On the Geotectonic Development of Taiwan (Formosa)

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In a series of the Ryukyu and northern festoon arcs in the northwestern side of the Pacific basin, virgation is undeveloped, while it is typically represented in another series comprising the Philippines and southern islands. Thus the two series indicate a remarkable contrast in the geologic structure of eastern Asia. As noted in my "Sakawa Cycle" (KOBAYASHI, 1941), Taiwan (Formosa), 25,570 sq. km., attracts special attention as their link. As I had the good fortune to be able to see the general picture of Taiwan's geology on the return trip from the VIII Pacific Science Congress held in the Philippines in 1953, I took a pleasure of discussing the tectonic development of the island.

I wish to express my most cordial thanks to Prof. Ting Ying H. MA of the National University of Taiwan, Messrs. L. S. CHANG (formerly Reikyoku CHOH), T. P. YEN (Soha GAN) and T. L. HSU of the geological survey of Taiwan for their guidance during my excursions, and to the survey and other Chinese government offices, as well as mining and other companies for the facilities provided during my visit.

Although some geological observations have been reported since the middle of last century, in the beginning they were fragmentary and Taiwan long remained as a terra incognita. Taiwan's geology was, however, immensely clarified in the half century from 1895 to 1945. During this period the geological sheet-maps of the northern part (scale 1:50,000 and in part 1:1,000,000) and the geological survey of the Neogene oil fields were completed. In addition, many valuable contributions were made, both in the basic and applied aspects. Knowledge of Taiwan was further advanced in the last quarter of a century by the works of many Chinese geologists besides several foreign geologists (B. ELISHWITZ, W. HASHIMOTO, A. HEIM, T. KIMURA, K. KONISHI, T. OINOMIKADO, A. SCHREIBER, L. STACH), notably in the fields of metamorphic and volcanic rocks (YEN), Tertiary biostratigraphy (CHANG, HUANG), Quarternary geology (MA, LIN), submarine geology (EMERY), geotectonics (BIG, HO) and petroleum prospecting (MENG). Among recent discoveries more important for stratigraphy are Permian and Cretaceous fossils in the metamorphosed complex (YEN), Mesozoic fossils in bore cores from drillings in the western coastal plain (LIN, MATSUMOTO et al.) and an Oligocene fauna in the central range (CHANG).

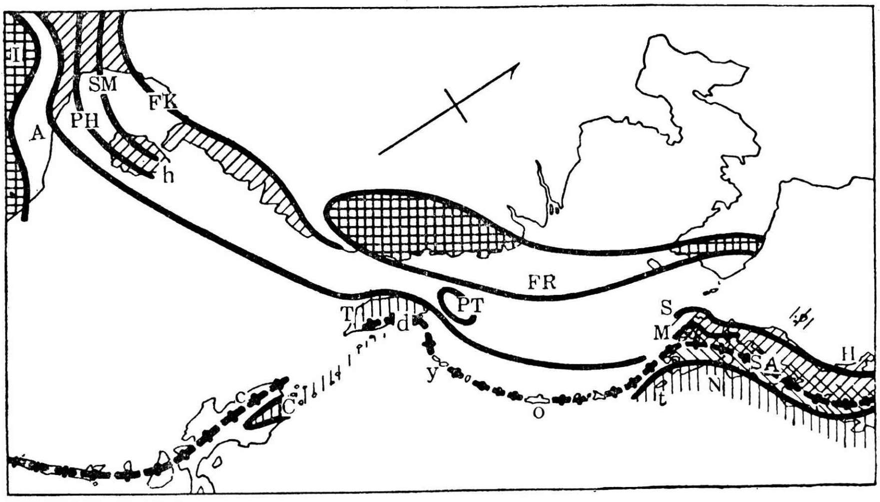


Fig. 1. Tectonic Position of Taiwan in Eastern Asia.

FR. Fukien-Reinan (Yongnam) massif
FK. Fansipan-Kuantung metamorphosed axis
SM. Song Ma arc with R. Noire nappe
PH. P'ou Huat arc
A. Annam zone
I. Indoshinian massif
PT. Pre-Taiwan dome
H. Hida gneiss zone of Akiyoshi folded mountains
S. Sangun principal metamorphic zone of Akiyoshi folded mountains

M. Motoyama auxilliary metamorphic zone of Akiyoshi folded mountains
SA. Axis of Sakawa folded mountains
T. Taiwan folded zone
C. Cagayan synclinorium
N. Nakamura folded mountains
t. Tanegashima
o. Okinawa-jima
y. Yaeyama insular group
d. Dainano metamorphic zone
c. Cordillera Central
h. Hainan island

Little, however, had been mentioned of the tectonic development of the island and its relation to the neighbouring areas before my synthetic paper (KOBAYASHI, 1956). The geological sketch is drawn here in further detail on the basis of new facts gathered since then. This synthesis is of course based on the mass of data accumulated during this time. The interpretation and coordination of these facts in the history of the development and the tectonic lineament of Taiwan in the geology of eastern Asia is based on my own judgement. In my opinion the metamorphosed Permian and older rocks belong to the axial zone of the Cretaceous Sakawa folded mountains. The Taiwan subgeosyncline was brought forth on the continental side of this axis. The Triassic Akiyoshi folded mountains further beyond were its foreland (see Fig. 1).

Neither angular discordance nor orogenic sediment is found in the Tertiary sequence except for the Koshun conglomerate (s. l.) in South Taiwan and the Pinanshan conglomerate in East Taiwan. Thus I was not convinced of the Oligocene or middle Tertiary orogeny or related metamorphism as emphasized by

HAYASAKA et al. (1947), YUAN (1953) and some other geologists. It is my opinion that the middle Tertiary event or the so-called Puli movement described by CHANG (1960) was not complicate foldings and thrustings but the westerly shifting of the sinking axis, caused by the upheaval of the embryonic geanticline of the Urai-Tananao zone and some related undulations. The shifting commenced with the so-called Puli movement described by CHANG (1960). BIQ (1956) distinguished the Neogene sequence of the West Taiwan zone into lower and middle Miocene suite and upper Miocene and Pliocene suite by subsequent shifting. Because there is no sharp boundary between the metamorphosed Palaeogene and nonmetamorphosed Neogene, metamorphism commenced probably in the middle Tertiary and is thought to have continued by the Plio-Pleistocene Penglai paroxysmal phase of the Taiwan orogeny.

The gentle foldings or warpings were repeated in the geosyncline. The mountain structure constructed at length by the orogeny consists of the Tananao (Dainano), Urai and West Taiwan zones in addition to the Hualienhsi (Kwarenkei) rift valley and Tatung (Daito) coastal range. The former three zones which are separated from one another by tectonic lines, indicate the western wing of the Taiwan anticlinorium. On the two sides of the Tatung coastal range there are still greater rupture lines with which its eastern wing was destroyed (see Fig. 2).

Like the south bend of the Japanese arc in Kyushu, the Ryukyu arc is abruptly bent toward North Taiwan. At this back bending the Taiwan geosyncline was strongly compressed resulting in thrustings that were repeated against the foreland and a typical imbrication was produced. There the Kiirun (Chilung) imbricated subzone and the Toen (Taoyuan) undulated subzone can clearly be distinguished in the west Taiwan zone. Subsequently, Taiwan was detached from the Ryukyu islands and performed geanticlinal upheaval by itself, causing dislocations among the tectonic zones. Because the geanticline was asymmetrical, the backbone range runs close to the eastern coast, Yüshan, 3,950 m high in the Urai zone being the highest.

The Penghutao isles to the west of Taiwan are ruins of a Pleistocene basaltic mesa in the Akiyoshi terrain. The eastern chain of dependent isles lies on the same submarine ridge on which Batan, Babuyan and other isles of the Philippines are located and which is a northern projectile from the Tertiary synclinorium of the Cagayan valley in Luzon. It is separated from the Tatung coastal range by a deep submarine trench.

Recently, I demonstrated that the Triassic Akiyoshi folded mountains on the inner side of Japan extend into Tonkin, North Viet-Nam through Hainan island (KOBAYASHI, 1951). Prior to this I concluded that the Cretaceous Sakawa folded mountains in the median part of Japan are traceable to the axial zone of the Ryukyu islands (KOBAYASHI, 1941). Permian fusulinids were first reported by HANZAWA (1935) from a limestone in the Motobu peninsula of Okinawa-jima. In the main part of the island the Palaeozoic formation is represented mainly by shale and sandstone, and is partly metamorphosed into chlorite schist and graphite

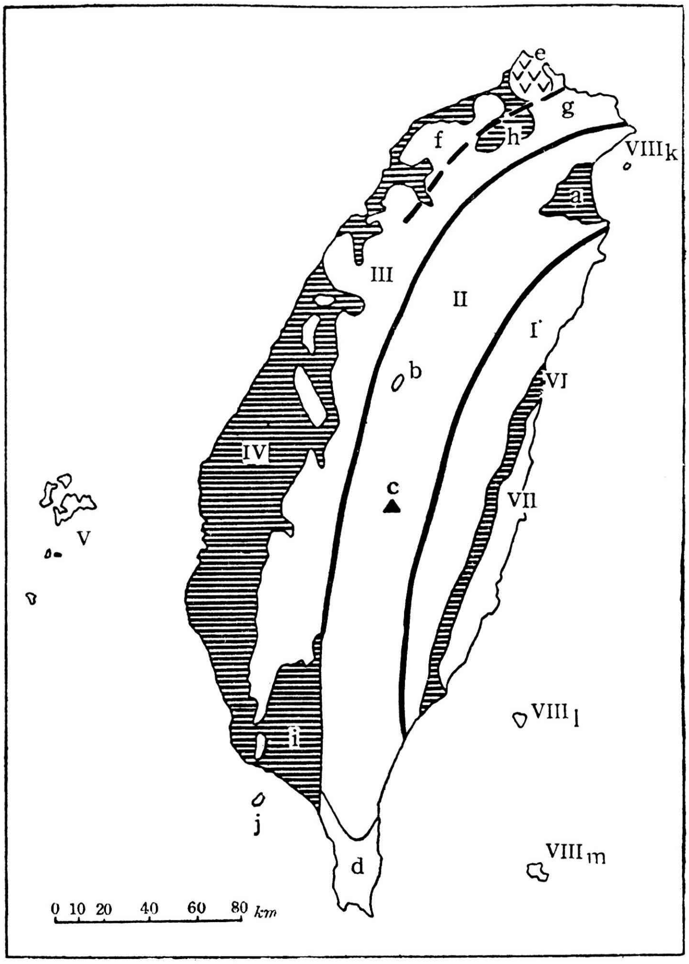


Fig. 2. Teconotic Division of Taiwan.

I. Dainano (Tananao) zone
II. Urai (Wulai) zone
  a. Ilan (Giran) plain
  b. Puli (Hori) basin
  c. Yüshan (Mt. Niitaka)
  d. Southernmost Neogene
III. West Taiwan zone
  e. Taitun (Daiton) volcanic group
  f. Taoyuan (Toen) undulated subzone
  g. Chilung (Kiirun) imbricated subzone
  h. Taipei (Taihoku) basin
  i. Pingtung (Heito) plain
  j. Liukiuyu (Ryukyusho)
IV. Western coastal plain
V. Penghutao (Boko island)
VI. Hualienkang (Kwarenkei) rift valley
VII. Taitung (Daito) coastal range
VIII. Eastern dependent islands
  k. Kueishantao (Kizanto)
  l. Lutao (Kwashoto)
  m. Lanhsu (Kotosho)

schist. In addition, however, there are limestone lenses, Radiolarian chert layers and conglomerate beds containing exotic granitic rocks like the Permian Usuginu conglomerate in North Honshu, Japan. The Palaeozoic formation is intruded by diabase or granite in Tokunoshima and Ishigaki-jima. Recently, ISHIBASHI (1969) discovered Carnic ammonites and *Halobiae* of the *styriaca* (KOBAYASHI and ISHIBASHI, 1970) and other groups in the Triassic Nakijin formation of the peninsula which is composed of pelagic sediments rich in limestone and basaltic lava. KONISHI (1963) on the other hand found calcareous algae, corals and stromatoporoids in the polymictic conglomerate of Attsu in the Kayo formation. These fossils are allied to the Torinosu biota of the Shimanto terrain in West Japan whose age ranges from late Jurassic to early Cretaceous. In the Ishigaki and Kohama isles in the Yaeyama group there are phyllites and crystalline schists which indicate the axial core of the Sakawa folded mountains.

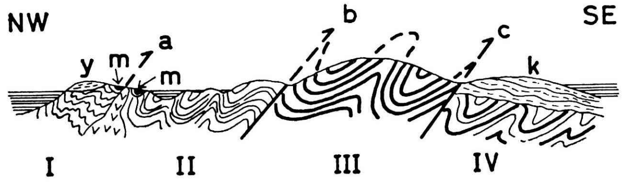


Fig. 3. Systematic Cross Section of the Ryukyu Islands (After KONISHI, 1963, simplified).

a. Omoto tectonic line
b. Hedo thrust
c. Tengan fault
I. Ishigaki belt (Palaeozoic Tumuru metamorphosed formation)
II. Motobu belt (Palaeozoic Fusaki, Yonami and Motobu formations, metamorphosed in part)
III. Kunigami belt (Mesozoic Nago and Kayo formations)
IV. Shimajiri belt (Palaeogene Kunigami formation)
m. Eocene Miyara formation
y. Miocene Nasoko and Yaeyama formations
k. Neogene Shimajiri and Kukinaga formations

Ryukyu islands	West Japan
Ishigaki belt	Sambagawa (or Nagatoro) terrain
Omoto tectonic line	Mikabu line
Motobu belt	Chichibu terrain
Hedo thrust	Butsuzo line
Kunigami belt	Shimanto terrain
Tengan fault	Nobeoka-Shiozan line
Shimajiri-Kumage belt	Nakamura (or south Shimanto) terrain

In Tanegashima in the north there is the strongly folded Palaeogene Kumage shale and sandstone formation, on which lies the Neogene Kukinaga sandstone and conglomerate formation containing *Vicarya callosa*. Therefore the Kumage, combined with the folded pre-Miocene Nakamura group in South Kyushu, Shikoku and the areas further to the east represents the middle Tertiary Nakamura folded mountains. KONISHI (1965) classified the pre-Miocene complex of the Ryukyu arc into four belts with three tectonic lines and showed their parallelism with the structure of West Japan from the continental to the other side as shown in the preceding tabel.

Combined with the discovery of Permian fossils it became evident that the metamorphosed Tananao formation indicates the extension of the Ryukyu axis, i.e., the Sakawa axis. There are three distinct belts in the Tananao metamorphosed zone, namely, (1) a belt of sericite-chlorite schist and chlorite schist, (2) a thick crystalline limestone belt and (3) a belt of chlorite schist and graphite schist enumerated from the east. In the third belt there are, in addition, quartz schist, quartzite and limestone lenses in the last of which YEN discovered Permian schwagerinids and *Waagenophyllum* which were determined, respectively, by THOMPSON and MA. These metamorphic rocks are intruded by diabase and gabbro in some places and partly altered into gneiss by injection of granitic magma. Like the metamorphic group in the Sakawa axis of Japan, Kieslager of Besshi type is imbedded in the Tananao group.

The schists and granitic rocks are discordantly overlain by the basal conglomerate of the Pihou formation. Its Upper Cretaceous age is determined by MA's study on hexacorals which were discovered by YEN in a thin limestone lens. This formation is overlain unconformably by the Suo (Suao) formation with a conglomerate at its base, which is composed mostly of black phyllitic clayslate and quartzose sandstone, and the calcareous layers above it yield Eocene foraminifera. YEN proposed the Nanao and Taiping movement, respectively, for the deformation before and after the Pihou sedimentation.

While the Neogene is extensive in the west Taiwan zone, the Urai zone is mostly occupied by Palaeogene formations. Clayslate and shale are leading components of the latter which can be divided into three parts with Yonryo sandstone in the middle. Eocene fossils have long been known to occur at some places. According to CHANG (1954) the Yuhangian foraminifers from the upper or Suichoryu division are Oligocene.

In North Taiwan four coal measures are intercalated in the formations from upper Oligocene to Miocene. They are inserted within neritic sediments, suggesting four minor cycles of sedimentation due to pulses of embryonic folding. There were some volcanic eruptions within the Tertiary geosyncline which were fairly strong in North Taiwan in the Miocene, as indicated by basalt flows, tuffs and agglomerates of Kokan (Kungkuan) on the lower coal measures (see Fig. 4).

The occurrence of the lowest coal measures of Aoti are restricted to the most northeastern part, while the lower coal measures are more extensive in North Taiwan. The middle coal measures are traceable as far south as Sinchu and Chunan and only the upper ones are distributed farther south to Alishan. Reciprocally to such a southern advance of coal measures, limestone lenses show a tendency to retreat. More precisely, Miocene *Lepidocyclina-Miogypsina* limestone occurs in

The Stratigraphic Sequence of Taiwan

Alluvium Holocene	Raised beach sand, raised coral reef	
	Lower terrace deposits, Peipin formation	
Diluvium Pleistocene	Lower coral reef limestone, Taoyuan (Toen) formation	
	Middle coral reef limestone, Higher river terrace deposits, Tainan formation	
	Lateritic gravel beds	
	Higher coral reef limestone, Tananwan formation	
	Kaenzan (Huoyenshan) conglomerate facies	Tokasan (Toukeshan) formation
	Kozan (Hsiangshan) sandstone facies	
Pliocene	Takuran (Chuolan) formation, 200 m	Miaoli (Byoritsu) group
	Kinsui (Chinshuei) shale, 450 m	
Upper Miocene	Tawo (Taika) siltstone, 750 m	Sankyo (Sanhsia) group
	Shihliufeng (Jurokufun) shale, 100 m	
	Kantosan (Taiho) sandstone, 450 m	
	Wuti (Nansho) upper coal measure, 1000 m	
Burdigarian	Nanko (Nankang) formation, 600 m	
	Sogo (Tsouhe) formation, 300 m	
Aquitanian	Shihti (Shikyakutei) middle coal measures, 450 m	
	Tairyo (Taliao) formation, 400 m	
	Kokan (Kungkuan) tuff, 150 m	
	Mokusan (Mushan) lower coal measures, 500 m	
	Wuchihshan (Seitan) formation, 1000 m	
Oligocene	Coal measures of Aoti, 600 m	
	Suichoryu (Shueichangliu) formation, 2000 m	
Eocene	Yonryo (Szuleng) sandstone, 500 m	
	Nishimura (Hsitsun) formation, 1000 m	
Cretaceous-Palaeozoic	Pihou formation	Buried Cretaceous of Peikang
	Dainano (Tananao) metamorphosed complex	

Average thickness is shown in meter.
Straight line: conformity.
Wavy line: unconformity.
Broken line: stratigraphic relation indeterminable.

North Taiwan (Taipei and Sinchu) and Pliocene *Gypsina* limestone in Central and South Taiwan (Tainan and Kaohsiung).

Alternations between shale and sandstone are conspicuously well developed in the Neogene formation. Because staurolite, garnet, purple zircon, monazite and several other heavy minerals in the sediments are exotic for Taiwan, the Fukien massif was suggested by ICHIMURA (1940) for their provenance. It may be, however, better elucidated if a pre-Taiwan dome is assumed in the foreland or in the Akiyoshi axial zone which must have been exposed before the sediments of the Yangtze and other rivers levelled the basement relief of the China Sea. This is because high grade minerals like staurolite are known to exist in the Hida gneiss group in Japan which belongs to the Akiyoshi metamorphic rocks. Furthermore, in this kind of folded mountains it is a tendency for the foreland to become warped by embryonic folding, as, for example, in the Ozark dome in front of the Ouachita mountains, and the Nashville, Cincinnati and Adirondack domes in front of the three arcs of the Appalachian mountains. The supposed dome must have been located to the northern part of Taiwan because a similar mineral assemblage is found also in the Miocene coal measures in the Yaeyama group.

Glauconitic sandstone is distributed in various Tertiary horizons and becomes more common upward, but is totally absent in the Suichoryu and older formations. It is an authigenic product agitated by a shallow sea. Together with foraminiferous or coralline limestones and false-bedded sandstone it suggests a shallow sea for the Neogene geosyncline. The Kinsui (Chinshuei) shale extensive in the lower part of the Pliocene merges with the Takuran (Chuolan) alternation in which sandstone exceeds shale. It becomes thicker in the south near Tainan where the thickness of the alternation measures 2,500 m. The retreat of the sea toward the south is shown by the distribution of *Ostrea* banks.

Thus there is no orogenic sediment in the above-mentioned Tertiary sequence, although some conglomeratic sandstone containing small pebbles are found in the Neogene formation. As is discussed later, the Koshun conglomerate (s. l.) in the southernmost part of the Urai zone is an exception. No clear-cut clinounconformity has as yet been found in the Tertiary sequence of Taiwan.

The Plio-Pleistocene Tokasan (Toukeshan) formation which is dated by a mammalian fauna, is a typical synorogenic sediment. It is generally conformable with the Pliocene, though local or minor erosion-unconformity is seen in rare instances. It consists of Kozan (Hsiangshan) sandstone facies and Kaenzan (Huoyenshan) conglomerate (Shokkozan conglomerate) facies where the former is mostly higher and the latter lower, but the two easily merge laterally or interfinger with each other.

The Kozan facies is chiefly composed of fine muddy silt or sand beside intercalations of clay and gravels; it often contains limonite and false-bedding is common. A copious neritic fauna comprising echinoids and molluscan shells is known in North Taiwan.

Though sandstone wedges and lenses are common in the other facies, con-

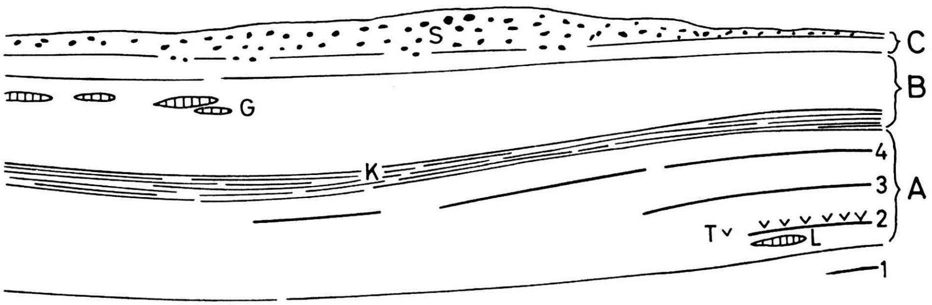


Fig. 4. Diagramatic meridional section showing the lateral change of facies and thickness of the geosynclinal sediments in the west Taiwan zone from the north (right) to the south (left).

C. Plio-Pleistocene
B. Pliocene
A. Miocene
S. Kaenzan conglomeratic facies
K. Kinsui shale
T. Kokan tuff
G. *Gypsina* limestone
L. *Lepidocyclina* limestone
4. Upper coal measures
3. Middle coal measures
2. Lower coal measures
1. Lowest coal measures

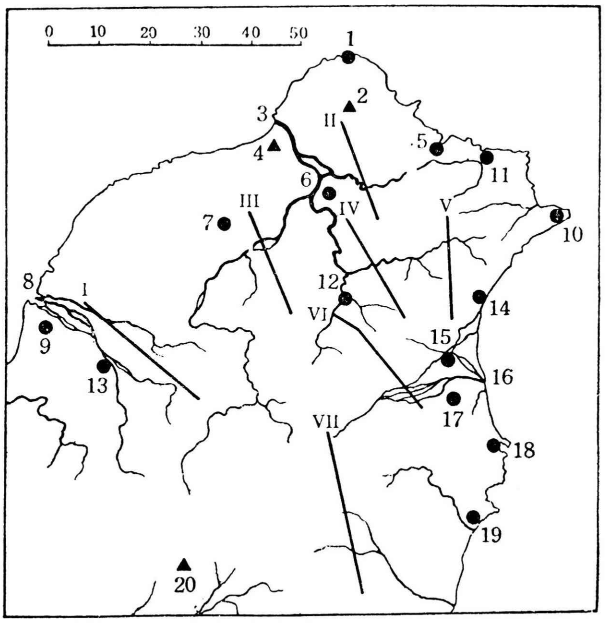
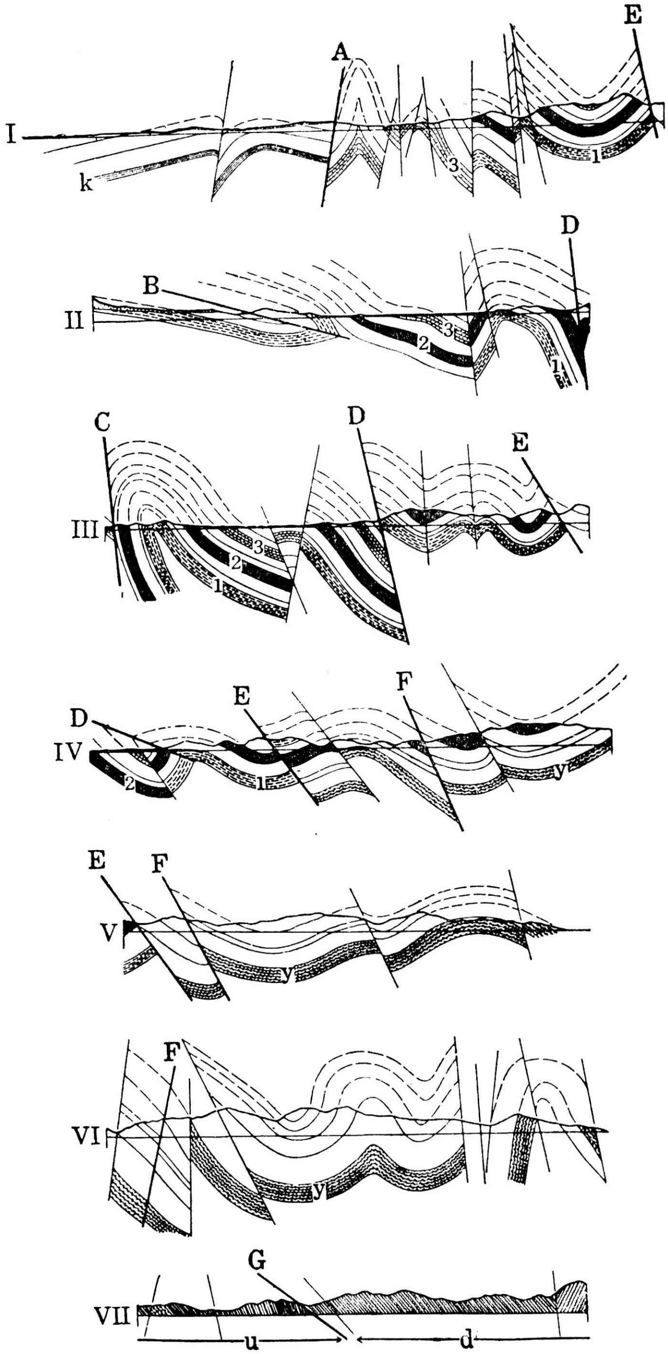


Fig. 5. Index map of the profiles through North Taiwan.

1. Fukueicho (Fukikaku)
2. Tatunshan (Daitonsan)
3. Tanshueiho (Tansuigawa)
4. Kuanyinshan (Kannonsan)
5. Chilung (Kiirun)
6. Taipei (Taihoku)
7. Taoyuan (Toen)
8. Fengshanchi (Hozankei)
9. Hsinchu (Shinchiku)
10. Santiaochio (Sanshokaku)
11. Juifang (Zuiho)
12. Wulai (Urai)
13. Chutung (Chikuto)
14. Touwei (Toi)
15. Ilan (Giran)
16. Choshueichi (Dakusuikei)
17. Lutang (Lato)
18. Suao (Suo)
19. Tananao (Dainano)
20. Tzukaoshan (Mt. Tsugitaka)



I–V. From the sheet maps of Chikuto, Taihoku, Toen, Shinten and Toi by Y. Ichikawa (1930–34).
VI. From Giran sheet map by M. Usami 1936
VII. From Dainano sheet map by M. Ogasawara, 1933; scale different from the precedings
A. Chikuto (Chutung) fault
B. Kankyaku (Chienchiao) fault
C. Shinoso (Hsinchuang) fault
D. Shinten (Hsintien) fault
E. Kushaku (Chuche) fault
F. Kinkwaryo (Chinhualiao) fault
G. Sanseizan (Sanhsingshan) fault
k. Kinsui shale
3. Upper coal measures
2. Middle coal measures
1. Lower coal measures
y. Yonryo sandstone
u in VII. Urai zone
d in VII. Dainano zone

Fig. 6. Profiles through North Taiwan.

glomerate is its principal member. Hence the name, Kaenzan conglomerate. Occasionally drift wood, and *Unio, Corbicula* and other shells are contained therein. Large boulders attain a maximum diameter of over 1 meter, but most of the gravel range in size from a man's fist to a man's head and are well rounded. Its thickness exceeds 1,000 m near Taichun in Central Taiwan, but is only 20 m minimum in North Taiwan.

It is reasonable to consider that the Kaenzan conglomerate is the sediments of deltas and alluvial fans on the west side of the backbone range at the time of its upheaval, because it is thick in Central Taiwan where the range was highest and because its material was mostly derived from the Urai zone. Because the Tokazan formation is folded to some extent, it is certain that the crustal disturbance was violent until the end of the Kaenzan age. Lin (1963) distinguished 7 ages in the Quaternary period of Taiwan and 7 phases in his Tungning orogenic cycle of the period, but, I think, these phases of movements would be metaorogenic episodes complicated by eustatic changes except for the Penglai phase which was paroxysmal for the Taiwan orogeny.

As shown in a series of profiles through North Taiwan, the geologic structure from the Tananao zone to the west Taiwan zone is a grand anticlinorium with the Sakawa metamorphic rocks at its core. The metamorphism becomes lessened distally (see Figs. 5 and 6).

Much cannot as yet be mentioned of the structure of the Tananao zone, but it is known that an overturned anticline near the western margin thrusts itself upon the Urai zone along the Sanseizan (Sanhsingshan) tectonic line. In the Urai zone, about 30 km in breadth, foldings and thrustings are repeated, the folded axes or thrust planes being inclined to the southeast in different degrees. The most important key bed is the Yonryo sandstone which shows the general tendency for the folds to be more compressed on the eastern side where the folded axis or thrust plane is subvertical. On the west side on the contrary the folding is more gentle, but the thrusts are more low angled.

The Kushaku (Chuche) thrust draws the boundary between the Urai and west Taiwan zones, but the degree of its displacement is not much different from the others in the Urai zone. In the Kiirun (Chilung) subzone, however, the Miocene is extensive and strongly compressed in form of imbrication; in the Toen (Tungyuan) subzone on the other hand the Pliocene extensive and gently folded. Their boundary is sharply demarcated by a low angle thrust on the north side of the Taipei basin and a few Klippen are found in its northeastern extension. The gentle undulation of the Toen subzone suggests its being the frontal part of the foreland.

Near Chutung, however, the boundary fault is normal and its downthrow on the northwest side. Because the embryonic folding in the Kiirun subzone was composed of brachyanticlines and brachysynclines arranged somewhat alternately in checker pattern, their end products are arcuate thrusts in a similar pattern. Their planes are inclined in different degrees between the median and lateral parts of each arc; the breadth of the thrusting sheets is changeable. The imbrication is cut by strike faults as well as diagonal or rectangular ones. The latter is mostly reverse but the former normal. These fault systems suggest that the folding and thrusting of the geosynclinal sediments gradually developed into a compressive block movement of the already imbricated terrain in which the basement blocks probably played a role. Later, however, a tension movement took place and the triangular Taipei basin was produced.

The two subzones are distinctly separated by a boundary thrust in North Taiwan where the West Taiwan zone is sharply bent, but in Central and South Taiwan the two subzones are inseparable because the imbricated subzone merges with the zone of open folds with subvertical axes. MENG (1965) is of opinion that the primary geologic structure of North Taiwan was secondarily modified by lateral movements and gravitational glidings in the latter part of the orogeny.

In the foreland geology the Chinese Petroleum Corporation drills PK–2 and PK–3 near Peikang on the west coast the logs of which reached older rocks to the depths of 1.462 m and 1.962 m respectively, are extraordinarily interesting. The older rocks are acidic tuff and purple shales in the upper 27 to 53 m. The middle 120 m or less is mainly composed of shale and sandstone and yields Albian-Aptian marine pelecypods and a few ammonites in upper horizons and Neocomian brackish pelecypods in lower horizons. The lower part consists of folded basement rocks of unknown age. The unconformity below the basal conglomerate of the Lower Cretaceous formation indicates the Wealden Oga phase of deformation. The upper volcanic rocks which is overlain by Burdigarian and younger soft rocks are comparable to Upper Cretaceous-Lower Tertiary ones in the inner zone of West Japan. The Middle Cretaceous time gap tells that like in the inner zone of West Japan the deformation here was not so strong in the Sakawa phase as in the Oga phase.

The Chuluangkeng (Shukkoko) oil field is particularly interesting for analysis of the tectonic development. There is a long anticline which is, however, bisected by an axial fault along which the eastern wing is a little sunk down. As it is a tension fault at the saddle, the displacement is presumably reduced downward. In the eastern wing, however, there is a thrust of greater displacement, and the same *Operculina* sandstone occurs twice. It is probably a dislocation in the course of the folding. The axial fault on the contrary may be the final adjustment (see Fig. 7).

The southern end of the Chuhuangkeng anticline is cut by a transverse thrust called Sancha (Sansa) along which the southern block thrusts itself upon the other. This thrust is cut by Hsinkai (Shinkai) and Tungluo (Dora) reverse faults at its lateral ends. Thus the folding developed into a compressive block movement which yielded the Sancha thrust and later the two others. Along the Tungluo fault the dislocation appears to have recurred after the deposition of the tableland gravels.

Seeing the differential movement among the brachyanticlines and brachy-

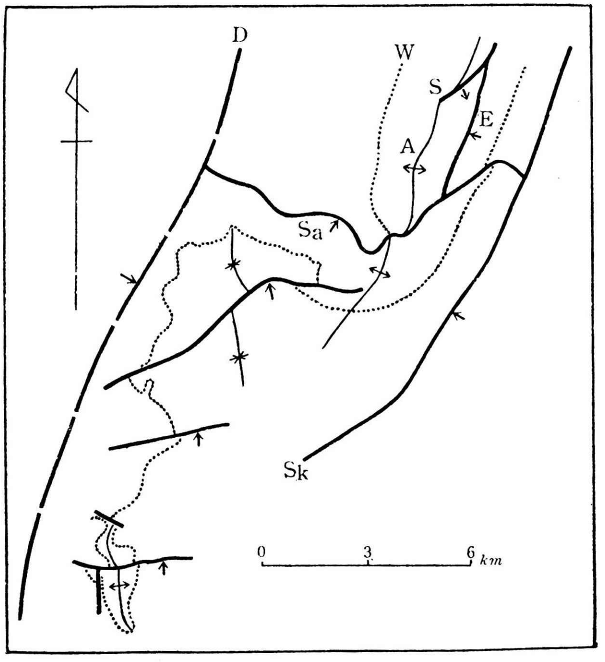


Fig. 7. Tectonic map of the Chuhuangkeng (Shukkoko) oil field. (After CHANG).

W. White sandstone
A. Chuchuangkeng anticline
S. Chuchuangkeng axial fault
E. East Chuchuangkeng thrust
Sa. Sancha thrust
Sk. Hsinkai reverse fault
D. Tungluo reverse fault

synclines and in considering their development from embryonic domes and basins alternately aligned in checker pattern, it is quite probable that the deformation of the geosynclinal sediments was controlled by the framework of their basement which belongs to the inner side of the Sakawa folded mountains. It is well known that in Japan the inner zone was already destructed into a faulted mozaic by block movements in the later Cretaceous and early Palaeogene periods.

Because the repetition of the embryonic foldings is well demonstrated by the middle Tertiary minor cycles of sedimentation in the Kiirun imbricated subzone and because neither the Kaenzan conglomerate nor the Pliocene sediment is developed there, the imbrication was nearly completed possibly before the main upheaval phase of the backbone range.

After the fundamental anticlinorium of Taiwan was built up with the Sakawa metamorphic rocks at its core, the Urai zone, instead of the Tananao zone, was most elevated. The upheaval in this phase attained its maximum in Central Taiwan instead of North Taiwan. Tectonic analysis in the west Taiwan zone has shown that the folding was followed by the compressive block movement. On the basis of these facts it is reasonable to consider that, caused by the geanticlinal upheaval, differential movements took place among blocks. The dislocation must have been especially great at the boundaries of the three tectonic zones of different plasticity. The displacement along the western boundary of the Urai zone was greater in Central Taiwan than North Taiwan, as can be recognized by a comparison between the Kushaku thrust in North Taiwan and the Nansei (Nanshih) fault in Central Taiwan. It is still a question whether the boundary is marked off by a continuous tectonic line or whether it is represented by a series of faults and thrusts en échelon. In all events it is certain that the orography was greatly changed by the upheaval of the backbone range.

As the result of such a great upheaval the Urai zone was strongly eroded. The clastic Urai rocks were transported in huge amounts beyond the western scarps through steep valleys. The Kaenzan conglomerate is such an orogenic sediment of tremendous thickness which was accumulated in a short time on the western lowland.

In the Neogene sediments rock fragments of clayslate and crystalline schists appear in Burdigarian and Helvetian in the southern part of the West Taiwan zone but were later distributed also in the northern part. Their amount increased near the end of the Miocene. In the Takuran and Tokasan formations lithic arenite containing 20 percent clayslate fragments are common in Central and South Taiwan, but their amount is reduced toward the North. Quartzite rudite of the Kaensan facies is, on the other hand, distributed in the west Taiwan zone to the north of Kagi. These sedimentological aspects reveal that the upeheaval of the central range began in the central part and accelerated toward the Miocene at one time and at another time more abruptly and greatly in the Urai zone in the late Pliocene (Huang and Lee, 1962, Lee, 1963).

Palaeo-Taiwan at this time was a peninsula connected with the continent by a land bridge probably through North Taiwan and pre-Taiwan dome. The Plio-Pleistocene mammals migrated through this bridge into the western lowland where the Shokkozan fans and deltas were alinged. The bay further to the west was extended as far as the neck of the peninsula.

On the east side of the backbone range there is the Tatung (Daito) coastal range which like the Neogene of the Uetsu subgeosyncline in North Japan, is composed of Neogene formations containing a large amount of volcanic and pyroclastic materials. The Pinanshan conglomerate, 1,800 m thick is rich in crystalline schists. It is now generally referred to Pliocene as primarily done by Ooe (1939) instead of lower Miocene as done by Hsu (1956). There the Milun conglomerate is the correlative of the Kaenzan conglomerate. It is noteworthy that the synorogenic conglomerates appeared earlier here than in the west Taiwan zone. The formations are moderately folded and cut by faults. The base of the Neogene is unexposed. The coastal range is detached from the Tananao zone by the Hualien Kang (Kwarenkei) rift valley. Whether it is a graben or not cannot actually be seen, because the rupture lines lie concealed beneath young sediments. Off the east coast there are three isles which are mostly composed of volcanic and pyroclastic materials. Quartz-schist caught in andesite as a xenolith in Kueishan isle is proof of the linking of the Sakawa mountains from the Tananao zone to the Yaeyama group. Lutao (Huoshaotao) and Lanhsu (Huangt'ouyu) are remnants of submarine volcanoes and in the latter Aquitanian limestone is inserted in andesitic tuff-agglomerate.

As noted already, these isles form a volcanic chain with the northern dependent isles of Luzon. They as a whole lie on the submarine projectile from the Cagayan valley. The Neogene formations in addition to the upper Oligocene Ibulao limestone in the valley form a synclinorium between the Sierra Madre range on the east and the Cordillera Central on the west side. Like the Yaeyama formation, the lower Miocene Lubugan is a coal-bearing formation. The middle Miocene Tugaegaro sandstone becomes tuffaceous in the south till at length it merges with volcanic rocks.

In the Philippine islands the middle Miocene, frequently quite thick, must be a sediment of the orogenic epoch. Conglomerate is well developed. Clino-unconformity is extensive between the middle and upper Miocene formations, although the latter is mostly composed of fine clastic rocks and limestones and the occurrence of conglomerate is restricted.

Because the Cordillera Central belongs possibly to the Sakawa axis and because the middle Miocene attains such an extraordinary thickness, 3,000 m, in the Bueda valley near the southern end of the range, the conglomerates near Hengchun (Koshun) must be discussed.

The Tertiary formations near Hengchun are very thick and consist of sandstone, shale and conglomerate, including volcanic material in part. TAN (1941) found *Operculina ammonoides* in a shale of the Miocene formation. The Koshun formation comprises various conglomerates rich in volcanic rocks, plutonic rocks and older sedimentaries. They vary in thickness. There are still some ambiguities in their stratigraphic horizons, but these orogenic conglomerates are most probably upper Miocene and Pliocene in age. The Koshun conglomerate s. str. on the other hand is now correlated to the Kaenzan conglomerate. In view of these facts it is presumable that the Taiwan orogeny culminated in the Urai zone already in the middle Neogene.

In the southernmost part of the Urai zone TAN discovered a phyllitic conglomerate containing clayslate and another containing *Discocyclina* limestone. These boulders are probably the upper Urai members, showing intermittent emergences. In the vicinity of Yüshan (Mt. Niitaka) the Urai formation is disconformably overlain by Miocene sandy shale containing *Opereulina venosa.*

If these conglomerates are excluded, the Tertiary of Taiwan is composed of fine rocks in main and the appearance of the Kaenzan conglomerate is quite sporadical in the West Taiwan zone. The next younger is the so-called Ryukyu limestone which is the old raised coral reefs and distinctly tilted, while the younger reef limestones in three series are all subhorizontal. At the Shoushan (Kotobuki hill) of Kaohsiung, 356 m high, in South Taiwan the Takuran formation is capped by the Ryukyu limestone clino-unconformably.

The West Taiwan hills, 300 m or less above the sea, are extensively covered by gravel beds about 30 m thick. Because their tops are flat, they were called "tableland gravels," but it happens also that the flat tops are slightly tilted or gently undulated. Gravel beds are distributed also in some intermontane basins. In the Puli basin the gravel beds attain heights as high as 700 m above sea level. Beneath them there are lignite-bearing lacustrine clay beds which are gently inclined and probably near the Ryukyu limestone in age.

It is an interpretation that the gravel beds were produced in the pluvial epoch in the Diluvium. River terraces incised in the tableland are classified by TOMITA (1951) into two groups. Like the tableland gravels, the higher terraces are capped by lateritic soil. Their relative height from the present river floor is generally 100 to 300 m, but this reaches 400 to 500 m on the east side of the backbone range. This difference reveals an asymmetrical geanticline caused by the upheaval of the range. The relative height of the lower terraces without lateritic soil on the top is generally 20 to 40 m and reaches 80 m at the maximum, but such a difference of height is recognizable between the two sides of the range.

While the geanticlinal upheavals were repeated, there were eruptions of dacite in the Kiirun subzone and of andesite in the Toen subzone. Because erosion is more advanced in the former than in the latter, the dacite eruption of Chinkuashih-Juifang must be a little older than the andesitic one of Tatunshan-Kuanyinshan. The early tuff of Kuanyinshan wedges into the lower part of the tableland gravels, while the piedmont of this volcano is covered by the gravels of the upper part. Therefore it is certain that the volcanoes appeared sometime in the Diluvium. Subsequent to the spreading of the tableland gravels the fault-angle basin of Taipei was brought about. It was an embayment at the beginning, because marine shells are contained in the lower part of the basin deposit.

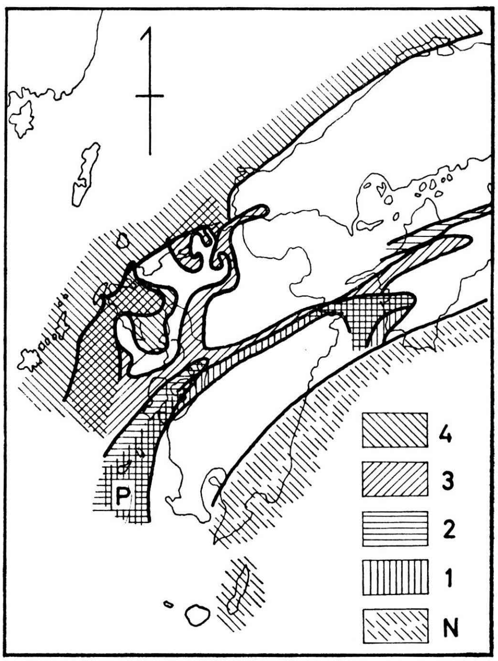
In Central and South Taiwan there is a wide coastal plain and marine shells and foraminifers are found at many places in the Alluvium. The plain is widest near Taichun. There, marine subfossils are found within 10 meters below the land surface near the eastern periphery of the plain. Therefore it was in the near past that the strand line ran along the foot of the hilly land. The retreat of the sea is vindicated by the historical record that a castle built at Anping in 1632 has been on a small island, notwithstanding that the locality is situated 2 km inland from the present shoreline.

According to YABE the drowned valley of the Hsiatanshueichi, 329 fathoms at the deepest point, carves the Ryukyu limestone. Assuming this dating to be correct, the subsidence of the sea bottom since the Diluvium is not a small amount. The Pescaror trench may be the axis of the subsidence which is reciprocal to the upheaval of Taiwan.

Incidentally it must not be overlooked that the time length of the Diluvium inclusive of the Alluvium is about a million years which is, as discussed elsewhere (KOBAYASHI, 1944–45), represents a time length of an instant in pre-Diluvium history. If this time relation in the geologic history is considered, it is not surprising that present Taiwan is not yet far removed from the paroxysm of orogeny. Taiwan is in fact still in a labile state as shown by the repetition of disastrous earthquakes. Among the earthquake faults produced by the Chiai (Kagi) earthquake in 1906, Central Taiwan earthquake in 1935, and the Tainan earthquake in 1946, all in West Taiwan, it is a remarkable habit of shifting of the northern block to the east along a hinge fault in the eastnortheast trend and the downthrow of the fault is always on the south side in the east but on the north side on the west side.

Before closing this paper a few problems are discussed from the comparative tectonic point of view. The Taiwan geosyncline agrees best with the Palaeo-Shiranuhi geosyncline in western Kyushu from the tectonic position not only at the western end of a festoon arc, but also in the inner side of the Sakawa axis. Both of them are therefore subgeosynclines, namely, minor subsiding zones which were produced secondarily in the already oronized area by its destruction (see Fig. 8).

It is certainly interesting to see the migration of the subgeosyncline toward the continental side which took place in northwestern Kyushu as in Taiwan. More



1. Turonio-Cenomanian basin
2. Senonian basin
3. Palaeogene basin
4. Miocene basin
N. Pre-Miocene Nakamura geosyncline
P. Palaeo-Shiranuhi subgeosyncline

Fig. 8. Palaeogeographic map of Kyushu showing the migration of the sedimentary basin behind the Sakawa folded mountains.

precisely, the oldest of the post-Sakawa depression in Kyushu was the Gyliakian or Cenomanio-Turonian one; the next the Urakawan or Senonian one; and the third the Palaeogene one. The sea ingressed toward the northeast repeatedly through the Palaeo-Shiranuhi bay, but in the inundation phase the flooded area farther beyond was shifted from time to time toward the northwest. The shifting in this trend took place at a bound in the middle Tertiary, that is, at about the time of orogeny of the Nakamura geosyncline. Through this upheaval the hinterland of this geosyncline emerged and the Oligo-Miocene sea flooded only the northwestern periphery of Kyushu.

Sometime in the midle Neogene the Neo-Cretaceous and Palaeogene formations in the Palaeo-Shiranuhi subgeosyncline were folded as the Tertiary formation in the Taiwan subgeosyncline, but the deformation of the Tertiary formations in well consolidated northern Kyushu was a kind of Bruchfaltung.

Because I have already discussed the linking of the Japanese arc with the Ryukyu arc (1956), I do not intend to reiterate here. But I shall call attention to the fact that the phases of crustal movements in Taiwan and the Ryukyu islands may be approximately correlated with one another, as suggested by KONISHIA (1963) as follows:

Age	Taiwan	Ryukyu islands
Plio-Pleistocene	Penglai movement	Kunigami phase
Oligo-Miocene	Puli movement	Takachiho phase
Cretaceous-Tertiary	Taiping movement	Miyara phase
Middle Cretaceous	Nanao movement	Attsu phase

Nearly simultaneous crustal deformations were, however, different between the two areas and even parts of either one of these areas in intensity and mode of deformation. The pre-Tertiary discordance in the Ishigaki zone indicated between the Eocene Miyara formation and the metamorphosed Palaeozoic rocks in the Yaeyama insular group is stronger than any discordance known among the older rocks in Taiwan. In the Ryukyu arc the Takachiho disturbance was much stronger on the outer side than the other side. While the Miyara formation is only tilted and undulated, the Palaeogene Kumage formation in Tanegashima is strongly folded. The Miocene and later formations are scarcely folded in the arc, whereas the West Taiwan zone was strongly deformed by the Plio-Pleistocene Penglai movement. An exact correlation of these geological events and their bearing on the areal geology are left for a future study.

The Ryukyu limestone is extensive in the Ryukyu islands as suggested by its name. The eroded flatplane on the limestone is covered by the Kunigami gravels, the correlative of the Pleistocene tableland gravels in Taiwan. *Palaeoloxodon* and other mammalian remains found in fillings of fissures and caves of the Ryukyu limestone indicate the latest connection of the islands with the continent which seems most probable to have been maintained at the neck of the Palaeo-Taiwan peninsula. The land bridge was, however, destroyed at length probably by the southern advance of the Ryukyu islands relative to Taiwan, yielding a flexuer between them.

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Postscript:—According to HUANG drill cores of Well Pk-3 near Peikang below the 1963 m depth contains Palaeocene planctonic foraminifers such as *Globigerina triloculinoides* and *Globorotalia psuedobulloides* commonly and *Globigerina spiralis* rarely. Therefore he remarked that "the Cretaceous megafossils were reworked into the Palaeocene beds" (HUANG, T. (1968), Some Planctonic Foraminiferids from Well PK-3 at Peikang, Yunling, Taiwan. *Proc. Geol. Soc. China, no.* 11.) Is there any possibility for these foraminifers to have become derived fossils in the course of drill sampling? Such a question arose in view of the facts that the supposed reworking have scarcely damaged the illustrated megafossils and that Neocomian-Albian brackish shells and Aptian ammonites and marine pelecypods occur in the normal order of superposition in Well PK-2 near Peikang where no Palaeocene foraminifers were found. While the mixing process of Palaeocene microfossils with Cretaceous megafossils is still a question, now it is evident that Aptian and Palaeocene seas flooded into West Taiwan.

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