41. SUMMARY OF LATE PALEOGENE-NEOGENE[1] INSULAR STRATIGRAPHY, PALEOBATHYMETRY, AND CORRELATIONS, PHILIPPINE SEA AND SEA OF JAPAN REGION

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INTRODUCTION

General

Island complexes loosely mark the boundaries of the Philippine Sea and almost isolate the Sea of Japan from the open Pacific (Figures 1 and 2). The Ryukyu, Mariana, and western Caroline islands march in thread-like fashion between the major insular exclamation points presented by the Philippines, Taiwan, Japan, and the genetically related Korean peninsula (Figure 2). Each of these islands presents an obvious and significant opportunity for obtaining basic geologic information bearing on the tectonic, volcanic, and sedimentary history of the region, and each offers a glimpse of much larger but more obscure submarine features (Figure 1). Some of the earliest notions regarding the geologic history of the marginal western Pacific were originally gleaned from studies of island geology, and in some cases not much more is known about some of these islands now than was available a half century ago. The ever-expanding search for mineral resources and accompanying political events in the region have provided impetus for geological study of a number of the islands. However, the quantity, quality, and general rigor of geological exploration has varied widely. The intensely studied Japanese islands of Honshu, Shikoku, and Kyushu stand at the well-lighted end of this spectrum, whereas some of the smaller islands in the region have never been visited by a geologist.

The continuing importance of island geology to modern tectonic reconstructions of the western Pacific margin is ably demonstrated in a recent compendium dealing with this topic edited by Coleman (1973). However, it was clear from precruise perusals of publications describing various aspects of island geology that a relatively modern, if somewhat speculative, correlation of these Tertiary insular sequences was unavailable. Indeed, the most recent comprehensive correlation chart is dated 1953 (Cloud, 1956).[2] Moreover, few of the island sequences have been re-evaluated in light of the now well-established low-latitude planktonic biozones developed and refined over the past decade along with correlations to the radiometric and paleomagnetic time scales (Berggren, 1972). Also, lithologies and associated benthonic fossil assemblages have not been subjected to paleobathymetric interpretation utilizing modern knowledge of depth-related benthonic foraminiferal biofacies, radiolarian-foraminiferan ratios, and other commonly used paleodepth indexes. Consequently, an attempt is made herein to bring together stratigraphic information on a number of the islands surrounding the Philippine and Japan seas.

The most recent publications dealing with relevant island geology were scrutinized, and special attention was paid to the extent of volcaniclastic deposits along with age and duration of major unconformities. Information on planktonic microfossils (primarily planktonic foraminifera) was utilized to date these sequences within the context of the Paleogene and Neogene planktonic foraminiferal zones of Blow (1969); Blow and Berggren (unpublished; see Berggren, 1972) and the working time scale of Berggren (1972). Benthonic foraminiferal data were utilized for interpretation of paleobathymetric and paleoecologic trends providing significant details concerning the history of subsidence and uplift of the islands and related submarine ridges. Compilations and interpretations made of island stratigraphy, age, and paleobathymetry are presented in a series of figures (Figures 3 through 14).

Methods

Reliance was placed on reported benthonic foraminifera for paleobathymetric interpretations, and on planktonic foraminifera and Radiolaria for purposes of dating stratigraphic units containing these fossils. The taxonomic validity of all paleontologic data utilized was tacitly assumed, thus age interpretations as well as paleobathymetric trends presented on the accompanying figures should be viewed as subject to possible significant revision in light of future restudies of existing samples, or more detailed studies utilizing new material and other fossil groups. Studies of calcareous nannofossils are badly needed and would no doubt help to clarify a number of ongoing controversies in this area.

Stratigraphic units were assigned to appropriate Neogene or Paleogene planktonic foraminiferal zones based on the reported presence (or absence) of key species of planktonic foraminifera following the system of planktonic datum planes and zones outlined by Blow (1969); Berggren (1972, 1973); and Berggren and Van Couvering (1974). For example, the *Globorotalia truncatulinoides* datum was utilized for identification of the

[1]Neogene, as used in this report, includes the Miocene through Pleistocene period.

[2]More recent but less comprehensive correlation charts have appeared including that presented by Ladd (1972).

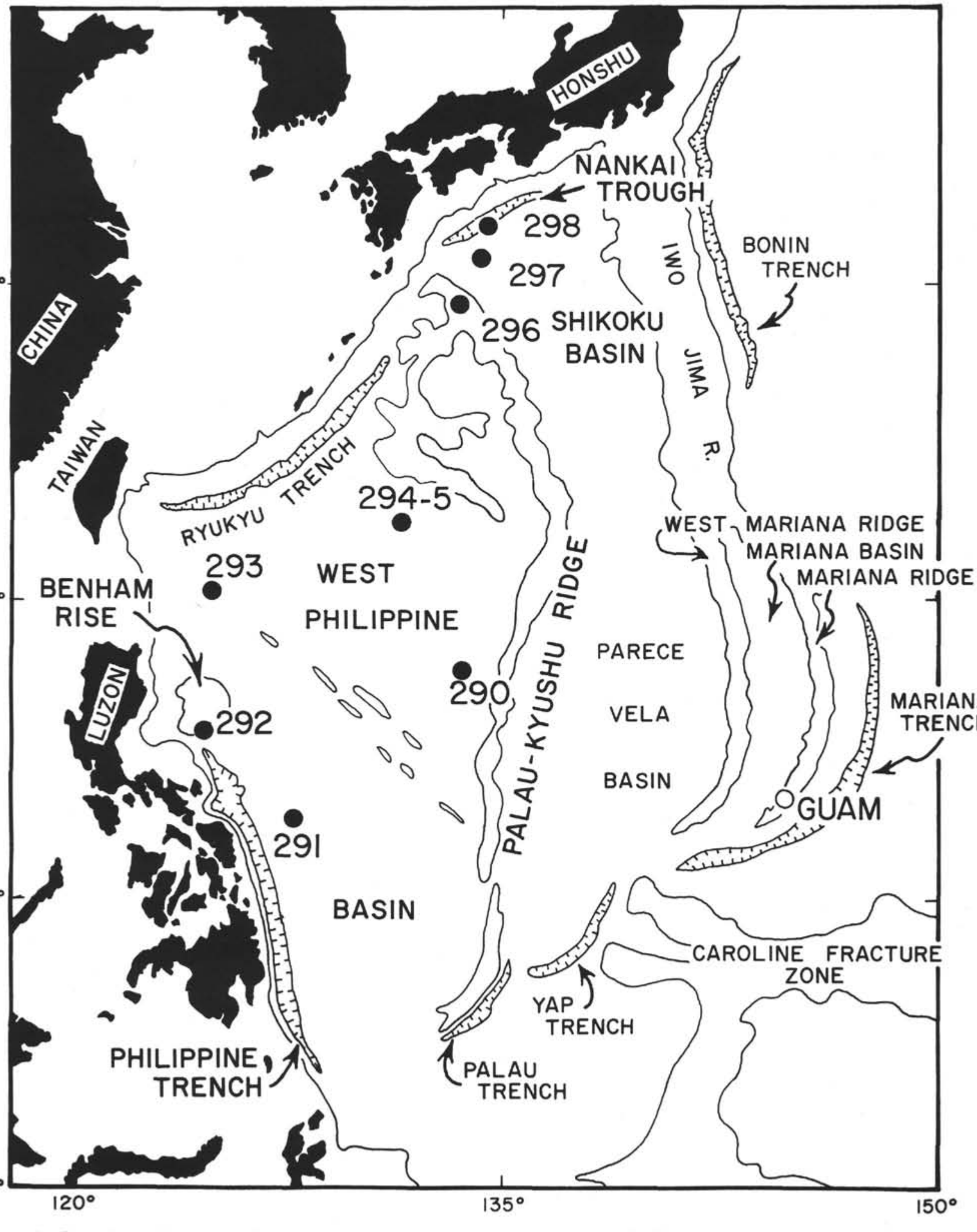


Figure 1. *Location of Leg 31 drilling sites and major bathymetric features in the Philippine Sea area.*

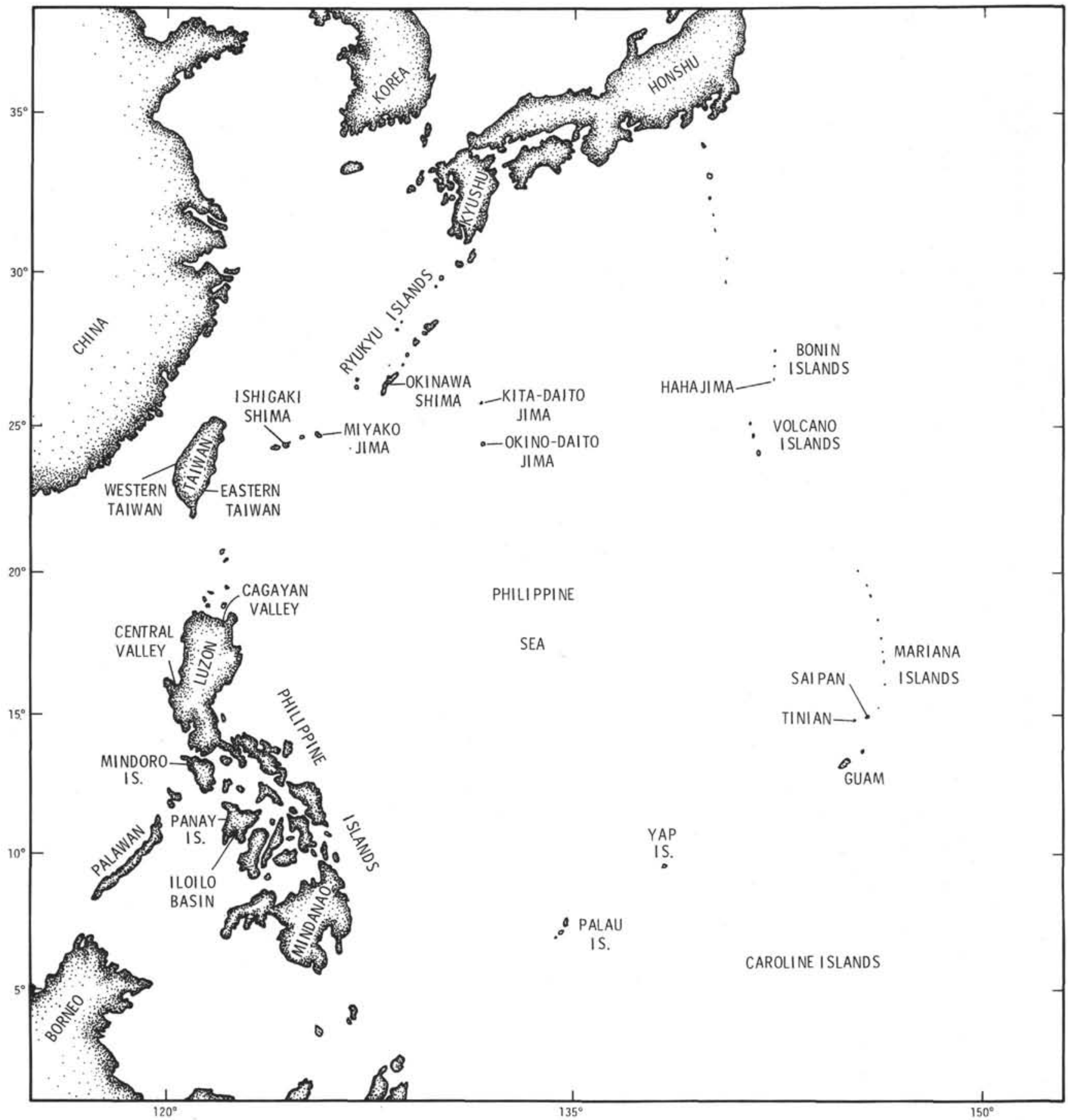


Figure 2. *Location of islands and island groups surrounding the Philippine Sea. Stratigraphic columns and paleobathymetric histories are presented herein for those islands and localities enclosed by boxes.*

Pliocene-Pleistocene boundary (N22/N21 boundary) recognizing that older references to this species may well include morphotypes now placed within *Globorotalia tosaensis*; a good example of where restudy of existing samples would help to clarify older age assignments.

The *Sphaeroidinella dehiscens* datum was used for recognition of the Miocene-Pliocene boundary (N19/N18 boundary), the *Orbulina* datum for the middle Miocene-early Miocene boundary (N9/N8 boundary), the *Globigerinoides* datum for the Miocene-Oligocene boundary (N4/N3 boundary), and the *Hankenina* extinction datum for the Oligocene-Eocene boundary (P18/P17 boundary). In many instances checklists of planktonic foraminifera provided by authors are sufficiently detailed so that placement of a fauna within an established zone is straightforward. In other cases, only the most obvious species of planktonic foraminifera are included in lists of primarily benthonic

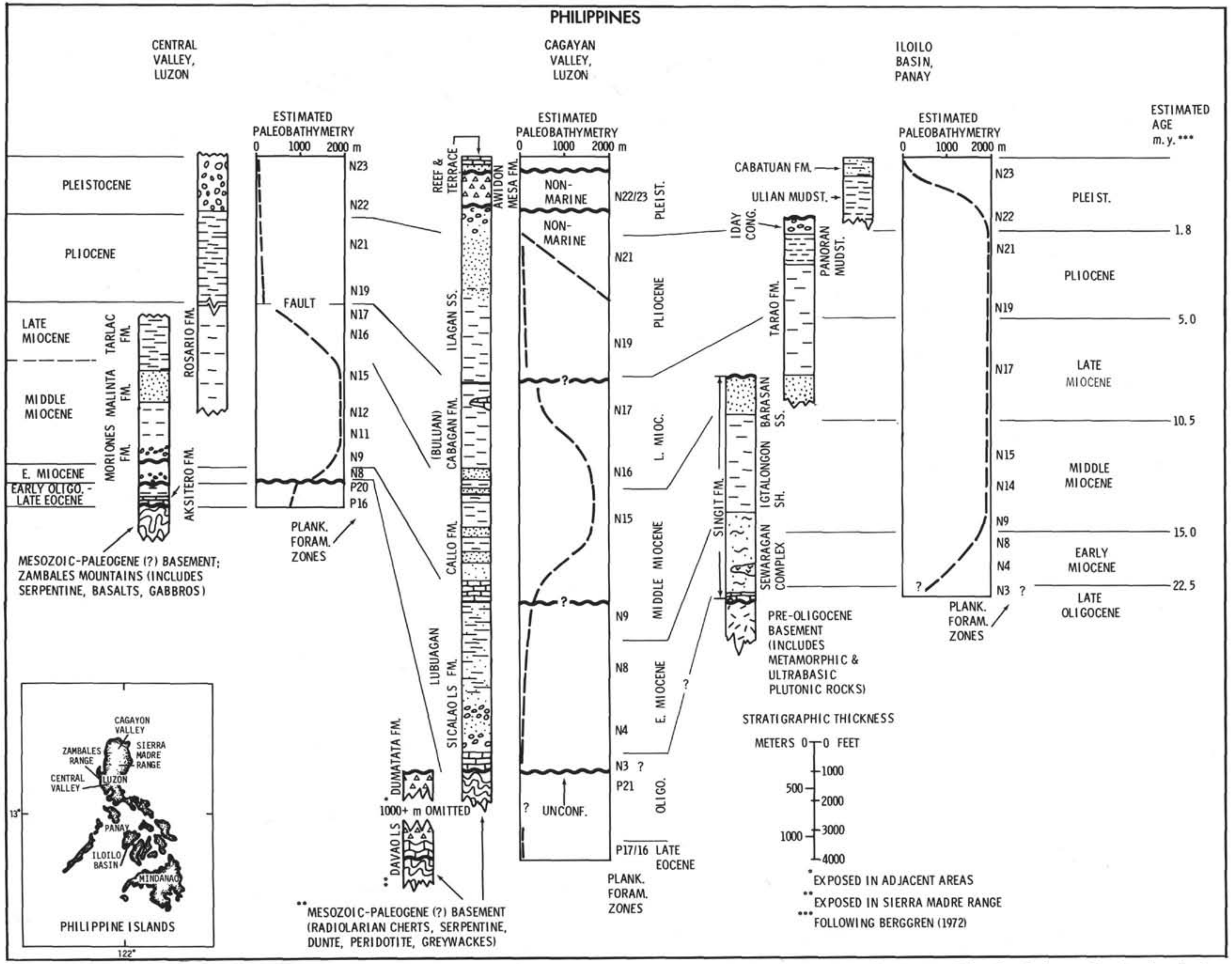


Figure 3. *Paleobathymetry, stratigraphy, ages of selected sedimentary sequences exposed on Luzon, Panay, and the Philippine Islands. Estimated paleodepths based on paleobathymetric analysis of reported benthonic foraminifera, abundance of planktonic foraminifera and Radiolaria, character of sediments. Ages based on reported occurrences of planktonic foraminifera, correlation of Far East letter stages (based on larger foraminifera). Planktonic foraminiferal zones following Blow (1969, p. 289), Berggren (1972), Berggren, and Van Couvering (1974). Correlation of epoch boundaries, planktonic foraminiferal zones, and estimated radiometric ages follows Berggren (1972).*

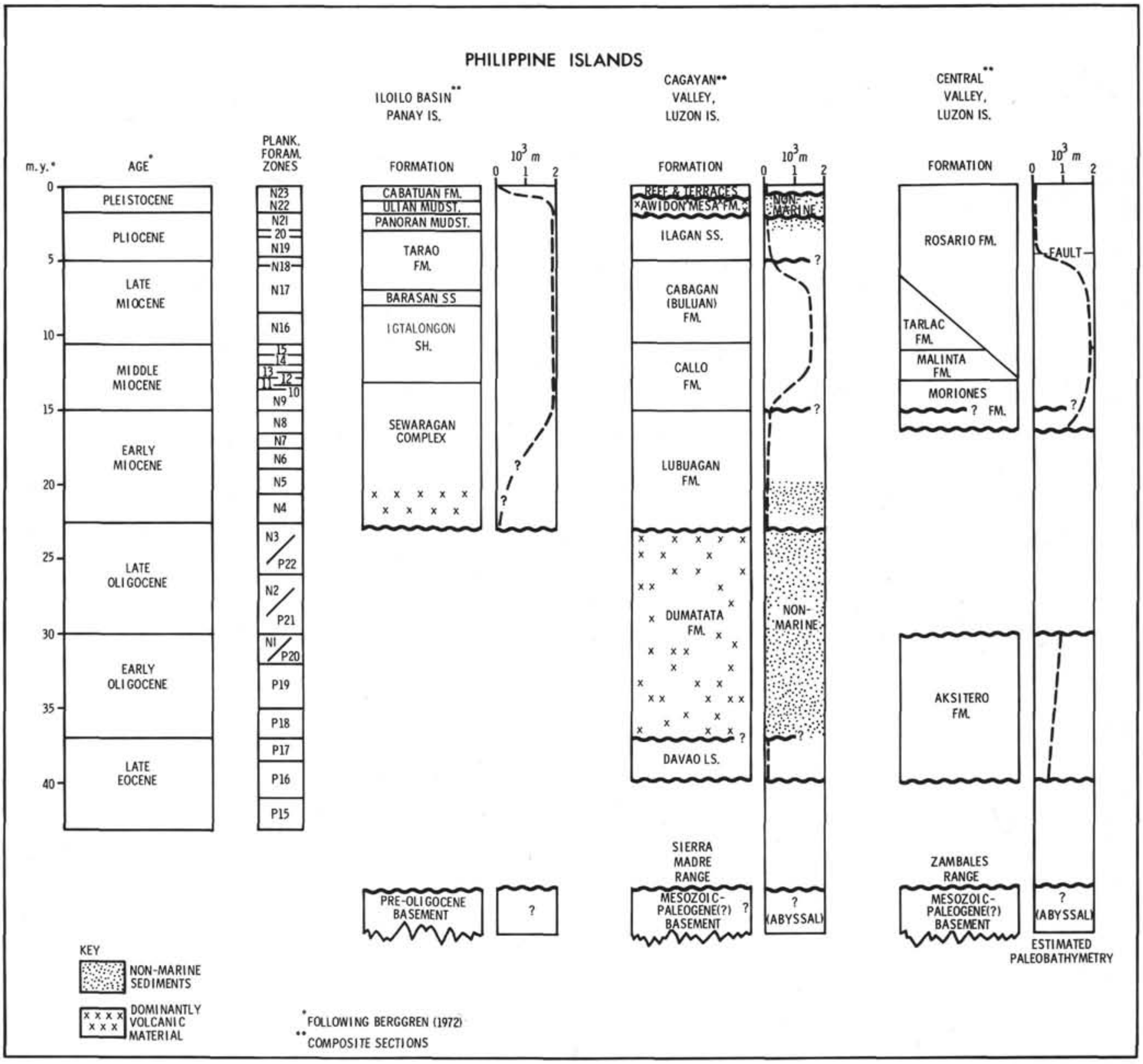


Figure 4. *Age, correlation, and estimated paleobathymetric histories of Tertiary sediments in the Central Valley, Cagayon Valley, and Iloilo Basin areas of the Philipping Islands and eastern Taiwan utilizing information presented on Figure 3 and the time scale of Berggren (1972); references for eastern Taiwan are presented with Figure 8. NOTE: this diagram depicts the estimated duration of each unit and does not illustrate stratigraphic thickness. References used in compiling this figure are the same as those listed for Figure 3.*

species. The only planktonic species cited in many of the older publications is the ever-present "*Globigerina bulloides*." Thus, the certainty and confidence of planktonic zonal assignments vary widely.

In cases where planktonic foraminifera were absent, unreported, or poorly described from a unit, reliance was commonly placed on reported species of larger foraminifera and calcareous algae following correlations of the Far East letter stages with ranges of critical genera of larger foraminifera and planktonic foraminiferal zones as detailed by Blow (1969); Adams (1970); and Berggren (1972, 1973). Radiolarian zonation was utilized only in the case of the Densinyamà and Hagman formations of Saipan and the Map Formation of Yap utilizing a report by Sanfilippo, Westburg, and Riedel prepared for this volume (Chapter 1), and following the radiolarian zones detailed by Riedel and Sanfilippo (1971).

Age assignment of units deposited around the rim of the Sea of Japan and characterized by subtropical through subarctic planktonic biofacies is based on reported occurrences of planktonic foraminifera,

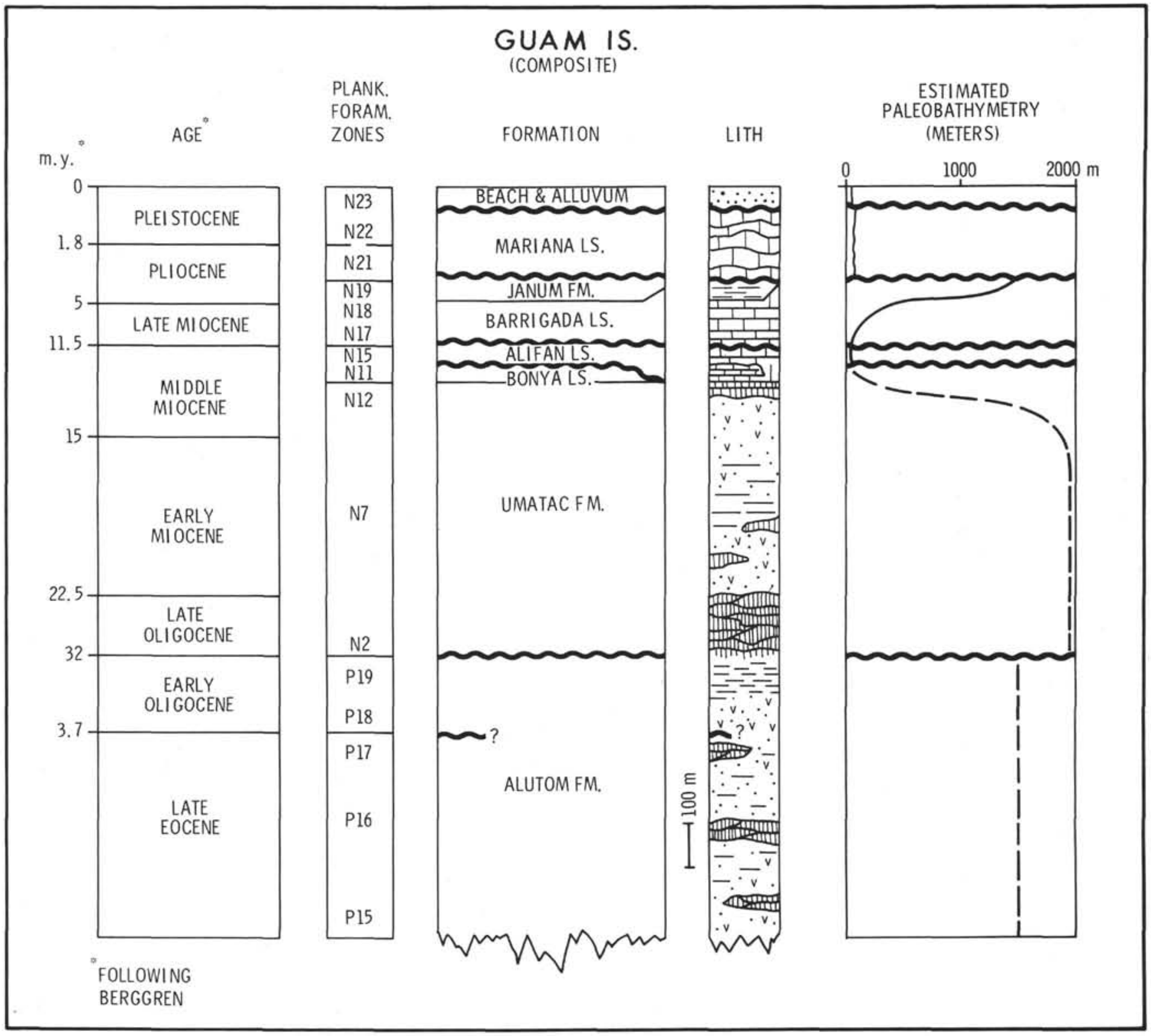


Figure 5. *Stratigraphy, ages, and estimated paleobathymetry of Tertiary rocks exposed on Guam, Mariana Islands. Paleobathymetry based on analysis of reported occurrences of benthonic foraminifera with ages based on planktonic and larger foraminifera. References used in compiling this diagram include Tracey et al (1964); Todd (1966); Blow (1969, p. 291); and personal field notes.*

diatoms, and tentative correlations of these higher latitude biofacies with the low-latitude Neogene zones of Blow (1969) following Ikebe et al. (1972); Ingle (1973b); and Koizumi (1973, this volume).

Paleobathymetric curves presented on figures accompanying this report are based primarily on paleodepth interpretations of reported occurrences and abundances of benthonic foraminifera. However, reported lithologies and sedimentary structures were also utilized. For example, the presence of laminated diatomaceous sediments such as those common to the Onnagawa Formation of northern Honshu are interpreted as direct evidence of deposition under anaerobic conditions associated with the oxygen minimum zone (Calvert, 1964; Ingle, 1967, 1973c), and many lithologic descriptions include unequivocal evidence of bathyal turbidite deposition. Standardized procedures for interpreting groups of depth-diagnostic fossil and recent benthonic foraminifera have been discussed in detail by Bandy (1960); Bandy and Arnal (1967, 1969); and Ingle (1967). These same techniques were utilized in interpretation of benthonic foraminiferal faunas reported from various island sequences utilizing distributional data on living benthonic foraminifera in this region provided by Graham and Militante (1959), Frerichs (1970), and others. Pertinent references dealing with living

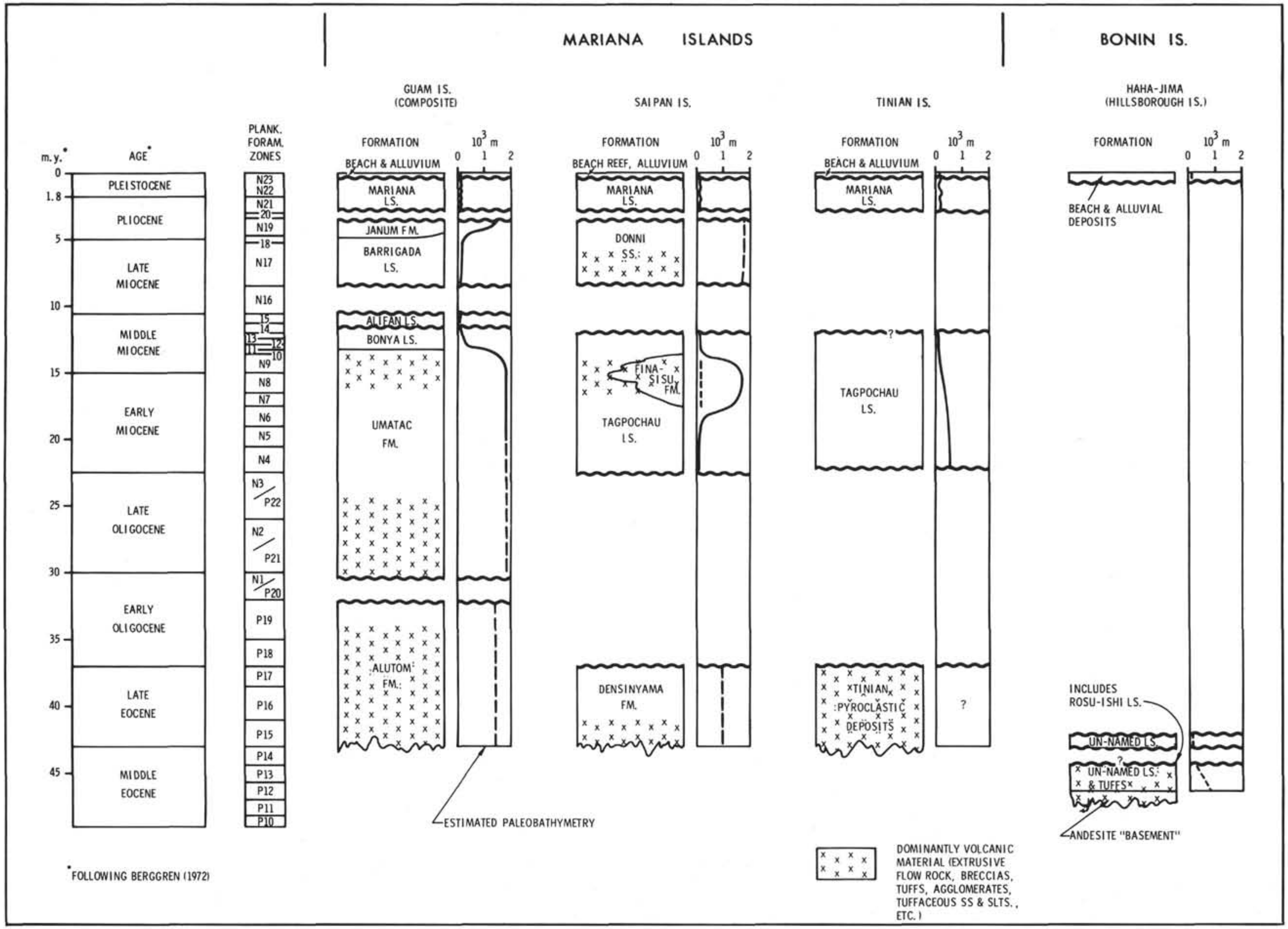
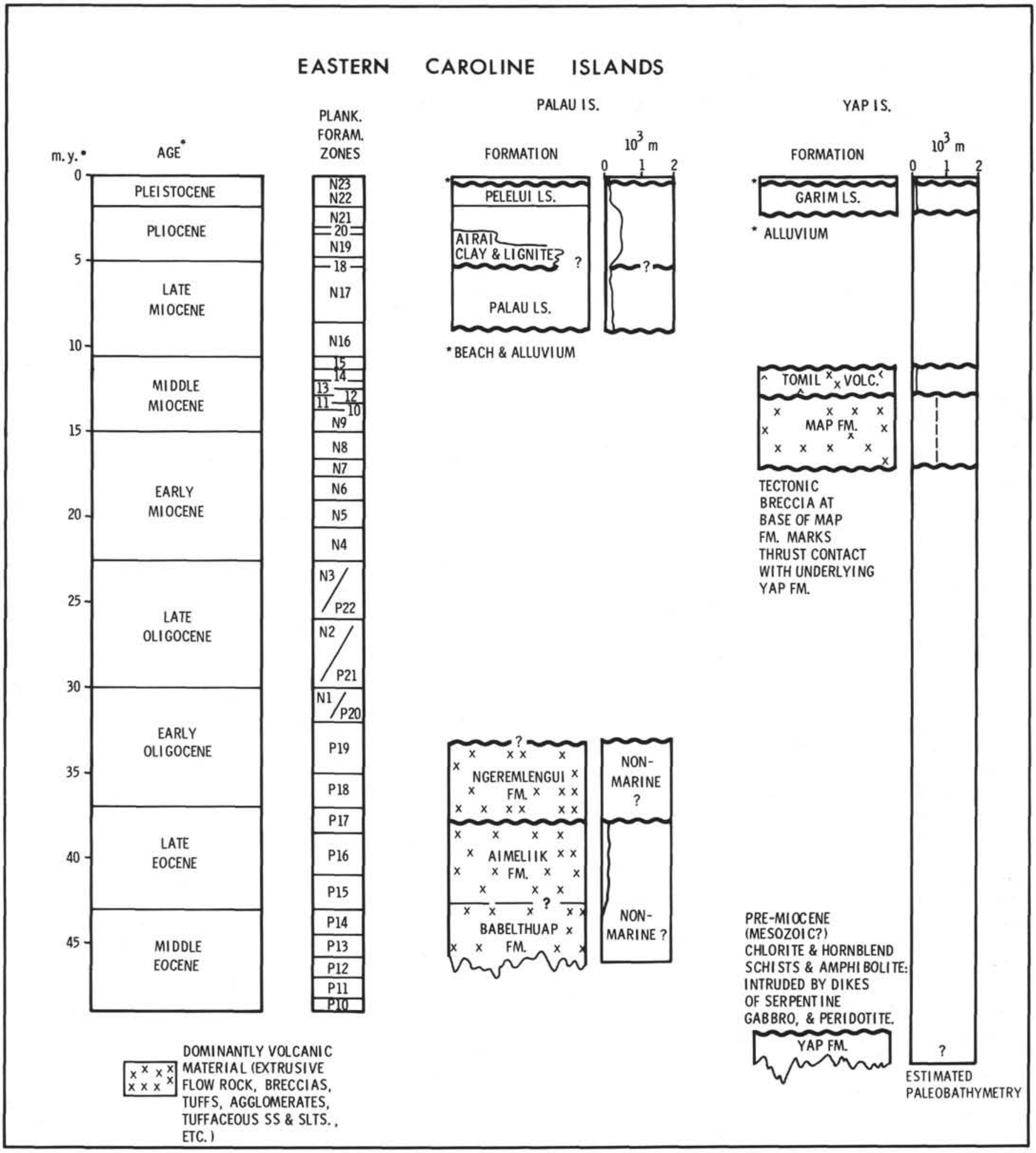


Figure 6. *Age, correlation, and estimated paleobathymetric histories of sedimentary sequences exposed on Guam, Saipan, and Tinian islands; Mariana Islands; and Haha-jima, Bonin Islands. References used for analysis of Guam section are the same as given for Figure 5. Paleobathymetric and age analysis of Saipan, Tinian, and Haha-jima sequences based on reported benthonic and planktonic foraminifera in papers by Hanzawa (1947); Cole and Bridge (1953), Cloud et al (1956), Todd (1957), Doan et al. (1960a), Saito (1962), and a report prepared by Sanfilippo, Westberg, and Riedel (Chapter 1) re-evaluating Eocene radiolarian assemblages from Saipan in light of the radiolarian zones presented by Riedel and Sanfilippo (1971). NOTE: this figure depicts the estimated age range of each unit and does not illustrate stratigraphic thickness.*



*FOLLOWING BERGGREN (1972)

Figure 7. *Age, correlation, and estimated paleobathymetric histories of sedimentary sequences exposed on Palau and Yap islands, eastern Caroline Islands utilizing data in Cole (1949), Mason, et al. (1956), Johnson, et al. (1960), and a re-evaluation of radiolarian assemblages from Yap Island by Sanfilippo, Westberg, and Riedel (Chapter 1) in light of the radiolarian zones presented by Riedel and Sanfilippo (1971). NOTE: this diagram depicts the estimated age range of each unit and does not illustrate stratigraphic thickness.*

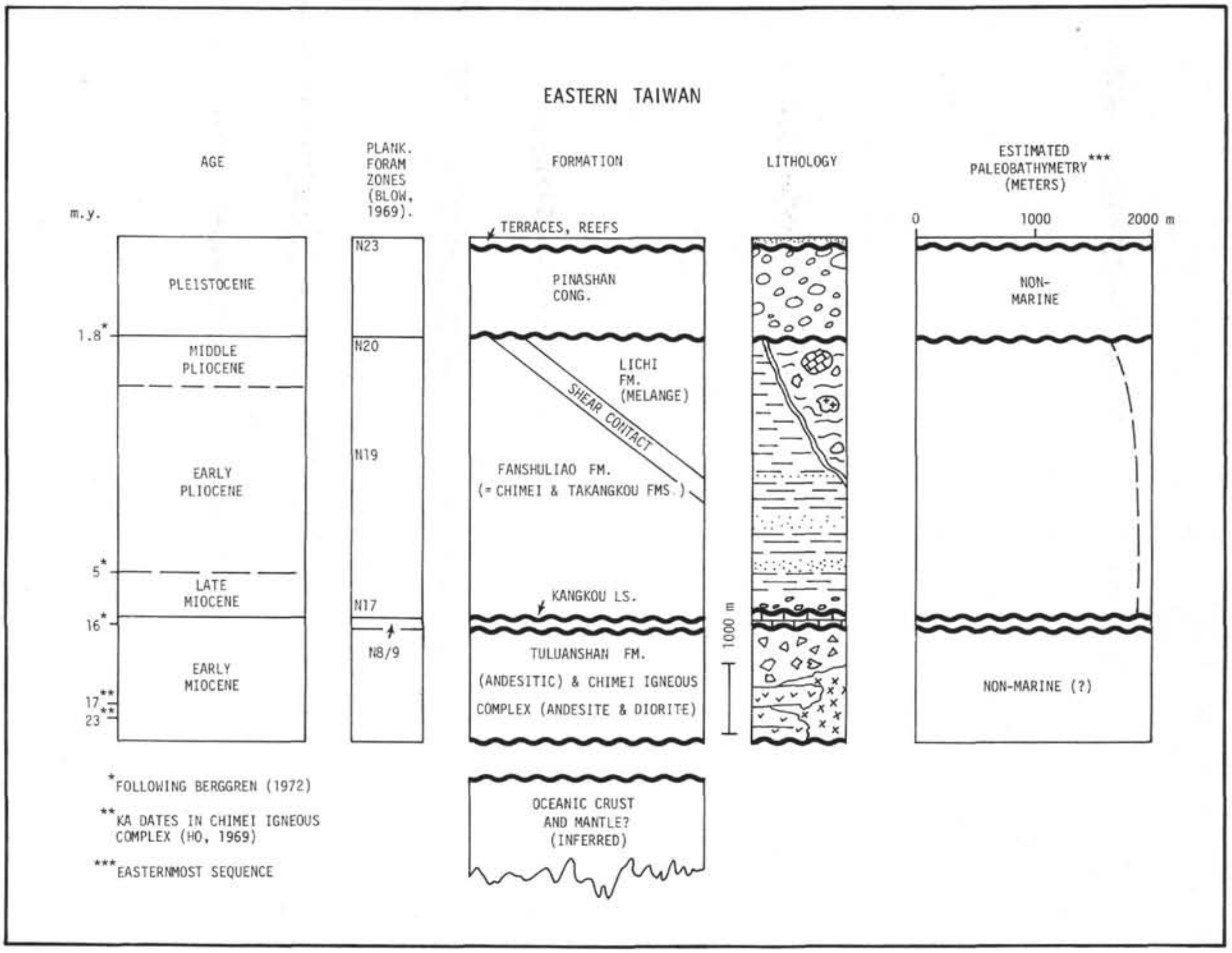


Figure 8. *Stratigraphy, age, and estimated paleobathymetry of eastern Taiwan based on data provided by Huang (1964); Chang (1967, 1968, 1969); Chang and Chen (1970); Chai (1972); and Page (1974). Paleobathymetric interpretation based on reported occurrences of benthonic foraminifera with ages based on associated planktonic foraminifera following the time scale of Berggren (1972). The Lichi Formation is interpreted as a melange which includes blocks of ophiolitic rock and is in part the same age as the Fanshuliao Formation. The sheared contact between these two units is thought to be associated with emplacement of the Lichi melange by submarine sliding during Plio-Pleistocene with incorporation of ophiolitic debris all associated with collision between an andesitic arc (Tuluanshan Formation) and the Asian margin (Page, 1974; personal communication, 1974).*

benthonic foraminifera around the Japanese islands including the Sea of Japan are reviewed by Asano et al. (1969) and are not repeated here. Reported occurrences of the isobathyal species *Melonis pompilioides* were particularly useful in identifying lower bathyal sequences deposited at depths of 1800 meters or deeper (Bandy and Chierci, 1966; Frerichs, 1969, 1970). Interestingly, a transition from a lower bathyal calcareous fauna containing *Melonis pompilioides* to an underlying almost wholly arenaceous benthonic fauna is present within the Shimajiri Formation of Okinawa (LeRoy, 1964) and may well represent evidence of deposition within the lysocline or top of the calcium carbonate compensation zone. This, in turn, is indicative of a water depth approaching or exceeding 4000 meters despite earlier interpretations of a much shallower origin for this unit.

Finally, it should be noted that the deepest dwelling species reported in any given assemblage were assumed to represent the in situ fauna, and that any species indicative of shallower depths were assumed to have been displaced downslope. Thus, estimated paleobathymetric curves presented in this report are based on the deepest biofacies reported at any given horizon in turn representing minimum depths of deposition.

COMMENTS ON PHILIPPINE SEA AND SEA OF JAPAN INSULAR STRATIGRAPHY

General

The figures accompanying this report are for the most part self-explanatory, and each reader will no doubt integrate and/or alter their interpretative content into his personal purview of the geological history of the Philippine Sea-Japan Sea region. Moreover, a comprehensive synthesis of Tertiary tectonic and volcanic events of this region is provided by Karig (this volume), and the

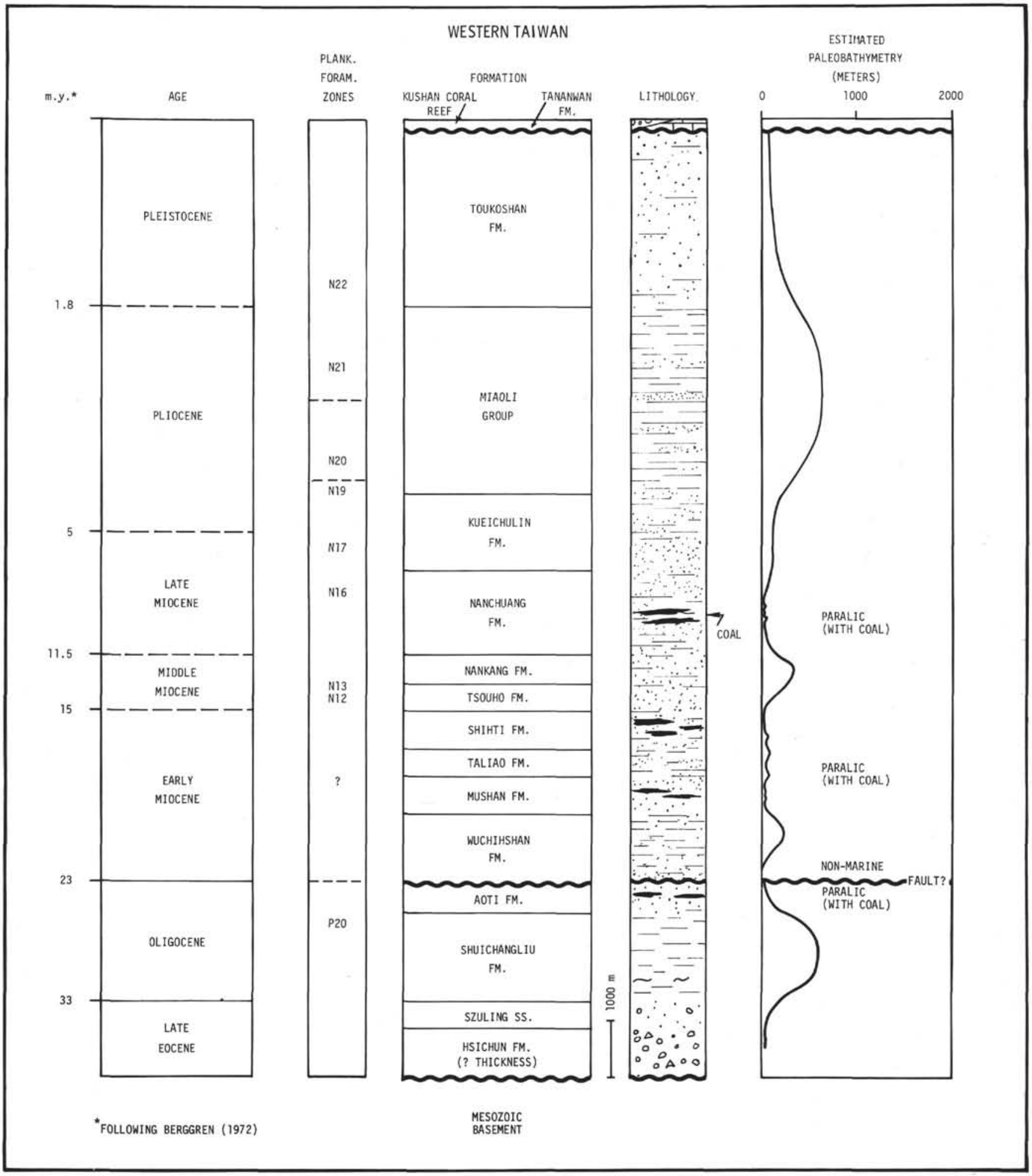


Figure 9. *Stratigraphy, age, and estimated paleobathymetry of Tertiary sediments exposed in western Taiwan based on analysis of paleontologic and lithologic data provided in Chang (1972). Ages based on reported occurrences of planktonic foraminifera in Chang (1972) and planktonic foraminifera in equivalent subsurface horizons detailed by Huang (1963); lack of zonal boundaries and limited zonal assignments reflects paralic deposition for significant portions of the sequence as well as limited information on planktonic assemblages present.*

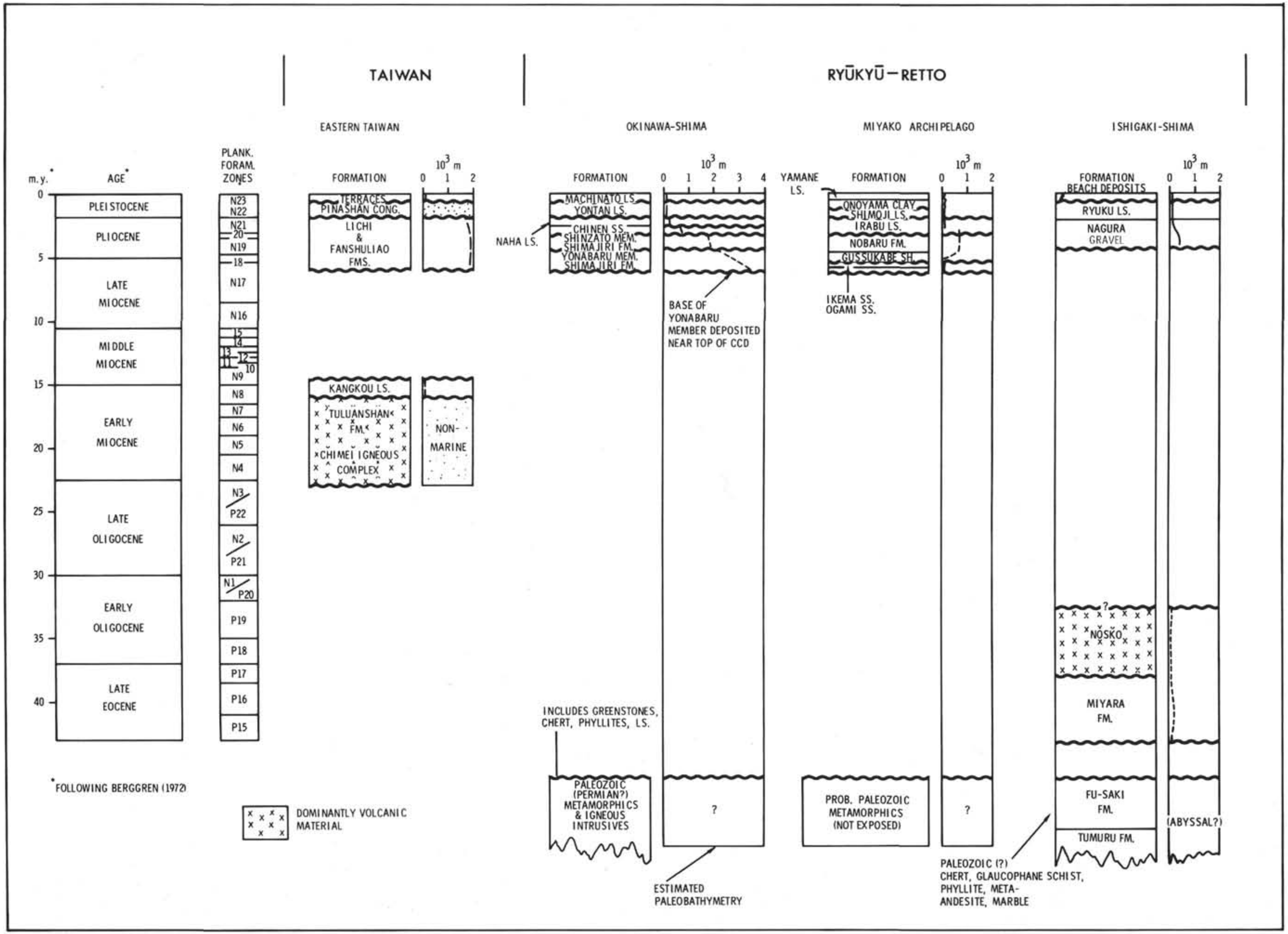


Figure 10. *Age, correlation, and estimated paleobathymetric histories of Tertiary sedimentary sequences exposed on Okinawa Island, the Miyako archipelago, and Ishigaki-shima Island of the Ryukyu chain (Figure 2). Paleobathymetric analyses and age assignments based on reported benthonic and planktonic foraminifera, respectively, utilizing data provided by authors listed on Figure 8 and papers by Flint, et al. (1965); Doan, et al. (1960b); Le Roy (1964); Foster (1965); Ujiié and Miyagi (1973). NOTE: this diagram depicts estimated age range of each unit and does not illustrate stratigraphic thicknesses.*

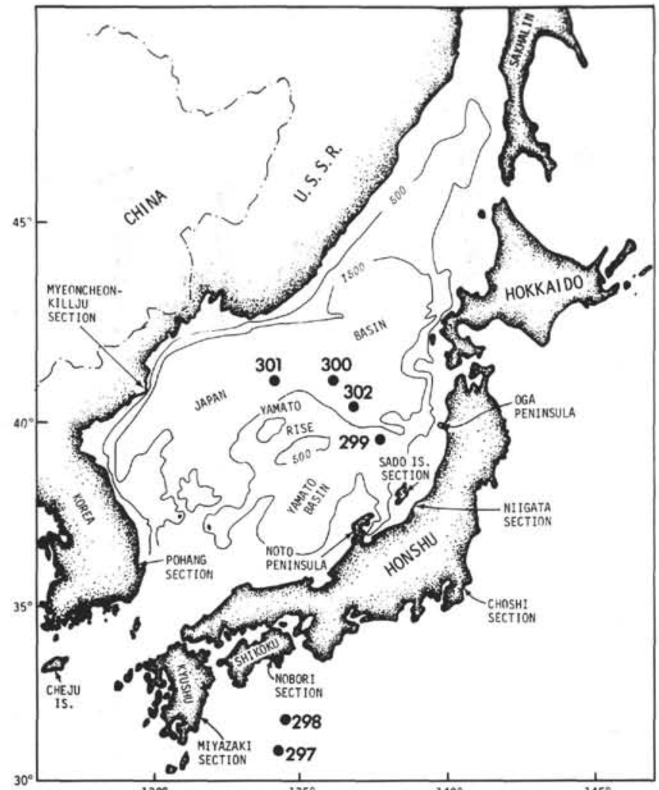


Figure 11. *Location of Leg 31 drilling sites and general bathymetry in the Sea of Japan as well as significant stratigraphic sections noted in this report. Stratigraphic colums and paleobathymetric histories are presented herein for those localities enclosed in boxes. Contours are in fathoms.*

details and interpretations of this latter paper need not be repeated here. Thus, the following comments simply call attention to some apparent and interesting sedimentary and tectonic trends contained within island rocks and sediments with reference to some of the major conclusions presented by Karig (this volume), and an overview of repetitive Neogene stratigraphic sequences in the North Pacific.

Philippine Sea Margin

The general late Eocene through Oligocene history contained within sediments on Luzon, Panay, Davao, and Mindanao islands (Melendres and Comsti, 1951; Ranaft et al., 1960; Figure 3) involves: (a) bathyal deposition of calcareous pelagic oozes in the newly extended West Philippine Basin (Akistero Formation of Luzon; Figure 3) and shallow deposition on adjacent highs (Davao Limestone) followed by (b) widespread uplift, erosion, and nonmarine deposition of volcaniclastic debris over a wide area of the Philippine in the later Oligocene (Figures 3 and 4) during a waning of a major Eocene-early Oligocene volcanic and tectonic pulse (Karig, this volume). These deposits commonly overlay complex ophiolitic sequences (Figure 3) representing the deformed remains of an east-facing Paleogene arc-trench system (Karig, 1973). Significantly, the period of widespread Oligocene erosion and nonmarine deposition in the Philippine area is also coincident with a general period of worldwide regressive seas. This regression is apparently the byproduct of global eustatic sea-level lowering produced by a major period of intense polar refrigeration commencing during late Eocene-early Oligocene time[3] and lasting through the mid-Oligocene. However, volcaniclastic sediments were deposited at bathyal depths in the vicinity of the present Mariana Ridge (part of the Palau-Kyushu Ridge at that time) during the same period (Figures 5 and 6), with upbuilding and deposition within wave base in the area of the northern Bonins as early as the late Eocene (Figure 6). Evidence of this same Eocene-Oligocene volcanic-extensional pulse (Karig, this volume) is also illustrated by the Nosoko Formation in the Ryukyu Islands and the Ngeremlengui, Aimeliik, and Babelthuap formations of Palau at the southern end of the Palau-Kyushu Ridge (Figures 7 and 10).

Widespread basin formation subsidence and transgressive marine sequences characterized many areas around the Pacific rim during the early Miocene coincident with a significant climatic warming, rising sea level, and several major tectonic events including massive volcanism, a possible major change in the vector of the Pacific plate and related variations in rates of subduction in the marginal western Pacific. Neogene sediments exposed on Luzon and Panay contain evidence of a similar history with subsidence, basin formation, and marine transgression accelerating toward a climax in the middle and late Miocene (Figures 3 and 4). This same period saw major rifting of the Sea of Japan as discussed later in this report, the apparent rapid opening of the Parece Vela-Shikoku basins (Karig, this volume), uplift, erosion, and shallow deposition on the southern portions of the Mariana and Palau-Kyushu ridges recorded on Guam and Yap (Figures 5, 6, and 7), and active andesitic volcanism along a westward-moving arc represented by the Tulanshan Formation of Taiwan (Figure 8). Cessation of volcanism and initiation of shallow carbonate deposition occurred in the latest early Miocene in this latter area (Figure 8). Yap records a more stable history for the southern tip of the Palau-Kyushu Ridge after mid-Miocene uplift with intermittent shallow carbonate deposition and erosion continuing through the Pleistocene. This is in contrast to further intervals of major subsidence and uplift recorded on the southern Mariana Ridge at Guam (Figures 5 and 6).

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[3]Accumulating evidence for a major period of rapid climatic deterioration and severe refrigeration during the latest Eocene and Oligocene includes major changes in the character of planktonic foraminiferal populations (Cifelli, 1964); major shifts in molluscan and floral diversities in mid and higher latitude areas (Addicott, 1969); isotopic paleotemperature data from the Antarctic area (Shackleton and Kennett, 1974); widespread regressive and nonmarine sequences characteristic of this period (Sespe Formation and equivalent beds along the Pacific Coast of North America; Daijima and related deposits in Japan); and evidence of increased planktonic productivity (see Chapter 4, Hole 292) in turn mirroring increased vigor of atmospheric transport and overturn of surface waters in equatorial and convergence zones.

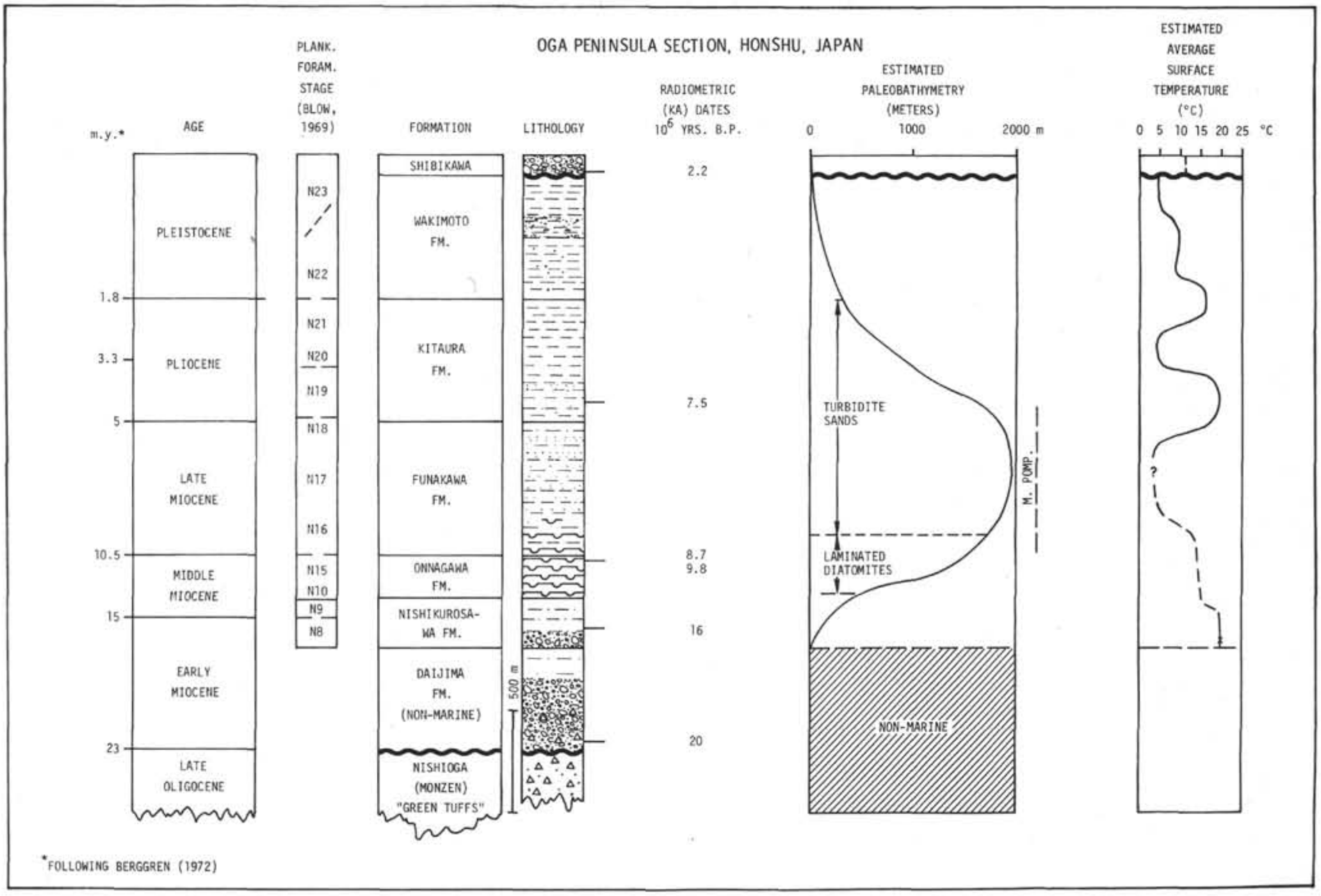

Figure 12. *Stratigraphy, age, and estimated paleobathymetry of Neogene marine deposits of the Oga Peninsula area, northern Honshu (Figure 11). Paleodepths based on paleobathymetric interpretation of reported benthonic foraminifera (Matsunaga, 1963; Asano, et al., 1969) and variation of lithology. Ages and estimated variations of surface temperature based on interpretation of reported ranges and abundances of planktonic foraminifera including coiling characteristics of* "Globigerina" pachyderma *utilizing the data of Saito (1963), Takayangi and Oba (1966), Asano et al. (1969), Saito and Maiya (1973), Maiya et al. (in press). Age interpretations also incorporate diatom zonations of Kanaya (1959) and Koizumi (1968). Details of radiometric dates (K-Ar) in this section are given by Ikebe et al. (1962).*

The most recent events recorded by island geology along the margins of the Philippine Sea include the cessation of subsidence and filling of Miocene basins in the Philippine area by the late Pliocene and early Pleistocene (Figures 3 and 4). Major uplift, folding, and erosion of these Neogene bathyal marine sediments in the Luzon and Panay areas began in the late Pliocene and continued into the Pleistocene coincident with collision of the Philippine and Ryukyu arcs (Karig, 1973). This same tectonic event apparently induced the first major Neogene subsidence of otherwise paralic deposits along the Asian margin as recorded by the Miaoli Formation of western Taiwan (Figure 9), with continued bathyal trench-slope deposition to the east represented by the Fanshuliao and Lichi formations of eastern Taiwan (Figures 8 and 10). Submarine sliding and tectonic mixing of these latter trench-slope deposits occurred in the latest Pliocene-early Pleistocene during the climax of the arc-arc collision (Figure 8; Page, 1974). The staggered history of uplift recorded on Okinawa during the late Miocene through Pleistocene (Figure 10) provides an especially clear picture of the episodic nature of the Luzon-Ryukyu collision process. In addition, late Miocene through early Pleistocene bathyal slope and shelf deposits of the Miyazaki area of Kyushu (Natori, 1962; personal field notes and samples) and the bathyal slope deposits of the Nobori Formation (Katto et al., 1953; Takayanagi and Saito, 1962; Uchio, 1967) of western Shikoku were uplifted and folded during the mid and later Pleistocene as the rate of subduction increased in the adjacent Nankai Trough (Karig, this volume; Chapter 9, Site 298).

Sea of Japan Margin

Unfortunately, Leg 31 failed to penetrate the entire sedimentary column at deeper sites in the Yamato and Japan basins of the Sea of Japan (Figure 11; Chapters 10-13) leaving the question of a possible Late Mesozoic and/or Paleogene marine incursion in this area unanswered. However, evidence for initial late Mesozoic-Paleogene (?) rifting and nonmarine deposition seems clear enough (Chapter 10, Site 299) and meshes well

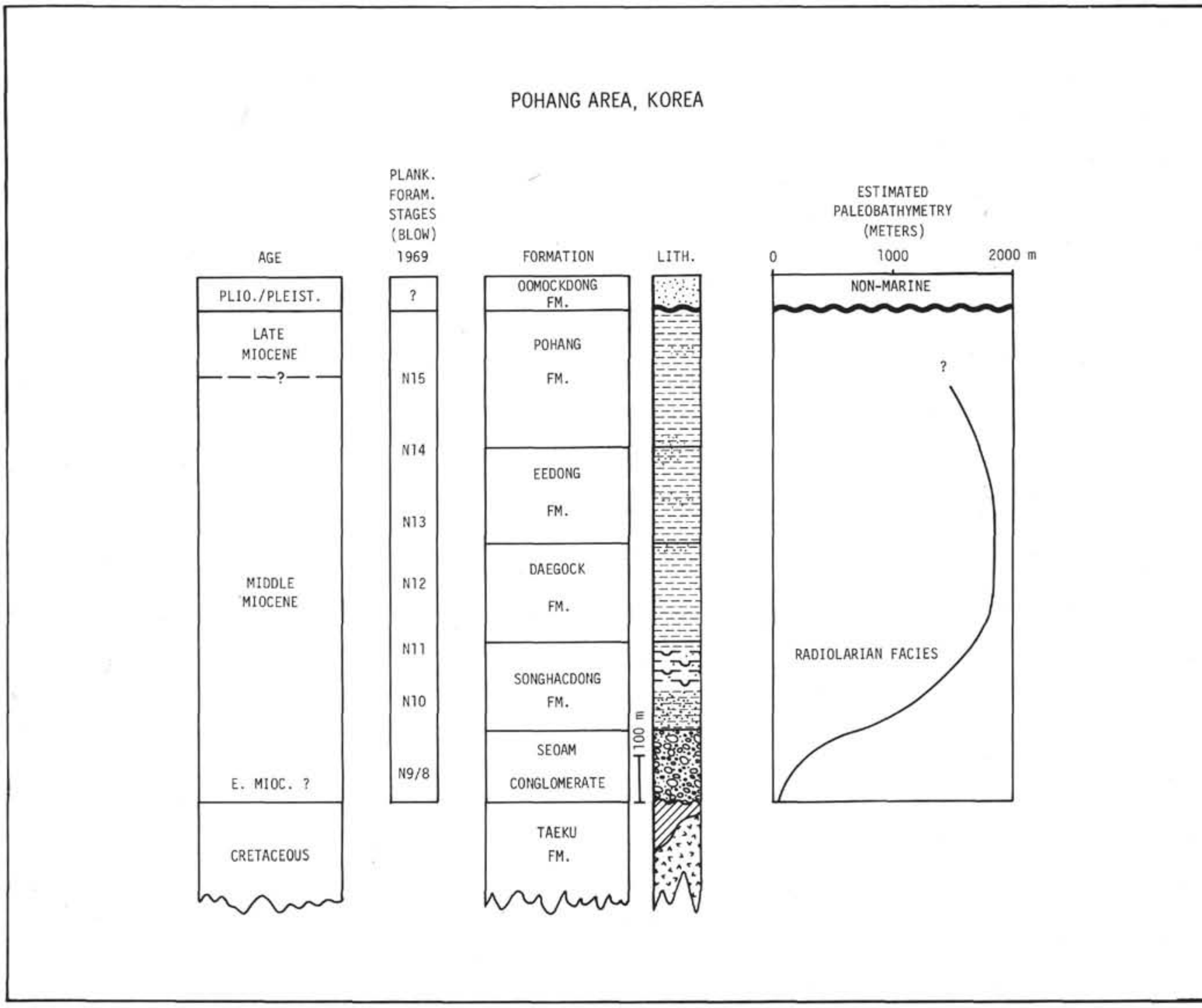

Figure 13. *Stratigraphy, age, and estimated paleobathymetry of Neogene marine sediments exposed in the Pohang area, Korea (Figure 11). Paleobathymetry and age based on interpreataion of reported benthonic and planktonic foraminifera, respectively, utilizing the data of Kim (1965).*

with a proposed initial period of back-arc extension (Uyeda and Miyashiro, 1974). Thus, Neogene marine sequences exposed along the eastern and southern rim of the sea in coastal Honshu and the Korean peninsula continue to provide some of the most definitive evidence of Tertiary marine events in the area (Figure 11).

The best and most intensely studied sequence of Neogene strata along the western coast of Honshu is present on the Oga Peninsula and adjacent Akita subsurface section (Figures 11 and 12). The late Oligocene and early Miocene history recorded in these sections consists of massive deposition of the so-called andesitic "green tuffs" (Nishioga and Monzen formations) and unconformably overlying nonmarine beds of the Daijima Formation (Kato, 1955; Kitamura, 1959; Kimura, 1972). These deposits are commonly viewed as evidence of the major rifting in the Sea of Japan area with marine transgression commencing with deposition of the littoral and neritic Nishikurosawa Formation and equivalent latest early Miocene deposits exposed elsewhere along the western coast of Honshu in the Niigata area, Sado Island, and the Noto Peninsula (Figures 11, 13, and 14).

Rate of subsidence increased in the middle and late Miocene with deposition of diatomaceous deposits assigned to the Onnagawa Formation (Figure 12). Similar middle Miocene laminated diatomites and siliceous shales are found in a number of Neogene sequences along the coast of Honshu as well as Sado Island and the Pohang area of Korea (Figures 11 and 14). All of these deposits are strikingly similar to the diatomaceous shales of the Monterey Formation of California and are interpreted as representing deposition in prominently silled basins (Asano et al., 1969; Ingle, 1973c) and likely correlative in part with

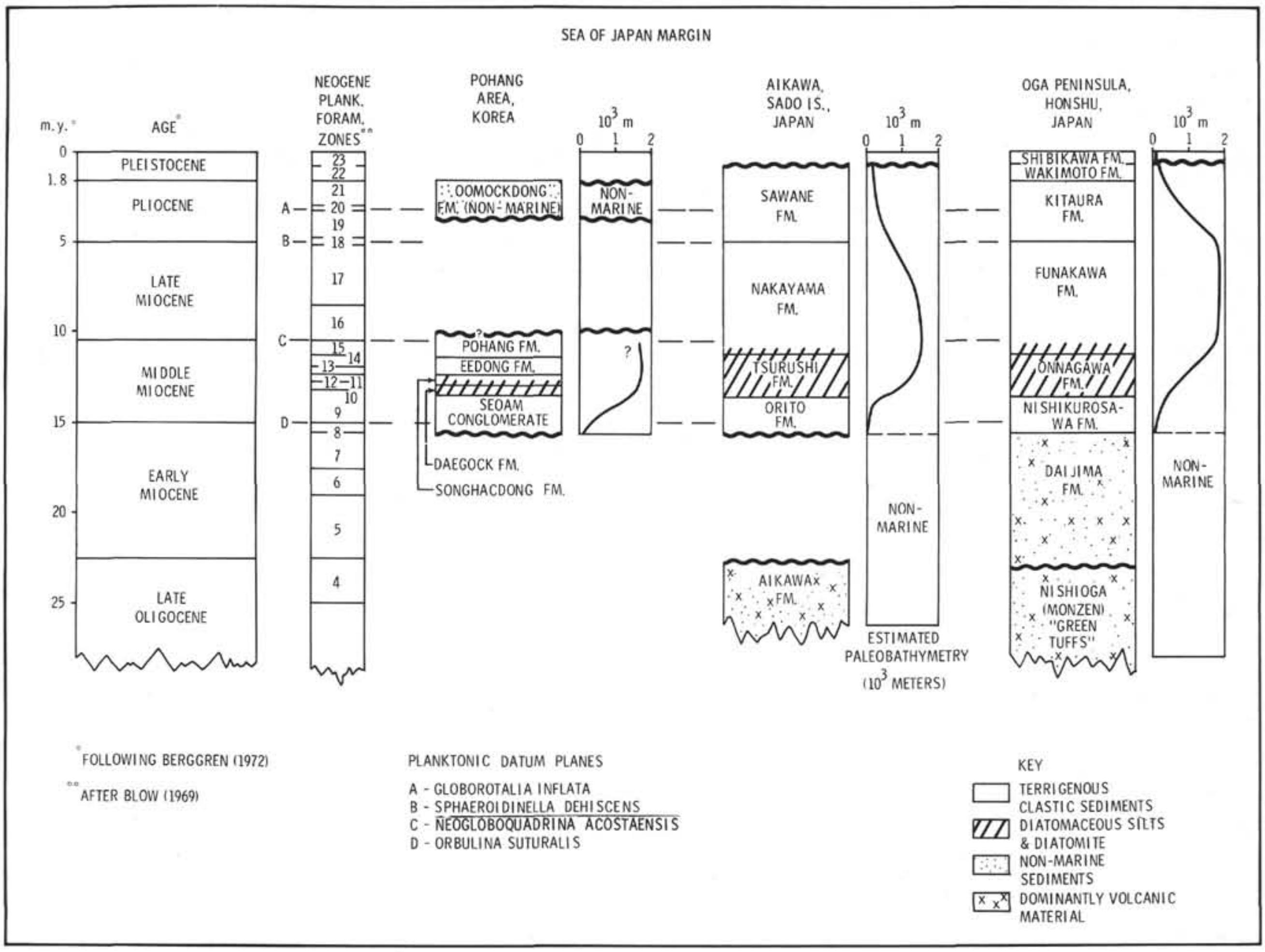

Figure 14. *Age, correlation, and estimated paleobathymetric histories of Neogene sediments exposed on the Oga Peninsula of Honshu, the Aikawa area of Sado Island, and the Pohang area, Korea (Figure 11). Paleobathymetry and ages based primarily on interpretation of benthonic and planktonic foraminifera reported by workers noted on Figures 12 and 13 as well as data on Sado Island by Shimazu et al. (1969); Kobyashi (personal communication); Koizumi (personal communication); and personal field notes. The Oga Peninsula section represents a revised version of a similar figure presented in an earlier paper (Ingle, 1973c).*

acoustically transparent sediments detected at Sites 299 and 301 in the Japan and Yamato basins (Chapters 10 and 12). Both massive and laminated diatomites are present within these deposits indicating occasional deposition under anaerobic conditions induced by the effects of sluggish bottom circulation and basin sills within the oxygen minimum zone (Emery and Hulesmann, 1961; Calvert, 1964). These same deposits also reflect prolific diatom productivity and a relative lack of terrigenous debris to dilute diatom frustules. However, basinward movement of turbidite sands and silts began to cap and dilute diatomaceous sediments near the margins of the Sea of Japan by the late Miocene as exemplified by the Funakawa Formation of the Oga Peninsula area (Figure 12). Interestingly, diatomaceous deposits remained essentially undiluted by terrigenous debris through Pliocene time in the deeper and more isolated portions of the sea (Chapter 12, Site 301) attesting to continued prolific diatom productivity. Areas elevated above the basin floors such as the flanks of the Yamato Rise penetrated at Site 302 have continued to accumulate undiluted diatomaceous sediments to the present (Figure 11; Chapter 13). The coarser nature of Miocene marine sediments in the southern reaches of the sea as exposed in the Pohang and Myeoncheon-Killju areas of Korea (Kim, 1965; Figure 13) indicates this area experienced less subsidence and was filled earlier than areas to the north and east.

Bathyal turbidite sequences and neritic deposits record the rapid filling of the near-shore basins in the Sea of Japan during the Pliocene and early Pleistocene (Kitaura and Wakimoto formations of the Oga Peninsula area; Figure 12) with major uplift and flexing of Neogene basinal sequences along the entire eastern and southern margins of the sea during the later Pleistocene as marked by angular unconformities in coastal sections. This latest tectonic event is coincident with an increased rate of subduction in the Nankai Trough (Chapter 9, Site 298, this volume) and ultimately readjusted the margins and sills of the Sea of Japan to their present configuration (Figure 11).

STRATIGRAPHIC SIMILARITY OF NEOGENE MARINE SEQUENCES IN THE MARGINAL PACIFIC

It is important to note in closing that the Neogene sedimentary sequences generated during basin development and filling in the Sea of Japan (exemplified by the Oga Peninsula section; Figure 12) are identical in many respects to the well-documented Neogene sequences produced during evolution of the continental borderland of southern California (Emery, 1960; Moore, 1973; Ingle, 1973a) and many other Neogene sections exposed along the Pacific Coast of North America and the Pacific rim in general (Ingle, 1973c). This ubiquitous episode of marginal basin development (Dott, 1969) was in all likelihood a product of a major adjustment of plate margins in the late Oligocene and early Miocene in response to closing of the Tethys Sea (Heirtzler et al., 1968; Packham and Falvey, 1971). Indeed, the widespread and rapid creation of marginal basins in the early Miocene presents an especially dramatic picture because it came on the heels of an equally widespread but primarily climatically induced period of regressive marine sequences, erosion,[3,4] and nonmarine deposition associated with late Eocene-early Oligocene refrigeration. The late Oligocene-early Miocene tectonic event apparently included a significant change in vector for the Pacific plate (Jackson et al., 1972) with increased rates of subduction in the western Pacific and back-arc extensional opening of the Sea of Japan and Sea of Okhotsk with synchronous basin development in the eastern Pacific of a different style (Atwater, 1970), but similar form including opening of the Gulf of California (Karig and Jensky, 1972; Moore, 1973).

The simultaneous readjustment of continental margins and rapid subsidence of adjacent basins created a series of essentially empty bathtubs some distance from the newly created strandlines all underlying marginal water masses experiencing prolific diatom productivity due to increasingly vigorous atmospheric and surface circulation associated with mid and higher latitude climatic events during the Neogene (Ingle, 1973c). Thus, predominantly biogenous debris in the form of diatomites and diatomaceous shales constitute a widespread and distinctive middle and late Miocene lithology within bathyal marine sequences exposed around the North Pacific rim[5] due to their initial deposition in Miocene basins momentarily deficient in diluting terrigenous debris. The Monterey Formation of California and Onnagawa Formation of Honshu represent two clear examples of this particular biofacies and lithofacies (Ingle, 1973c). All of these deposits were ultimately capped by seaward-advancing wedges of terrigenous material deposited via nepheloid layers and turbidites during the Pliocene as clearly recorded in the Oga Peninsula section (Figure 12) and in the Los Angeles and Ventura basin sections of California (Ingle, 1967), with successive filling and overflow of basinal complexes. Although diatom productivity remained high in these areas, dilution and destruction of diatom frustules occurred within the coarse Plio-Pleistocene deposits.

Miocene basins located beneath less-productive waters such as the Luzon and Panay areas (Figure 3) were entirely filled with terrigenous debris. Nevertheless, the distinctive twofold package of Miocene diatomaceous shales and overlying Pliocene-Pleistocene turbidites constitutes the stratigraphic norm in most of the marginal North Pacific representing the combined product of widespread Neogene tectonic and climatic events.

[4]Deep-sea erosion and resulting unconformities characterize large areas of the South Pacific during Oligocene time reflecting development of the circum-Antarctic current and polar climatic events (Kennett et al., 1972) in addition to the better known strandline and nonmarine Oligocene unconformities associated with regressive marine sequences.

[5]Similar climatic and tectonic events produced similar, but to date poorly documented, stratigraphic sequences in the marginal South Pacific, most notably in Chile.

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