Geol. Soc. Malaysia, Bulletin 16, December 1983; pp. 47–60

Significant datum planes of the Western Taiwan Neogene

TUNYOW HUANG
Chinese Petroleum Corporation, Taipei, ROC

Abstract: Twenty planktonic foraminiferal datum planes and eleven benthonic foraminiferal events useful for intraregional and international correlation have been recognised in the shallow marine Neogene sediments of Western Taiwan.

Planktonic foraminiferal datum planes are based on first occurrences (thirteen datums), last occurrences (five datums) and on changes in the coiling direction of *Pulleniatina* (two datums). Benthonic foraminiferal events comprise first occurrences (six events), concentration zones (four events) and last occurrences (one event).

Correlation of these datum planes and events with standard Neogene foraminiferal zones indicates that in the Foothills Region of Western Taiwan, the Early-Middle Miocene boundary occurs within the Nanchuang Formation, the Miocene-Pliocene boundary in the uppermost part of the Kuantashan Sandstone and the Pliocene—Pleistocene boundary in the middle part of the Cholan Formation.

INTRODUCTION

The Chinese Petroleum Corporation (CPC) established its micropaleontological laboratory in 1954. The laboratory began detailed investigations on the sequence of benthonic foraminiferal biostratigraphy for many type sections in different regions of Taiwan. Most of the upper Cenozoic sediments in Taiwan are of shallow occurrences, which may be due to differences in the physical conditions of the paleoenvironment, can usually be distinguished in one stratigraphic subdivision. This indicates the need for a careful approach by dating and correlation with smaller foraminifera.

In addition to the benthonic foraminiferal study started earlier, CPC's paleontological laboratory has also attended to planktonic foraminiferal research for accurate correlation.

Planktonic foraminiferal research is for determining the subdivisions in the stratigraphic sequence and to do intercontinental correlation with areas outside of Taiwan.

Planktonic foraminiferal zones of the Miocene-Pliocene of Taiwan was presented earlier by Chang (1959, 1960a, b, 1962, 1972, 1975a, b, 1976) and Huang (1963, 1967, 1970, 1971a, 1975, 1978); the zonation has been restudied with additional samples.

The planktonic foraminiferal zones established by Bolli (1957, 1966) and Blow (1969) and Banner and Blow (1965) have been recognized in the Tertiary of Taiwan. It seems worthwhile to carry the stratigraphic correlation a step further with new evidences obtained in the planktonic biostratigraphic study of the Neogene in Taiwan.

Presented at GSM Petroleum Geology Seminar December 1982

GENERAL GEOLOGY

The island of Taiwan is situated between the Ryukyu Islands and the Philippine Archipelago and located on the eastern border of the Asian Continental margin. The island is mountainous and rises very abruptly above sea level. Geologically, Taiwan is situated on a compressive boundary between the Eurasian and Philippine sea plates. Collision of the two plates occurs along the present Longitudinal Valley, which extends for a length of nearly 150 kms. East of the valley is the Coastal Range developed on the edge of the Philippine sea plate and composed of an ophiolitic-melange complex and volcanic rocks originated from arc-magmatism. West of the valley is the Eurasian plate from which rises the main topography of the island.

The island is for the greater part built up of marine sedimentary rocks of Tertiary age. The distribution of Paleozoic and Mesozoic rocks is limited to the eastern slopes of the Central Range (Yen, 1971).

The backbone Central Range has a core composed prevailingly of phyllite and slate of Mesozoic (?) and Eocone ages and a young cover mainly of Miocene age, which has also been metamorphosed into slates (Yen, 1971).

The submetamorphosed Hsuehshan Range belt on the western slope of the Central Range, consists chiefly of Oligocene argillites and subordinately of Eocene and possible older slates.

The non-metamorphased Neogene belt, in the western foothills of the Central Range and beneath the coastal plain, is composed of a mightly series of sandstone and slate having its oldest record traceable basinwards back to the Upper Oligocene (Huang, 1982).

Neogene sequences are well developed in the present Hsueh-shan Range, western foothills, and offshore region of western Taiwan. Subjected to no, or only a slight, degree of metamorphism, these sequences are paleontologically the best known interval of the sedimentary column of the island.

From the view point of basin analysis, sedimentation of the Oligocene and upward sequences occurred in three distinct provinces: 1) Taihsi-Taichung Basin in northern Taiwan, 2) Penghu platform in central Taiwan, and 3) Tainan basin in southern sediments were transported from the foreland north or northwest of the present northern part of Taiwan. Proximal to the sediment source, northern Taiwan (Taihsi-Taichung Basin) is characterized by the rythmic occurrences of progradational sequences, which range in environments from offshore marine to non-marine (coal-bearing) conditions. The resulted lithofacies is generally highly quartzose. The standard succession of the Neogene is well exposed in an area from Miaoli northward to the coast (T. Y. Huang, 1971).

The Penghu platform is a structurally stable element which divides the northern (Taihsi-Taichung) and the southern (Tainan) subbasins (Sun, 1982). The platform runs NE-SW with its north-eastern extremity submerged beneath the present Chiayi-

Yunlin coastal plain. Typical Neogene sequences lying above the platform are not outcropped but have been recovered from CPC's wildcat drillings. The platform and its vicinity, being distal to sediment source, is characterized by deposition of suspension materials, mud and siltstone, with an extremely low rate of accumulation. Thin-bedded limestone of shallow shelf origin has a wide distribution on the platform.

The southern (Tainan) subbasin is located southeast of a distinct Neogene hinge fault zone which runs NE-SW and forms the southern limit of the Peikang platform. Development of this basin is apparently through collapsing of the passive Penghu platform. The rate of sedimentation is variable but generally exceedingly high because of extensive growth faulting. This province is now covered mostly by late Neogene sediments composed prevailingly of mudstone (T. Y. Huang, 1971).

BIOSTRATIGRAPHY

The succession of Tertiary smaller foraminifera has been studied from many type sections in different regions since 1955 (Huang, 1971a and 1978).

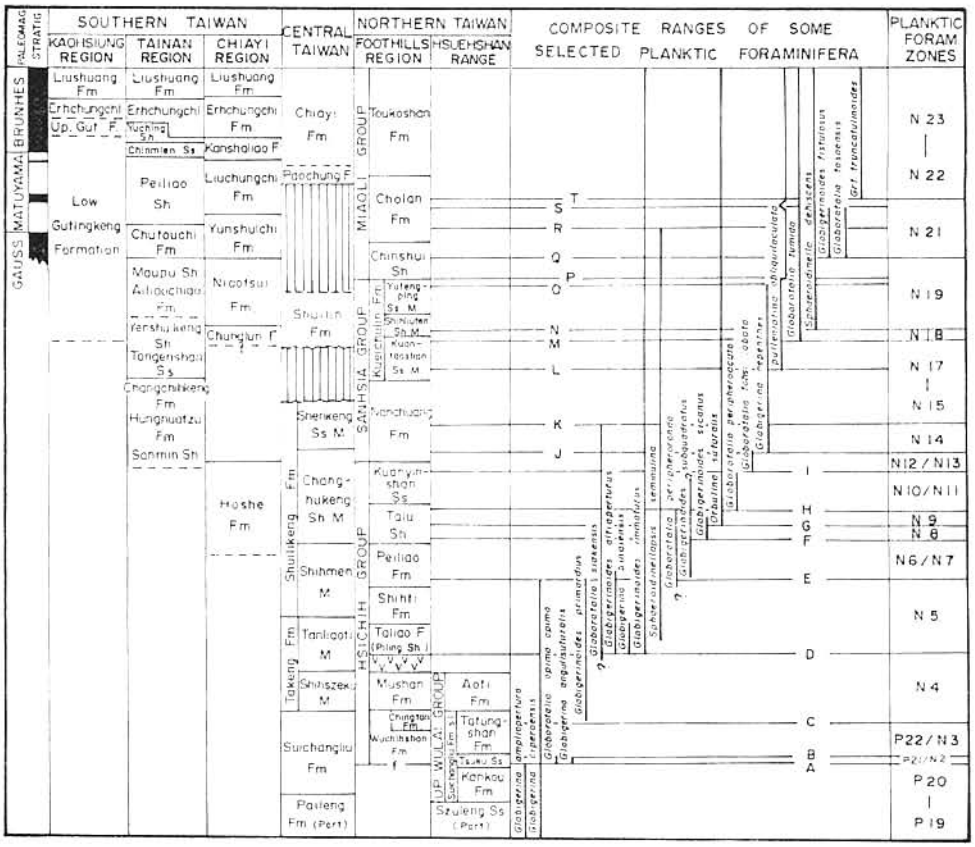

Fig. 1. Range chart of selected Neogene planktonic foraminifera and lithostratigraphy of western Taiwan, showing planktonic foraminiferal datum levels.

The Fig. 1 is a compilation of all of the planktonic foraminiferal biostratigraphic events considered to be useful for the regional and intercontinental correlation.

The lithostratigraphic units of each of the aforementioned provinces and the composite ranges of key planktonic foraminiferal taxa and zones are shown on the figure (1 and 2). A total of 20 datums (Datum A through T) are indicated. The datum levels are explained from the oldest to the youngest:

Datum A: Last occurrence of *Globigerina ampliapertura* in the lower part of the Tsuku Sandstone and the lower part of the Shuichangliu Formation of the Hsuehshan Range.

Blow (1969) defined the base of his Zone P. 21 at the level of the first evolutionary appearance of *Globigerina angulisuturalis* which occurs at a horizon near the level of extinction of *Globigerina ampliopertura*. *Globorotalia opima opima* occurs in the interval of Zone P. 21.

Datum B: Last occurrence of *Globorotalia opima opima* in the upper part of the Tsuku Sandstone and the lower part of the Schuichangliu Formation of the Hsuehshan Range.

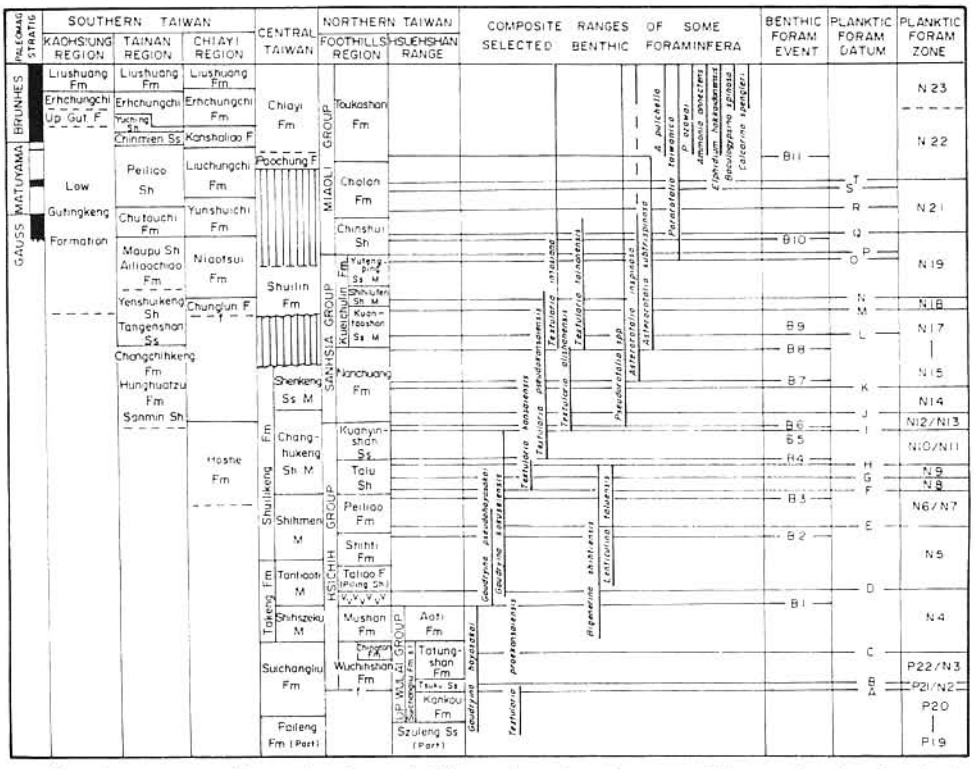

Fig. 2. Neogene biostratigraphy and lithostratigraphy of western Taiwan, showing benthonic foraminiferal event levels and its relation to planktonic foraminiferal datum levels.

The horizon of the last occurrence of *Globorotalia opima opima* is considered to be useful biostratigraphic correlation by Blow (1969) who used this datum to define Zone P. 22.

Datum C: First occurrence of *Globigerinoides primordius* in the upper part of the Tatungshan and in the upper part of the Tatungshan and in the upper part of the Chingtan Formation of the western foothills region.

The first evolutionary stratigraphic occurrence of *Globigerinoides primordius* indicates the base of Zone N. 4. This datum is most valuable and reliable for world-wide correlation comparable in biostratigraphic value to the well-known evolutionary first appearance of the genus *Orbulina*. According to Blow (1969), the Oligocene/Miocene boundary is placed at the first appearance of *G. primordius*.

Datum D: First occurrence of *Globigerinoides altiaperturus* in the basal part of the Taliao Formation and in the Takeng Formation of the western foothills region.

Blow (1969) defined the base of Zone N. 5 at the horizon of the extinction of *Globorotalia kugleri* and this species has not yet been known from the Miocene sediments in Taiwan. Therefore, the first occurrence of *Globigerinoides altiaperturus* is used for the extinction of *Globorotalia kugleri*, because *G. altiaperturus* occurs at a horizon near the base of Zone N. 5.

Datum E: First occurrence of *Globigerinoides subquadratus* in the basal part of the Peiliao Formation and in the lower part of the Shuilikeng Formation of the western foothills region.

The base of Zone N. 6 is defined by the first appearance of *Globigerinatella insueta* and this species is sporadically found in the Miocene sediments in Taiwan. Therefore, this datum is difficult to place precisely in the Miocene sequence of Taiwan. The horizon of the first stratigraphical appearance of *Globigerinoides subquadratus* is considered to be useful for biostratigraphic correlation. According to Blow (1969), the level of the first occurrence of *Globigerinoides subquadratus* within the later part of Zone N. 5. Therefore, this datum is closely related to the base of Zone N. 6. According to Blow (1969), *Globigerina ciperoensis* (s. l.) is from the early part of Zone P. 19. to within Zone N. 5.

Datum F: First occurrence of *Globigerinoides sicanus* in the lower part of the Talu Shale and in the middle part of the Shuilikeng Formation of the western foothills region.

Globigerinoides sicanus is a prior synonym of *G. bisphericus* Todd. Blow (1969) defined the base of Zone N. 8 at the first evolutionary appearance of *G. sicanus*.

Datum G: First occurrence of *Orbulina sutularis* in the middle part of the Talu Shale and in the middle part of the Shuilikeng Formation of the western foothills region.

Since the evolutionary lineage of *Orbulina* from *Globigerinoides sicanus* through the species of *Praeobulina* was studied in detail by Blow (1969). Its evolutionary appearance has been recognized in the Miocene sequence of warm-water regions by

many workers and is now regarded as one of the most reliable datum levels for long-distance stratigraphic correlation. The first appearance of *Orbulina suturalis* marks the base of Zone N. 9 according to Blow (1969). According to Berggren (1972), the Early, Middle Miocene boundary is placed at the first appearance of *O. suturalis*.

Datum H: First occurrence of *Globorotalia peripheroacuta* in the upper part of the Talu Shale and in the middle part of the Shuilikeng Formation of the western foothills region.

The *Globorotalia fohsi* lineage is one of the best demonstrated evolutionary series in the planktonic foraminifera. Blow and Banner (1969) critically reviewed the taxa closely related to *Globorotalia peripheroronda*. This datum can be recognized in various areas in western Taiwan, and is one of the remarkable events in the Taiwan Miocene sequence. Blow (1969) used this datum to define the base of Zone N. 10.

Datum I: First occurrence of *Globorotalia fohsi lobata* in the based part of the Sanmin Shale of the western foothills region.

The first evolutionary appearance of *Globorotalia fohsi lobata* is just above the base of Zone N. 12 according to Blow (1969).

Datum J: First occurrence of *Globigerina nepenthes* in the upper part of the Sanmin Shale of the western foothills region.

Blow (1969) defined the base of Zone N. 14 as the level marked by this phylogenetic event.

Datum K: Last occurrence of *Globorotalia siakensis* in the middle part of the Hunghuatzu Formation of the western foothills region. The level of the last occurrence of *Globorotalia siakensis* is considered to be a reliabiable datum level for biostratigraphic correlation within the warm-water provinces. Blow (1969) defined the base of Zone N. 15 as the level immediately above theextinction level of this species.

This datum is difficult to place precisely because of its last foraminiferal event occurrence.

Datum L: First occurrence of *Pulleniatina obliquiloculata* (s. l.) in the lower part of the Tangenshan Sandstone of the western foothills region.

According to Banner and Blow (1967), *P. primalis* appears to have directly descended from *Globorotalia acostaensis* with the middle part of Zone N. 17 of Blow (1969).

Datum M: First occurrence of *Globorotalia tumida* in the upper part of the Tangenshan Sandstone and in the Chunglun Formation of the western foothills region.

The horizon of the evolutionary first appearance of *Globorotalia tumida* indicates the base of Zone N. 18.

Datum N: First occurrence of *Sphaeroidinella dehiscens* in the middle part of the Yenshuikeng Shale of the western foothills region.

According to Blow (1969), the level of the first occurrence of *S. dehiscens* is just subsequent to the base of Zone N. 19. Among the foraminiferal criteria advanced to date for the recognition of the Miocene/Piocene boundary, the initial appearance of *S. dehiscens* is considered the best.

Datum O: Last occurrence of *Globigerina nepenthes* in the upper most part of the Ailiaochiao Formation of the western foothills region.

The level of the last occurrence of *Globigerina nepenthes* is considered to be useful for biostratigraphic correlation by Hays *et al.* (1969) who used this datum to define their Datum IV.

Datum P: *Pulleniatina* coiling change from sinistral to dextral in the basal part of the Maupu Shale of the western foothills region.

The horizon of coiling change from sinistral to dextral of *Pulleniatina* is within the upper part of Zone N. 19. This datum occurs just above the last occurrence of *Globigerina nepenthes* in western Taiwan.

Systematic changes with time in the coiling direction of genus *Pulleniatina* have been considered to be a useful datum level for interregional correlation of Pliocene-Quaternary marine sediments by Saito (1976). The datum P may be correlateable to Saito's left coiling interval 17.

Datum Q: First occurrence of *Globorotalia tosaensis* in the basal part of the Chutouchi Formation and in the lower Gutingkeng Formation of the western foothills region.

Blow (1969) defined the base of Zone N. 21 as the level of the first evolutionary appearance of *G. tosaensis*.

Datum R: Last occurrence of *Sphaeroidinellopsis seminulina* in the uppermost part of the Chutouchi Formation of the western foothills region.

According to Hays *et al.* (1969), a core-to-core correlation of the ranges of such solution-resistant species as *Sphaeroidinellopsis* can be easily done due to the cortical covering of the test.

The level of the genus *Sphaeroidinellopsis* has been considered a useful biostratigraphic level by Hays *et al.* (*op. cit.*, their Datum V), Berggren (1973), Cita (1973), and others.

Datum S: *Pulleniatina* coiling change from dextral to sinistral in the lower part of the Peiliao Shale and in the lower Gutingkeng Formation of the western foothills region.

The horizon of coiling change from dextral to sinistral of *Pulleniatina* is within the upper part of Zone N. 21. This datum may be correlatable to part of Saito's coiling interval L8 to L4.

Datum T: First occurrence of *Globorotalia truncatulinoides* in the lower part of the Peiliao Shale and in the lower Gutingkeng formation of the western foothills region.

The horizon of the first evolutionary appearance of *Globorotalia truncatulinoides* indicates the base of Zone N. 22.

Since the evolutionary lineage of *G. truncatulinoides* from its immediate ancestor, *G. tosaensis*, was first suggested by TaKayanagi and Saito (1962a, it has been recognized in the late Cenozoic sequence by many workers. Berggren *et al.*, (1967) compared the phylogeny of *G. truncatulinoides* with the paleomagnetic stratigraphy in a North Atlantic deep-sea core and slowed that this evolution occurred within the Olduvai Event of the Matuyama reversed Epoch. This evolutionary appearance within or near the base of the Olduvai Event was also recognized in the Atlantic (Glass *et al.*, 1967, Phillips *et al.*, 1968) and in the equatorial Pacific (Hays *et al.*, 1969) and has been considered by Hays and Berggren (1971) to be chronostratigraphically reliable for world-wide correlation within the warm-water regions.

Consequently, the first appearance of *G. truncatulinoides* defines the Pliocene/Pleistocene boundary.

In general the sequence of planktonic foraminiferal assemblages in Taiwan is similar to that which occurs in the Indo-Pacific tropical area, and the zonation scheme used in those areas is of use in Taiwan also.

The Figure 2 is to demonstrate that benthonic foraminifera is a useful tool for island-wide stratal correlation. A total of 11 events can be recognized in the Cenozoic sequence of Taiwan.

In general, benthonic foraminifera not reliable for long-distance correlation. The first evolutionary appearance of benthonic foraminifera taxa is as significant to correlation as that of planktonic foraminifera.

In the Neogene series of Taiwan, some benthonic species, such as *Gaudryina*, *Textularia*, *Pseudorotalia*, *Asterorotalia*, and *Pararotalia* are significant in regional stratigraphic correlation.

Based on the paleontological studies of the Neogene sequence in Taiwan, a number of occurrence events of benthonic foraminifera has been recognized. A total of 11 events (Event B1 through B11), including 4 (B2, B3, B5 and B9) concentration zones, are recognized. And the precise stratigraphic levels of these events have been estimated with planktonic foraminifera.

The event levels are explained from the oldest to the youngest:

Event B1: Last occurrence of *Gaudryina hayasakai* in the uppermost part of the Mushan Formation.

Event B1 is marked by the development of *Gaudryina pseudohayasakai*, from its immediate ancestor, *Gaudryina hayasakai*. It appears in the top of the Mushan

Formation (C. Y. Huang, 1981). The cause of *Gaudryina hayasakai* abrupt extinction may be due to the environmental change.

Based on the ubiquitous occurrence of *Gaudryina hayasakai* in the samples from the Oligocene terrain, Chang (1960a) proposed the *G. hayasakai* Zone and corresponding time-stratigraphic unit, the Shihtsaoan Stage, to include the formations characterized by the presence of the Zone marker. Recently, *G. hayasakai* has been bound to occur in the Szuleng Sandstone (Y. M. Chang, 1973) and Mushan Formation (C. Y. Huang 1981) also.

Event B2: *Operculina barthschi multiseptata* concentration zone in the upper part of the Shihti Formation.

Event B2 is characterized by about 30cm in thickness of *Operculina bastschi multiseptata* concentration zone. This marker zone lies in the upper most part of the Shihti Formation (Huang and Chiu, 1973). This marker Zone is considered to be useful for correlation in the field.

Event B3: *Heterolepa praecincta* concentration zone in the upper part of the Peiliao Formation.

Event B3 is characterized by about 1–2 meters in thickness of *Heterolepa praecincta* concentration zone. This marker zone lies in the top of the formation, near the upper boundary of the Peiliao Formation (Huang and Chiu, 1973).

Event B4: First occurrence of *Textularia pseudokansaiensis* in the basal part of the Kuanyinshan Sandstone.

Event B4 is marked by the first evolutionary appearance of *Textularia pseudokansaiensis*, from its immediate ancester, *Textularia kansaiensis*. This horizon lies just above the first occurrence of *Globorotalia peripheroacuta* datum (Datum H). Thus, this benthonic foraminiferal event is considered to be useful for biostratigraphic correlation in Taiwan (T. Y. Huang, 1971b and 1978b).

Event B5: *Operculina ammonoides* concentration zone in the Kuanyinshan Sandstone.

Event B5 is characterized by the formation rich in *Operculina ammonoides*. Thus, this formation is called *Operculina* Sandstone as previously.

Event B6: First occurrence of the genus *Pseudorotalia* in the upper most part of the Kuanyinshan Sandstone.

Event B6 is marked by the first appearance of the genus *Pseudorotalia* which occur at a horizon near the top of the Kuanyinshan Sandstone. This horizon lies above the first occurrence of *Globorotalia fohsi lobata* datum (Datum 1) in Taiwan. This horizon is considered to be a significant biostratigraphic level in the Neogene sequence of Taiwan (T. Y. Huang, 1964, 1971b and 1978b).

Event B7: First occurrence of *Asterorotalia inspinosa* in the middle part of the Nanchuang formation.

Event B7 is marked by the first appearance of *Asterorotalia inspinosa* in the middle part of the Nanchuang Formation (T. Y. Huang 1971b). This horizon lies above the last occurrence of *Globorotalia* siakensis datum (Datum K) of Taiwan.

Event B8: First occurrence of *Asterorotalia subtrispinosa* in the basal part of the Kuantaoshan Sandstone.

Event B8 is marked by the first appearance of *Asterorotalia subtrispinosa*. This horizon is recognized in near the upper boundary of the Nanchuan Formation (T. Y. Huang, 1964).

Event B9: *Operculina ammonoides* concentration zone in the lower part of the Kuantaoshan Sandstone.

Event B9 is characterized by *Operculina ammonoides* concentration zone in the lower part of the Kuantaoshan Sandstone.

Event B10: First occurrence of *Pararotalia taiwanica* in the middle part of the Chinshui Shale.

Event B10 is marked by the first appearance of *Pararotalia taiwanica*. This horizon is recognized in the middle part of the Chinshui Shale (T. Y. Huang, 1964) and lies just below the first occurrence of *Globorotalia tosaensis* datum (Datum Q).

Event B11: First occurrence of *Asterorotalia pulchella* in the basal part of the Tokoshan Formation.

Event B11 is marked by the first evolutionary appearance of *Asterorotalia pulchella*, from its immediate ancestor, *A. subtrispinosa*. *A. pulchella* appears in the basal part of the Toukoshan Formation. *Parorotalia ozawai*, *Ammonia annectens*, and *Elphidium hokkaidoensis* seem to have their first occurrence in this horizon. Therefore, this benthonic foraminiferal event is considered to be useful for biostratigraphic correlation in Taiwan (T. Y. Huang, 1964, 1971b and 1978b).

AGE AND EPOCH BOUNDARY ASSIGNMENT

In the following lines, stratigraphic relations between the planktonic foraminiferal biostratigraphy and the Oligocene/Miocene, Early/Middle Miocene, Middle/Late Miocene, Miocene/Pliocene, and Pliocene/Pleistocene boundaries are discussed are discussed by referring to recent investigations in Taiwan.

According to Blow (1969), the Oligocene/Miocene boundary is placed at the first appearance of *G. primordius*.

Lamb and Stainforth (1976) recorded the presence of primitive *Globigerinoides* in

the *Globigerina ciperoensis* Zone (P. 22/N. 3), they suggested that "the change from *Globigerina* to *Globigerinoides* may be a fundamental response to environmental change rather than a genetic response to evolutionary tendences". This finding seems to have provided an explanatory ground for what would otherwise be a puzzle in Taiwan. Therefore, the Oligocene/Miocene boundary has been provisionally assigned to coincide with the top of the Tatungshan Formation in Taiwan.

Based on the planktonic foraminiferal stratigraphy in the western foothills region, the Early/Middle Miocene boundary is placed within the Talu Shale by the *Orbulina* datum.

In the interval of the upper Miocene, after the disappearance of *Globorotalia fohsi* to the first occurrence of *Globorotalia tumida* was a time of great tectonic unrest and extensive paralic deposits were developed in Taiwan. Consequently, fossils are scarcely found in the sediments.

Based on the above mentioned occurrence of the planktonic foraminifera and nannofossils in the upper Hsihchih Group, the Kuanyinshan Sandstone is approximately correlated with N. 10 to N. 12 of Blow (1969), and the lower part of the Nanchuang Formation down to the uppermost part of the Kuanyinshan Sandstone may be correlated with N. 13 of Blow. And the upper part of the Nanchuang Formation and the lower part of the Kuantaoshan Sandstone may be correlated with N. 15 to N. 17 of Blow. Therefore, the Late/Middle Miocene boundary can be settled within the middle part of the Nanchuang Formation. But no distinct boundary can be drawn in the stratigraphic column.

For the Miocene/Pliocene boundary, Berggren and Couvering's (1974) suggestion is followed and the boundary is drawn at the base of the Blow's Zone N. 18 which corresponds with the Datum M in Taiwan. Consequently, the boundary should be placed at the upper most part of the Kuantaoshan Sandstone. Such a boundary that is not against the existing paleontological data can be readily recognized in the field.

The Pliocene/Pleistocene boundary (N21/N22) is one of the important boundary in Blow's system and is defined by the initial appearance at the base of the Pleistocene of *Globorotalia truncatulinoides*. The P/P boundary should be placed at the middle part of the Cholan Formation. The first occurrence datum level of *G. trancatulinoides* lies slightly below the base of the Olduvai, showing an age of about 1.9 my.

Blow Zone N. 23 is consistently present, but no sharp boundary can be drawn between it and N22. *Sphaeroidinella dehiscens excanata* is characteristic of Zone N23. This form appeared first within the upper Gutingkeng Formation and scarcely in the sediments. Therefore, we the N22/N23 boundary in the geological section of Taiwan could not be distinctly distinguished.

In the other hand, the *Elephas/Stegodon* fauna were found in the Hsiangshan Facies of the Toukashan Formation in the north and their equivalent formations in the south (Hayasaka, 1942; Chang, 1975; Shikama, *et al.*, 1975; Huang, 1977).

The Tsailiao-chi area of Chochen near Tainan has been a well known mammalian fossil district. This fauna is closely related with the Akashi (Japan) fauna, and probably belong to the middle Villa-franchian (Shikama, *et al.*, 1975). And so the Chochen fauna is correlatable to the so-called *proximus-shigensis* Zone in Japan (Horizon IV of Osaka Group) and belong to Blow's Zone N23.

Mammuthus armeniacus taiwanicus and other land mammalian fossils all appeared in the base of the Erchungchi Formation. They would lie about 2000 meters above the first occurrence of *G. truncatulinoides* (T. Huang, 1977).

Based on the above mentioned occurrence of the planktonic foraminifera and mammalian fauna, the upper Toukoshan Formation and equivalent formations are correlated with N23.

ACKNOWLEDGEMENTS

I wish to thank Mr. T. M. Wu, the ex-Vice president and Mr. S. Yang, Vice President of CPC, and Dr. Stanley S. L. Chang, Chief Geologist, CPC, for their support and encouragement, and to the Chinese Petroleum Corporation for permitting to publish this paper.

REFERENCES

BANNER, F.T. and BLOW, W.H., 1965, Progress in the planktonic foraminiferal biostratigraphy of the Neogene. *Nature*, v. 208, p. 1164–1166.

BANNER, F.T. and BLOW, 1967, The origin, evolution and taxanomy of the foraminiferal genus *Pulleniatina* Cushman, 1927. *Micropaleont.*, v. 13, no. 2, p. 133–162. text-figs. 1–14, pls. 1–4.

BERGGREN, W.A., 1969, Cenozoic chronostratigraphy, planktonic foraminiferal zonation and radiometric time scale. *Nature*, v. 224 no. 5224, p. 1072–1075, talb. 1–4.

BERGGREN, 1972, A Cenozoic time-scale—some implications of regional geology and paleobiogeogaraphy. *Lethaia*, v.s., p. 195–215, figs. 1–9.

BERGGREN, 1973, The Pliocene time-scale: caribration of planktonic foraminiferal and caleareous nannoplankton zones. *Nature*, v. 243, p. 391–397.

BERGGREN, PHILLIPS, J. D., BERTELS, A. and WALL, D., 1967, Late Pliocene-Pleistocene stratigraphy in deep-sea cores from the south central North Atlantic. *Nature*, v. 216, p. 253–254.

BERGGREN, and J. A& COUVERING, 1973, *The Late Neogene: Development in paleontology and stratigraphy* 2. Elsevier Scientific Publ. Comp., Amsterdam, 216pp.

BOLLI, H.M., 1957, Planktonic Foraminifera from the Oligocene-Miocene Cipero and Lengua Formations of Trinidad, B.W.I.U.S. *Natl. Mus. Bull.*, no. 215, p. 97–123.

BOLLI, 1966, Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminiferal. *Bol. Inf. Asoc. Venez. Geol. Min. Pet.*, no. 8, p. 119–149.

BLOW, W.H., 1956, Origin and evolution of the foraminiferal genus Orbulina d'Orbigny. *Micropaleont.*, v. 2, no. 1, p. 57–70, text-figs. 1–4.

BLOW, 1969, Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. *Proc. 1st. Int. Conf. Plank. Microfossils*, v. 1., p. 199–421.

BLOW, W.H., and BANNER, F.T., 1966, The morphology, taxonomy and biostratigraphy of *Globorotalia barisnensis* LeRoy, *Globorotalia fohsi* Cushman and Ellisor, and related taxa. *Miocropaleont.*, v. 12, no. 3, p. 286–302.

CHANG, L.S., 1959, A biostratigraphic study of the Miocene in Western Taiwan based on smaller foraminifera (part 1: Planktonics). *Geol. Soc. China, Proc., no. 2, p. 47–72.*

CHANG, 1960a, Tertiary biostratigraphy of Taiwan with special reference to smaller foraminifera and its bearing on the Tertiary geohistory of Taiwan. *Geol. Soc. China, Proc.*, no. 3, p. 7–30.

CHANG, 1960b, Tertiary biostratigraphy study of the Miocene in western Taiwan based on smaller foraminifera (part 2: benthonics). *Geol. Surv. Taiwan, Bull.*, no. 12, p. 67–91.

CHANG, 1962. A biostratigraphic study of Oligocene in northern Taiwan based on smaller foraminifera. *Geol. Soc. China, Proc.*, no. 5, p. 47–64.

CHANG, 1972. A. Biostratigraphic study of the so-called Slate Formation on the east flank of the Central Range between Tawu and Taimali, southeastern Taiwan, based on smaller foraminifera. *Geol. Soc. China, Proc.*, no. 13, p. 129–142.

CHANG, 1975a. Biostratigraphy of Taiwan. In Kobayashi, T. and Toriyama, R., eds., *Geol. Palaeont. Southeast Asia*, v. 15, p. 337–361.

CHANG, 1975b. Miocene Pliocene boundary in Taiwan. Late Neogene Epoch Boundaries, *In* Saito, T. and Burkle, L. H. eds., *micropaleont. Spec. Public.*, no. 1, p. 106–114.

CHANG, 1976. The Lushanian Stage in the Central Range of Taiwan and its fauna. *Progress in Micropaleontology*. Micropaleont. Press, p. 103–109.

CHANG, Y.M., 1973. Biostratigraphic study of smaller Foraminifera from the Wu-Chi section, Kuohsing, Nantou, Taiwan. *Petrol. Geol. Taiwan*, no. 2, p. 183–206.

CHEN, P.H., HUANG, T.C., HUANG C.Y., JIANG M.J., LO, L.L. and KUO, C.L., 1977a. Paleomagnetic and cocolith stratigraphy of Plio-Pleistocene shallow marine sediments, Chuhuangkeng, Miaoli. *Petrol. Geol. Taiwan*, no. 14, p. 219–239.

CHEN, P.H., HUANG, T.C. and TSAI, L.P., 1977b. A study of the late Neogene marine sediments of the Chishan area, Taiwan: paleomagnetic stratigraphy, biostratigraphy, and paleoclimate. *Geol. Soc. China, Mem.*, no. 2, p. 169–190.

CITA, M.B., 1973. Pliocene biostratigraphy and chronostratigraphy. *In*: W.F.B. Ryan, K.H.Hsu *et al.*, *Initial Reports of the Deep Sea Drilling Project*, XIII. U.S. Government Printing Office, Washington D.C., p. 1343–1379.

GLASS, B., ERIESON, D.B., HEEZEN, B.C., OPDYKE, N.D. and GLASS, J.A., 1967. Geomagnetic reversals and Pleistocene chronology. *Nature*, v. 216, p. 437–442.

HAYS, J.D., SAITO, T., OPDYKE, N.D. and BURCKLE, L.H., 1969. Pliocene Pleistocene sediments of the equatorial Pacific-Their paleomagnetic, biostratigraphic and climatic record. *Geol. Soc. Am.* Bull., v. 80, p. 1481–1514.

HAYS, and BERGGREN, W.A., 1971. Quaternary boundaries and correlations. In: B.M. Funnel and W.R. Riedel (Eds), *Micropaleontology of the Oceans*. Cambridge Univ. Press, Cambridge, p. 669–691.

HUANG, C.Y., 1981. *Smaller Foraminiferal Study on the Oligo-Miocene Formations in Northern Taiwan*. Dept. Geol., National Taiwan Univ., Dr. Thesis, in Chinese.

HUANG, CHENG, Y.M. and HUANG, TUNYOW, 1978. Preliminary biostratigraphic study of the Nankang Formation in the Lilao section, near Taipei, northern Taiwan. *Ti-Chih*, v. 2, p. 1–11. (in Chinese with English abstract).

HUANG, T.C., 1980. Oligocene to pleistocene calcareous nannofossil biostratigraphy of the Hsuehshan Range and western foothills in Taiwan. *In* Kobayashi, T. and Toriyama, R., ed., *Geol. Paleontol. Southeast Asia*, v. 21, p. 191–210.

HUANG, 1982. Tertiary calcareous nannofossil stratigraphy and sedimentation cycles in Taiwan. *Proc. 2nd ASCOP Conf.*, Oct. 7–11, 1981, Manila, Philippines, A. Saliver-Sali ed., Tech. Progr. commit., ASCOPE' 81, p. 873–886.

HUANG, TUNYOW, 1963. Planktonic Foraminifera from the Peikang PK-3 Well in the Peikang Shalf area, Yunlin, Taiwan: *Petrol. Geol. Taiwan*, no. 2, p. 153–181, Pls. 1–6, text-figs. 1–4, tabs. 1–2.

HUANG, 1964. "Rotalia" group from the upper Cenozoic of Taiwan, *Micropaleontology*, v. 10, no. 1, p. 49–62.

HUANG, 1967. Late Tertiary planktonic foraminifera from southern Taiwan. Tohoku Univ., *Sci. Repts., 2nd ser. (Geol.)*, v. 38, no. 2, p. 165–192.

HUANG, TUNYOW, 1970. State of Micropaleontological study in Taiwan. *Petrol. Geol. Taiwan*, no. 7, p. 195–208.

HUANG, 1971a. New developments in stratigraphic correlation of the Neogene sequence in western Taiwan. *Petrol. Geol. Taiwan*, no. 9, p. 19–27.

HUANG, 1971b. Some foraminiferal lineages in Taiwan. *Geol. Soc. China, Proc.*, no. 14, p. 76–85.

HUANG, 1975. Late Neogene foraminiferal zonation of south-western Taiwan. *In* Saito, T. and Burckle, L.H., eds., *Late Neogene Epoch Boundaries*. Micropaleont. Spec. Publ., no. 1, P. 106–114.

HUANG, 1976. Some significant biostratigraphic events in the Neogene formations of Taiwan. *In* Takayanagi, Y. and Saito, T., eds., *Progress in Micropaleont.*, p. 103–109.

HUANG, 1977. Late Neogene planktonic foraminiferal biostratigraphy of the Tainan foothills region, Tainan, Taiwan. *Petrol. Geol. Taiwan*, no. 14, p. 121–145.

HUANG, 1978a. Foraminiferal biostratigraphy of the Hunghuatzu section, southern Taiwan. *Petrol. Geol. Taiwan*, no. 15, p. 35–48.

HUANG, 1978b, Two important benthonic foraminiferal datum in the Neogene of northern Taiwan. *T-chih*, vol. 2, p. 19–23, (in Chinese with English abstract).

HUANG, and CHIU, H.T., 1973, Some diagnostic Miocene Planktonic foraminifera from west central Taiwan. *Geol. Soc. China, Proc.*, no. 16, p. 59–68.

HUANG, and HUANG, T.C., 1982, *Evaluation of Biostratigraphic Datum Planes of the Pacific Neogene, Taiwan*, ROC. Final Report of IGCP Project 114, N. Ikebe, ed. (in Print).

IKEBE, N., CHIJI, M. and TUNYOW, 1981, Important Datum Planes of the western Pacific Neogene. *Osaka Museum of National History Bull.*, no. 34, p. 79–86.

LAMB, J.L. and STAINFORTH, R.M., 1976, Unreliability of Globigerinoides datum. *Amer. Assoc. Petrol. Bull.*, v. 60, no. 9, p. 1564–1569.

OINOMIKADO, and HUANG, TUNYOW, 1957, Micropaleontological investigation of Kueitanchi section near Chutouchi oilfield. *Symmposium on Petroleum Geology of Taiwan in the Celebration of the Tenth Anniversary*, CPC, p. 257–265.

SAITO, T., 1976, Geologic significance of coiling direction in the planktonic foraminiferal *Pulleniatina*. *Geology*, v. 4, p. 305–309.

SUN, S.C., 1982, The Tertiary basins of offshore Taiwan. *Proc. 2nd. ASCOPE Conf.*, Oct. 7–11, 1981, Manila, Philippines, A. Saliver-Sali ed., Tech. Prog. Commit., ASCOPE '81, p. 125–135.

YEN, T.P., 1971, Geology of Taiwan-A review especially on stratigraphy: *Sino-Amer. Sci. Coorper. Collg. Ocea. Res.* Preprint, v. 1, p. 1–24.

Manuscript received 7 April 1983
Revised manuscript received 16 March 1984.