table 1 Nankaido Earthquake Chronology (according to the Chronological Science Tables [Japanese reference book])



第 10 図地殻変動と海面変化の推移,および両者を複合した結果
太い実線:地盤の海抜高度の変化
細い実線:海面変化(R. W. Fairbridge, 1961, による)
細い破線:地殻運動の積算値
これら 3 つの量は右側の目盛で示す,左側の目盛は,太い実線を地盤に対する海面の変化と見た時の海面高度を示す目盛である.

Fig. 10: Crustal movement and sea level change, and the result of combining both
Thick solid line: Change in elevation above sea level
Thin solid line: Sea level change (according to R. W. Fairbridge, 1961)
Thin dashed line: Accumulation of crustal displacement
These three quantities are indicated by the scale on the right side, and the scale on the left side indicates sea level when the thick solid line is viewed as the change in sea level with respect to the ground.

III-3 地殻変動と glacial eustasy の superposition による地形発達の解釈

第四紀の海面変化については,最近 R. W. Fairbridge が公表した概説的な論文がある[24].この論文には,なお検討すべき多くの問題点もあるが,彼が提示した海面変化の大勢については,現在までの知識を包括しているものといえよう.そこで,海面変化については, Fairbridge の考えをそのまま用い,これに 2mm/年の一様な隆起が重なった場合をグラフに描いた(第 10 図).この図における太線はこうして得られたもので, Tyrrhenian 期のはじめに海面の高さにあった地点の海抜高度が,時間とともにいかに変化したかを,図示してある(目盛は右側).なお,この太線は,地盤は不動で海面のみが相対的に変化したと考えた時の海面変化のグラフともみることができる.その時には,左側の目盛でよめばよい.

それでは,この合成曲線が示すような海抜高度の,変化をたどってきた海岸にできる地形が,現在の室戸岬付近の地形と合致するかどうかを検討してみよう.

(i) M 面についてすでにのべたことであるが,室戸岬付近の M1 面の旧汀線は,この図からも,実際にも,海抜 190m の高さにある.

また,この図において, M1 面はその形成前に少なくとも 40m 沈水したことが読取れる.地盤の隆起速度が 2mm/年 より小さい高知よりの地域ならば,この沈水量は 40m をこえるはずである.この沈水は,事実として, M1 面の段丘堆積物が,ところによって,厚い埋積谷堆積物になることをよく説明する.

Monastirian 期の段丘が 3~4 段に細分されそうなことはこのグラフから予想されるが, M1, M2, M3 などの面との対応ははっきりのべることができない.また,このグラフは,海抜 50m 内外に, Early Wurm 期と Late Wurm 期との間に作られた段丘が存在する可能性を示している.実際には,室津~行当岬間で,ほぼこの高さに河成の岩石段丘がみられる(第 2 図では M3 面に含ませて表現されている).

III-3 Explanation of geological evolution by crustal deformation and superposition of glacial eustasy

A review paper on Quaternary sea level changes by R. W. Fairbridge[24] presents many challenges but it corresponds to our contemporary understanding on the question. Therefore, we use the sea level curve of Fairbridge relative to the beginning of the Tyrrhenian stage (MIS 5e) as is, and combine it with a uniform uplift of 2 mm/yr to obtain the thick line in Fig. 10. It shows how relative sea-level changed with time (scale is on the right side). The thin line shows reference sea level relative to a fixed ground datum using the scale on the left side of the plot.

Now, let's examine whether the topography formed at the coast that by a changing sea level like the composite curve matches the topography near Cape Muroto.

(i) As already mentioned about the M surface, the old shoreline on the M1 terrace near Cape Muroto is actually at a height of 190 m above sea level, as shown in this figure.

Also, given Figure 10, the M1 surface would have been submerged at least 40 m before its formation. If the rock uplift rate is smaller than 2 mm/yr, the transgression would exceed 40 m depth. This submergence, in fact, explains well that the terrace deposits on the M1 surface, in some cases, become thick buried valley sediments.

It can be expected from this graph that the terraces of the Monastirian period are subdivided into 3 to 4 steps, but the correspondence with the surfaces M1, M2, and M3 is not clear. This graph shows that there may be terraces formed between the Early Wurm period and the Late Wurm period approximatively 50 m above sea level. In fact, between Murotsu and Cape Gyoto. A river terrace can be seen at that height above sea level (In Fig. 2, it is included in the M3 plane).

(ii) L 面についてさらにこのグラフは, Late Wurm 期には海面低下に伴なう河川の下刻,ならびに後氷期の海面上昇に伴なう約 60m の沈水のあったことを示している.しかし,室戸市付近のL面はその証拠に乏しい.もっとも,約 60m の沈水は, Wurm 氷期の低い海面に注ぐ河口付近での値であるから,現在の海岸線よりもずっと沖合の地点でおこったと期待されるものである.したがって,当 時はそれよりも上流にあった現海岸線付近では,このような規模の沈水の痕を残しているとは考えられない.地盤の隆起量が 2mm/年より小さく,後氷期の海面上昇量が 60m より大きいことが予想される高知よりで,しかも大きい河川の河口に当っている安 芸の沖積平野に認められる厚さ 30m 以上の沖積属は,この時期の沈水による堆積物であろう.

また,海岸付近の L 面は,この後氷期海進によって作られたものと考えられる.グラフによれば, L 面の旧汀線は海抜 10m 位の高さにあることになるが,これも事実とほぼ一致する.

(iii) H 面について第 10 図は Tyrrhenian 期のはじめまでさかのぼって描いてあるが,合成曲線が示す Tyrrhenian 期の海岸地形と H 面の地形とは,かなり合致する点がある.まず,グラフでは Tyrrhenian 段丘が 3 つに分かれているが,これと H1, H2 などの面との対応関係はあまりはっきりしない.もともと,グラフのもとになる Tyrrhenian 期の資料も,室戸岬での H 面も不確実な点が多いから,くわしい論議はできないのである.しかし,しいてのべれば,前に記したように, M1, H2 両面の旧汀線の高度関係を示す回帰方程式タり, H2 面の旧汀線高度は,同じ地域の M1 面のそれの約 1.3 倍であることが期待されるから,このグラフの Tyrrhenian 期の最後の小海進が H2 面を形成した可能性がある.そして,そ の高さは,室戸岬に もっとも近いところに残る H2 面である行当岬北方の H2 面の高さ 265m とほぼ一致する.しかし,このグラフには, H2 面形成前の沈水があらわれていない点が,事実と相違する.

(ii) About the L surface. Figure 10 further shows that during the Late Wurm period, sea level dropped and rose again by 60 m during the postglacial period. However, there is little evidence of the L-surface near Muroto City. The ca. 60 m submergence is near the river mouth flowing into the low sea level during the Wurm glacial period. It must have been located far offshore from the existing coastline. Therefore, no evidence of transgression is expected near the current coastline which was upstream of the river mouth at that time. 30 m thick or more marine deposits found in the plain of Aki is probably a deposit caused by transgression during that period because Aki is located at the mouth of a big river and close to Kochi where the rate of rock uplift is less than 2 mm/yr, and the amount of sea level rise in the postglacial period is larger than 60 m.

In addition, it is probable that the L-surface near the shore was created by the transgression during the postglacial period. According to Figure 10, the old shoreline of the L-surface is at a height of about 10 m above sea level. This is also almost the same as in reality.

(iii) Regarding the H surface, Fig. 10 is drawn as far back as the beginning of the Tyrrhenian stage (MIS 5e), but there is a point where the coastal topography of the Tyrrhenian stage and the topography of the H surface shown by the compound curve are in good agreement. The Tyrrhenian terrace is divided into three parts, but the correspondence between these and the surfaces such as H1 and H2 is not very clear. There are many uncertainties about the Tyrrhenian stage — which is the origin of the plot in Figure 10 — and detailed discussions about its link to the H surface are cannot be made. However, as mentioned earlier, the regression line showing the altitude relationship of the old shoreline on both the M1 and H2 surfaces is expected to be about 1.3 times that of the M1 surface in the same area. It is possible that the last small transgression of the Tyrrhenian stage formed the H2 surface. Therefore, this height is almost the same as the 265 m elevation of the H2 surface north of Cape Gyoto, which is the remaining H2 surface closest to Cape Muroto. However, the thick line in Figure 10 differs from the observations in that no submergence is documented before the formation of the H2 surface.

なお,Fairbridge の 海面変化のグラフでは,Tyrrhenian, Monastirian 両期の海面の高さの差は約 20 m であるが, H2, M1 両面の旧汀線高度の関係式は,両期で海面の高さが約 19m ちがっていたことを示しているので,この点でも一致をみるのである.

(iv) 海蝕崖形成期の問題 渡辺光の海岸段丘の地形分析の考え [7]によれば,海蝕崖の形成期は地盤の隆起が非常におそい時期か地盤の静止期であるという.しかし,第 10 図の合成曲線と現実の地形との対応を上記のように考えると,海蝕崖の形成期は地盤の相対的な沈降期(海 進期)と考えなければならない.合 成曲線と現実の地形の対比そのものが,もともと渡辺が見落していた海岸段丘堆積物 の示す沈水現象の説明の必要から出発して到達した結果であるから,上のように考えなければならないのは,むしろ当然である.

それでは,海 蝕崖の後退は海進期と海退期のどちらでおこ りやすいかといえば, W. C. Bradley[28] の研究が示すように,地盤が海面に対して静止している時には,形成される海蝕台の幅は限られたものであり,したがって海蝕崖の後退にも限りがある.したがって,海蝕崖の形成は,海退より海進の時に条件のよいことは明らかであろう. H 面と M 面, M 面と L 面を区別する海蝕崖は,それぞれ Monastirian 海進と後氷期海進によって形成され, M 面や L 面の概形もそれぞれの海進の時にでき.

(v)日本の他の地域の海岸段丘との対比この問題はこの論文の主題ではないので,簡単に記す.対比の目安となるものは,段丘面の開析の程度,海面変化史との関係,段丘堆積物の風化の程度や段丘面上の土壌の性質などであろう.このうち,風化の程度や土壌は段丘によってはっきりちがうとはいい難いので [29],主として前 2 者による対比を考えると, M1 面は関東の下末吉面(S 面)に, H2 面は多摩下位面(T2 面)に対比されるものと考えられる.

Footnote 29: しかし,前述したように, M 面では土壌がうすく,礫の風化も進んでいないのに対して, H 面では礫層の風化が進み,赤色土をのせていることは,対比の目安の一つということもできよう.

In the sea level curve of Fairbridge, the difference in sea level between the Tyrrhenian (MIS 5e) and Monastirian (MIS 5bc) stages is about 20 m. The elevation of the old shorelines on both H2 and M1 surfaces should reflect the sea level height in both periods. Field measurements show an elevation difference of about 19 m. We see a match in this respect as well.

(iv) Problem of sea cliff formation period. According to the idea of topographic analysis of the coastal terraces of Watanabe Hikari[7], the sea cliff formation period happens when the rock uplift is very slow or stationary. However, considering the similarities between the composite curve in Fig. 10 and the topography described above, the sea cliff formation period must be considered as a period of rock subsidence relative to rising sea level. The difference between the compound curve and the actual topography itself results logically from the need to explain the submergence event indicated by the coastal terrace deposits that Watanabe originally overlooked.

Is sea cliff retreat more likely to occur during transgression or regression? When the ground is stationary with respect to sea level, as the study of W. C. Bradley[28] shows, the width of marine platforms is limited and the sea cliff retreat is accordingly limited. It appears that the conditions for sea cliff erosion are good during transgressions. The sea cliffs that distinguish the H and M surfaces and the M and L surfaces are formed by the Monastirian transgression and the post-glacial transgression, respectively. We propose that the rough outline of the M and L surfaces were also created during each transgression, while the finer surface characteristics were created at the time of the subsequent regression.

(v) Comparison with coastal terraces in other areas of Japan. This issue is not the subject of this paper, so we only will briefly describe it. The framework for comparison is the degree of alteration of the marine terrace surface: the history of change, the degree of weathering of terrace deposits, the nature of the soil on the terrace surface, etc. Of these, it is difficult to say that the degree of weathering and soil differs clearly from one terrace to the next[29]. The M1 surface is considered to be comparable to the Shimosueyoshi surface (S surface) in the Kanto region, and the H2 surface is considered to be compared to the Tama lower surface (T2 surface).

Footnote 29: However, as mentioned above, the soil is thin on the M surface and the gravel is not weathered, whereas the gravel layer is weathered on the H surface and covered by red soil, which could be a clue for comparisons.

IV 結論と残された問題点

以上にのべた考察から,まえがきで指摘した問題に対して次の結論が得られた.

(1) 佐湾北東岸においては,現在知られる大地震時の急激な地殻変動と地震間の逆むきの緩慢な変動が,歴史時代のみならず,少なくとも過去十数万年にわたって,ほぼ同じような傾向と速さをもってくりかえされてきた.

(2) 室戸岬付近の 3 段に大別される海岸段丘の地形は,地 殻変動の速さの変化によって生じたものではなく,地殻変動の速さはほぼ一様であったが,第四紀におこった glacial eustasy が地殻変動と複合した結果生じたものと考えられる.この考えは,従来の諸見解よりも,現在知られている第四紀の諸事象をより包括的に取り入れた見解といえるであろう [30].

Footnote 30: この 2 つの結論をうる過程で, M1 面の形成 時代を Riss-Wurm 間氷期(約 9 万 年前), L 面の形成 時代を後氷期の約 5,000 年前と考えたのであるが,この考えは,現在の段階でもっとも probable なものであるとしても,確 実なものというには資料が不足である.今 後,何らかの方法で,これらの面の形成時代の絶対年代を知ることが要請される.
なお,もし地殻変動の速さの推移が判明し,段丘の形成時代の推定を十分行ないうるようになれば,安定地域でよりも,室 戸岬のような隆起地域での方が,海 面変化の研究に都合がよいということができるであろう.

IV Conclusion and Remaining Problems

From the above considerations, the following conclusions were drawn for the problem outlined in the preface.

(1) On the northeastern coast of Tosa Bay, rapid crustal movements during the current major earthquakes and slow reverse movements between earthquakes have occurred not only in historical times but also over the past 100,000 years at least. It has been repeated with similar trends and speeds.

(2) The topography of the marine terraces, which are roughly divided into three levels near Cape Muroto, was not caused by changes in uplift rate, but were created while crustal deformation rates were almost uniform. It is probably the result of a combination of Quaternary glacial eustasy with crustal deformation. It can be said that this idea is a more comprehensive view of the currently known Quaternary events than the conventional views[30].

Footnote 30: In the process of drawing these two conclusions, we considered the M1 plane formation era to be the Riss-Wurm interglacial period (about 90,000 years ago) and the L plane formation era to be about 5,000 years before the post-glacial period. Even if this idea is very probable at the current stage, there is not enough material to say that it is accurate. Future work will require to know their absolute age formation.
If changes in uplift rates can be clarified and the age of terrace formation can be properly estimated, it will be easier to focus on uplifted areas such as Cape Muroto rather than in stable areas to conveniently study sea level changes.

なお,今までに触れることができなかった二三の問題点として,次 のようなものがある.

(1) M1 面の旧汀線高度と現在の地殻変動との関係この関係は第 7 図に示されており,第 4 図からもある程度わかるが,地 震時の急激な変動も,地震間の緩慢な変動も,M1 面の旧汀線高度とは直線釣な関係を示さない.すなわち,室戸岬に近い地域では,M1 面の旧汀線高度と現在の地殻変動量とは直線的な関係を示しているが,高知よりでは,旧汀線高度が低くなるにともない,地殻変動量が急激に小さくなっている.ところが,第 6 図に示すように,地震間の慢性的変動と地震時の急激な変動とは直線釣な関係にあるから,もしこの 2 つの変動の差が積算されて海岸段丘の高さが決定されたとすれば,第 7 図は両者のもっと直線的な関係を示すはずである.しかし,実際にそうなっていないのは,何 故であろうか.

考えられる 1 つ の理由は,ここに示した水準測量の結果は, 1 回の大地震を含むせいぜい 70 年位の間の地殻変動の様子を示すだけであって,まだ大地震 1 周期の間の地殻変動量を与えておらず,将来大地震 1 周期の間の地殻変動量がえられれば,それは M1 面の旧汀線高度ともっと直線的な関係を示すかも知れないということである.こう考えるのは,室戸岬では,地震時の隆起運動の 1/3 回復するのに約 6 年を要したが,高 知での検潮記録によると,ここで は地震時の沈降量 1.2m の 1/3 を回復するのに 100 日くらいしかからなかった [31] という事実が知られているからである.また,河角らは,古い記録を見ても,高知では,大地震の時には沈降するが,次の地震の直前にはほぼ元の高さに回復しており,大地震 1 周期をとると,沈降していないとのべている.そうであるとすれば,大地震 1 周期の間の地殻変変量は M1 面の旧汀線高度ともっと直線的な関係を示す可 能性がある.

There are a few problems that we haven't been able to touch upon until now.

(1) Relationship between the altitude of the old shoreline on the M1 surface and the current uplift rates. This relationship is illustrated in Fig. 7, and as can be partly seen from Fig. 4, neither the rapid movement during the earthquake nor the slow deformation between the earthquakes shows a linear relationship with the elevation of the old shoreline on the M1 plane. That is, in the area near Cape Muroto, the elevation of the paleoshoreline on the M1 surface and the current uplift rate amount show a linear relationship. However, in Kochi, the amount of crustal deformation decreases sharply as the altitude of the old shoreline decreases. As shown in Fig. 6, the interseismic deformation and the sudden coseismic movement have a linear relationship. Therefore, if the difference between these two deformations is added up to determine the height of the coastal hill, Figure 7 should show a more linear relationship between the two, but why isn't that the case?

One possible reason is that the results of the leveling shown here only show the state of crustal movements for at most 70 years including one large earthquake, and only one period of large earthquakes. If the amount of crustal movement during the first period of the next earth earthquake cycle is given without giving the amount of crustal movement between them, it may show a more linear relationship with the altitude of the old shoreline on the M1 plane. The idea is that at Cape Muroto, it took about 6 years to recover 1/3 of the coseismic uplift movement, but according to the tide survey records in Kochi, this is the case. This is because it is known that it took only about 100 days to recover 1/3 of the 1.2 m subsidence during an earthquake according to the record by Kawakaku et al.[31]. Looking at it, in Kochi, it subsides during a large earthquake, but it has recovered to almost the original height just before the next earthquake, and it has not subsided after one period of the large earthquake. If so, the crustal deformation during one period of a major earthquake may show a more linear relationship with the altitude of the old shoreline on the M1 plane.

高知平野の海岸段丘土佐湾北東岸の海岸 段丘が地殻変動と glacial eustasy の複合した結果生じたものであるとすれば,隆 起量の小さい手結付近でも M 面や H 面が海抜 40m 内外以上の高さに分布しているから,高 知平野が著しい沈降地域でない限り,そこにも Monastirian 海進や Tyrrhenian 海 進に対応して形成された海岸段丘の分布する可能性がある.ところが,前項でのべたことからわかるように,高知付近は現在沈降地域であるということはできない [32]から,今までのべてきたこの地域の地殻変動の性質から考えて,高知平野に海岸段丘の分布する可能性は非常に大きい.

Footnote 32: 高知平野に散在する山地やその周縁の山麓の地形は,いわゆる沈降山地の特徴をを示しているが,これは後氷期海進によって沈水したからであって,こ の地域の地盤が現在沈降していることを必ずしも示していないと考える.このような山地と低地の配置を生じた地殻変動は,四 国島の概形を決定した地殻変動と 関連を有するものであり,その時代は本稿で論じた時代よりもさかのぼると予想している.

このような見地から,高 知平野周縁の山麓や平野に散在する山地を短時間調査したが,十分な資料はえられなかった.しかし,これらの山地のまわりには,狭い段丘状の平坦面が様々の高さに点在していることは事実で,今 後の精査が必要である.これらの中には,高 知北方の愛宕山のように,河成堆積物ののる海抜 30m あまりの平坦面もあるが,一 般に堆積物に乏しく,海成層ののる平坦面はまだ発見していない.また,山田から御免にかけてひろがる物 部川の隆起扇状地は,その西南縁で沖積面下に没しており,おそらく M1 面よりは新しく, Wurm 海退期の低海水準において形成されたものであろう.この台地の北縁から国府にかけて,これより少し高い海抜 40m 内 外の台地が見られるが,そ の一部では海成らしい円礫やシルト層がみられ,M1 面に対比される可能性が大きい.その他の段丘状平坦面については取りまとめてのべるほどの資料もない.この問題は従来あまり触れられたことのないものであるから,ここに新しく提起しておきたい.

Marine terraces in the Kochi Plain. If the marine terraces on the northeastern coast of Tosa Bay are the result of a combination of crustal movements and glacial eustasy, it is possible to find marine terraces formed in response to the Monastirian and Tyrrhenian transgressions in the Kochi Plain, unless it is subsiding significantly, because M and H surfaces are distributed at ~40 masl or higher even around Tei where uplift is moderate. Given that crustal deformation in the area (see above) does not indicate ongoing subsidence in the Kochi area[32], therefore, the presence of marine terraces at this location is very likely.

Footnote 32: The topography of the mountains scattered in the Kochi Plain and the foothills around it shows the characteristics of so-called subsidence mountains. However, this is because they were submerged by transgression during the postglacial period, and not because the ground currently subsiding. The crustal movements that resulted in the arrangement of mountains and lowlands like this are related to the crustal movements that determined the sawtooth outline of Shikoku Island whose era is still older than the era discussed in this article, we expect.

From this point of view, we conducted a short survey of the mountains around the Kochi Plains, but we could not obtain sufficient data. Narrow terraced flat surfaces are scattered at various heights, and further investigation is required. Among these sites, there is Mt. Atago in the north of Kochi. As you can see, there is a flat surface about 30 m above sea level on which river deposits are placed, but sediment deposits are generally scarce, and the strath on which the marine layer is placed has not yet been found. The uplifted alluvial fan of the Monobe River, which extends from Yamada to Gomen, is submerged below the offshore surface at the southwestern margin of the river, and is probably younger than the M1 surface, and was formed at low sea level during the Wurm regression. From the northern edge of this plateau to Kokufu, there are plateaus ca. 40m above sea level, partly covered by marine gravel and silt layers similar to the M1 surface. There is not enough data to summarize the other terraced flat surfaces. This problem has not been touched upon in the past and we want to raise it.

(3) 行当岬東側における海岸段丘面の変位すでにのべたように,行当岬の東 側において M1 面の旧汀線高度は東へ約 50m 急に低くなっている(第 4 図).このような高度の急変は,M1 面形成後の変位を示すものであるが,それが断層運動によるか,あるいは撓 曲運動によるかはわからない.第 4 図らは,行当岬より北東にのびる線を境として 2 地塊に分れ,いずれもほぼ同じような北西への傾動をしているようにみえる.しかし,行 当岬の東側から室津.にかけての地域では,海岸段丘面の発達が悪く,H 面のみならず,M1 面についても,旧汀線高度をより密に測定することが困難であるから,現在のところ,この問題についての解答をえていない.この地 域における断層の有無など,今後になすべき調査ものこされている.

この研究を行うにあたり,国土地理院の羽田野誠一氏より水準測量の資料の入手について格別の御配慮を頂いた.この機会に深く感謝する次第である.(1964 年 8 月 6 日受理)

(3) Displacement of the marine terrace on the east side of Cape Gyoto. As already mentioned, the altitude of the M1 paleo shoreline on the east side of Cape Gyoto is drops by about 50 m to the east (Fig. 4). The sudden change in the M1 surface indicates displacement after its formation, but it is not clear whether it is due to fault or flexural motion. Northeast of Cape Gyoto, M1 surface is divided into two blocks with a NE-direction line at Cape Gyoto as boundary, and both blocks seem to have almost the same inclination to the northwest. However, in the area east of Cape Gyoto toward Murotsu, the development of the marine terrace surface is difficult to constrain because it is challenging to measure the old shoreline altitude more precisely not only on the H plane but also on the M1 plane. Future investigations should be done on the presence or absence of faults in the area.

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Original English summary

On the southwest coast of Muroto Promontory, the southeastern tip of Shikoku, develop very magnificent coastal terraces, gradually descending toward northwest (Figs. 1 & 2). while on the east coast featureless steep scarps stretch northwards and, then, pass into ria-coast, submerged into the Kui Strait. The coastal terraces in this region are classified into two levels, which are called Muroto-misaki [T.N. Cape Muroto] Terraces (M) and Hane-saki Terraces (H) in the ascending order. Terraces on each level are separated further into two or three subordinate levels (Fig. 3).

Most of these terrace surfaces are abraded flat rocky ones, usually covered by thin beach gravel beds. At some places, especially at mouths of comparatively large rivers in the northwestern part of the coast, however, terrace surfaces on both levels are composed of marine and fluvial gravel beds more than 20 meters in thickness. Narrow abraded lowlands lower than 15 meters above sea level extend along the coast and merge in alluvial plains of comparatively large rivers, which consist of gravel and sand layers thicker than 30 meters. From these facts is it inferred that the coastal region has been deeply dissected and then relatively submerged three times in process of formation of these coastal terraces.

On the south coast of Shikoku, it has been elucidated that severe earthquakes originating below the oceanic floors have occurred at an interval of about 120 years in the historic time and accompanied acute upheaval of the promontory, which amounts have diminished northwestwards, while in pre-seismic periods chronic subsidence increasing toward the promontory has been detected by precise levellings. In consequence of such pre- and post-seismic land deformations, Muroto Promontory has been upheaved, since amounts of acute upheaval accompanied by earthquakes have exceeded those of pre-seismic chronic subsidence.

Terrace surfaces on each level are generally flat and smooth, but are interrupted by many minor scarps lower than 5 meters. A. Watanabe (1961) explained, as the authors agree, that such characteristic features of terrace surfaces had been modelled in succession of intermittent small upheavals as was accompanied by the great earthquake in 1946. And further, heights of raised beaches preserved on coastal terraces have a positive and negative correlation respectively with amount of post-seismic acute and pre-seismic chronic displacements of their neighbouring bench marks, as shown in Figs. 4 and 7. It is considered, therefore, that upheaval of coastal terraces has been mainly influenced by land deformation as have been accompanied by great earthquakes.

It is proper to put a question why submergence has taken place three times in process of formation of coastal terraces on the coast where upheaval has predominated. The Japanese Islands have suffered from remarkable crustal movements throughout the Holocene, but velocity of upheaval of coastal regions has been generally far less than that of the post-Glacial eustatic rise of sea level. Accordingly, even actively upheaved coasts may have been submerged in consequence of the post-Glacial eustatic rise of sea level. From this point of view, it should be recognized that the physiographic development of Muroto Promontory has been achieved in composite process of crustal movement and eustatic change of sea level.

Judging from their physiographic development, it is reasonable to assume that Muroto-misaki Terraces were formed at a higher sea level in the hiss-Worm Interglacial, which commenced about 90,000 years B. P. (H. E. Suess, 1956; R. W. Fairbridge, 1961). Using results of precise levellings and geomorphic observations of land deformation accompanied by the most recent great earthquake in 1946 on this coast, it is estimated that amounts of acute upheaval by great earthquakes exceed about 25 cm those of chronic subsidence during the period of about 120 years between two consecutive great earthquakes on the coast of Muroto Promontory. In other words, the mean velocity of upheaval in the region is about 2 mm per year. If the region has been upheaved at this rate since the beginning of the Riss-Worm Interglacial, coastal terraces formed at the time should be expected to be about 180 meters high above sea level at present. This expected height of coastal terraces coincides fairly well with the height of Muroto-misaki Terraces in the region.

In general, however, results of precise levellings give us only data on change of relative heights between two bench marks and absolute amounts of vertical displacement relative to sea level have not always been measured in levellings. On the other hand, since amounts of acute land deformation accompanied by earth quakes have been obtained mainly by geomorphic methods, these are less precise than those of chronic changes measured by levellings. It is, therefore, more appropriate to compare gradients of raised beaches on coastal terraces with change of relative heights between bench marks, surveyed by precise levellings.

The mode of change of relative heights between Bench Marks No. 5148 at the Kira River and No. 5158 at Yasuda is shown in Fig. 9, using results of levellings executed three times in the pre-seismic period and frequently carried out immediately after the great earthquake in 1946. In this diagram relative upheaval of Bench Marks No. 5148 to No. 5158 is calculated as 145 mm during the period of about 120 years between two consecutive great earthquakes. That

is to say, the cast at Kiragawa is upheaved by 1.2 mm per year higher than at Yasuda as a composite result of pre-seismic chronic subsidence and post-seismic acute upheaval. If land tilting toward northwest has occurred at this rate since the beginning of the Riss-Wurm Interglacial, the height of Muroto-misaki Terraces at the Kira River is expected to be about 110 meters heigher than at Yasuda. In fact, heights of Muroto-misaki Terraces are 175 meters at the Kira River and 85 meters at Yasuda, and their difference fairly well coincides with the above estimated amount. It is safely concluded, therefore, that crustal movement, such as post-seismic acute upheaval and pre-seismic chronic subsidence occuring throughout the historic time, has uniformly succeeded since the beginning of the Riss-Würm Interglacial on the southeast coast of Shikoku.

According to this conclusion, the coastal development of Muroto Promontory deduced as a result of composite process of crustal upheaval at the rate of 2mm/year and the eustatic change of sea level in the Quaternary as was presented by R. W. Fairbridge (1961) is diagrammatically shown in Fig. 10. This theoretical diagram explains the physiographic development of this coast very well and it is assumed that Hanesaki Terraces may have been formed at a higher sea level in the later stage of Tyrrhenian. Although it has been accepted that the formation of coastal terraces on this coast has been resulted from changing intensity of crustal upheaval, the authors infer that the differentiation of coastal terraces was caused by the eustatic change of sea level in the late Quaternary, while crustal movement has been in a uniform process of reiteration of minor acute upheavals and chronic subsidence throughout the time.