Stratigraphic Revision of the Neogene Rocks of Saipan Island, Commonwealth of the Northern Mariana Islands

By David J. Weary and Jean M. Self-Trail

Chapter D of
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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times \sim °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Datums

Vertical coordinate information is referenced to Mean Sea Level (MSL).
Horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 1984)

Abbreviations

CNMI	Commonwealth of the Northern Mariana Islands
e	easting
n	northing
N/P	Neogene and Paleogene
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WGS 1984	World Geodetics System of 1984

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Chapter D

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By David J. Weary and Jean M. Self-Trail

Abstract

Geologic mapping in 2006 and 2007, and calcareous nannofossil biostratigraphy combined with comparative analysis of other published data, have resulted in a reinterpretation and revision of the ages and stratigraphic relationships of the Neogene lithostratigraphic units exposed on Saipan Island. These units, chiefly limestone and admixed volcaniclastic rocks, form much of the bedrock of Saipan Island. Stratigraphic revisions include a redefinition of the Tagpochau Limestone, restricting it to rocks of the newly named I Etdot, Tipo Poli, and Marpi Members. Other rocks, formerly included in the Tagpochau Limestone (the Donni Sandstone and the Machegit Conglomerate Members, and an informal transitional facies), are herein assigned to the newly defined Gloria Formation. The Gloria Formation comprises three members: the Machegit Conglomerate Member, the new As Teo Member, and the Donni Sandstone Member.

The Tagpochau Limestone contains larger foraminifera that indicate an early Miocene (Aquitanian through middle Burdigalian) age, or a numerical range of about 23 to 18.7 Ma. Overlying the Tagpochau Limestone, both the Fina-sisu and the Gloria Formations are recognized herein to be distinctly younger than the Tagpochau Limestone and not correlative with any parts of that formation as had been previously thought. Basaltic lava flows in the Fina-sisu have yielded radiometric ages that indicate a middle Miocene age, whereas planktonic foraminifera recovered from interbedded sedimentary rock indicate a latest early Miocene age (Langhian). Assemblages of planktonic foraminifera and calcareous nannofossils recovered from the Gloria Formation indicate a latest Miocene age (Messinian) and a numerical age range of about 5.8 to 5.5 Ma.

Additional studies could help to constrain the ages of these units more precisely because none of the biostratigraphic samples were taken in the context of measured stratigraphic sections. On an island dependent on groundwater, the revised stratigraphic understanding can inform the development of groundwater models and strategies for identifying water-well sites and targeting drilling depths for potable water. The new stratigraphic understanding can inform future interpretations of the geologic structure of Saipan Island and the Neogene tectonic history of Saipan Island and the Mariana subduction zone.

Introduction

The geology of the Saipan Island was comprehensively documented by Cloud and others (1956) where they established a lithostratigraphic framework for the Eocene to Holocene rocks on the island that has been utilized by subsequent geologic and hydrologic studies. A new geologic map was published in 2011 and was based on an integration of the data from Cloud and others (1956) with new field data collected in 2006 and 2007 (Weary and Burton, 2011). These new data, which resulted in a refined understanding of the stratigraphic framework of the Neogene section on Saipan Island, require formal documentation and changes to the lithostratigraphic rank, nomenclature, and stratigraphic order of several of the Miocene lithostratigraphic units. Some of these revisions were informally described in text accompanying the new geologic map (Weary and Burton, 2011). In this paper, we substantiate and formalize those stratigraphic revisions on the basis of physical relationships between the various lithostratigraphic units, review of published paleontologic and radiometric age data, and analysis of new biostratigraphic data.

Saipan Island is in the Mariana Islands, located between the Philippine Sea and the Pacific Ocean, at lat 15°12′30″ N., long 145°45′00″ E. (fig. 1). Saipan Island is approximately 120 miles (mi; 193 kilometers [km]) northeast of the island of Guam. Politically, Saipan Island is the seat of government for the Commonwealth of the Northern Mariana Islands (CNMI), a U.S. territory that consists of the Marianas archipelago north of Guam. Saipan Island is about 14 mi (23 km) long and 6 mi (10 km) wide at its widest point. Elevations range from sea level to 1,529 feet (ft; 466 meters [m]) at the peak of Okso‘ Takpochao.

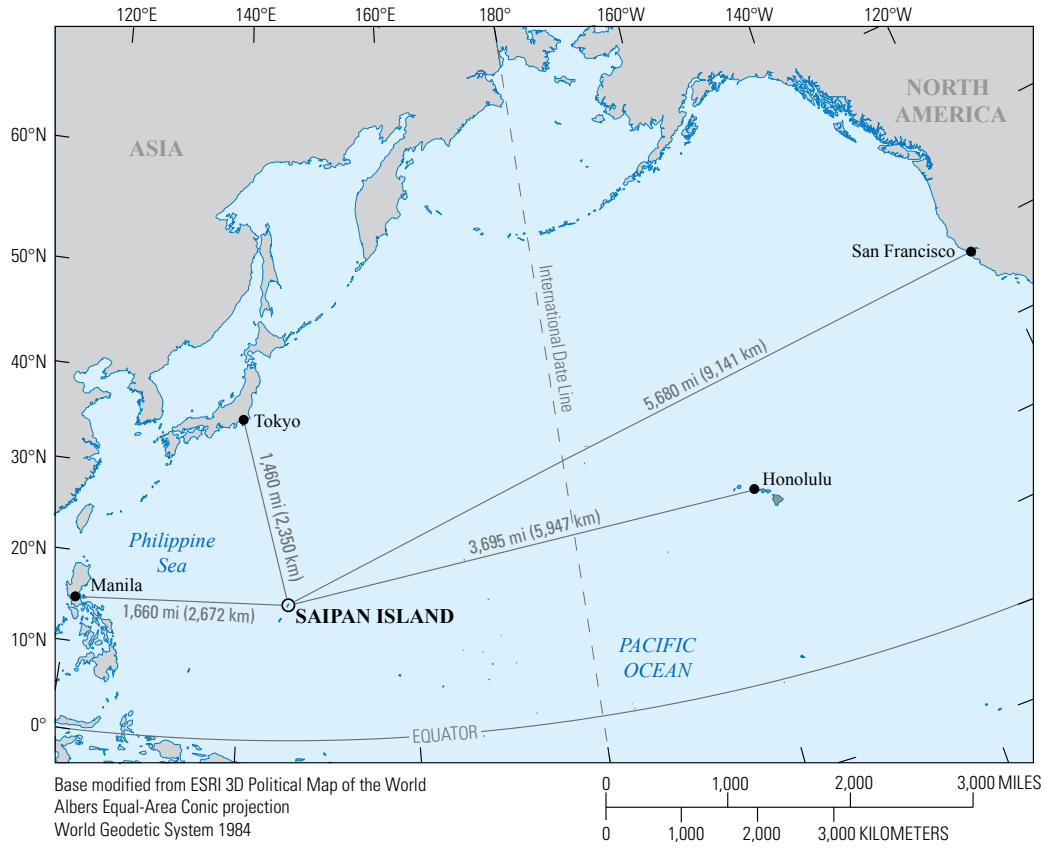


Figure 1. Location map showing position of Saipan Island in the western Pacific Ocean.

Physiography

According to Cloud and others (1956) Saipan Island can be subdivided into seven generalized geomorphic regions for geographic and geologic reference (fig. 2). These regions are the western coastal plain, low terraced benches, low limestone platforms, southeastern coastal fault ridges, Donni clay hills, volcanic core hills, and limestone axial uplands. For more detailed discussion of the physiography of Saipan Island refer to Cloud and others (1956, p. 20–33; and plate 8).

Previous Geologic Mapping on Saipan Island

Japanese geologists investigated the geology of Saipan Island before World War II (Tayama, 1936). Soon after the war, and with transfer of administration of the island to the United States, a team of U.S. Geological Survey (USGS) geologists led by Preston E. Cloud Jr. mapped the geology of the island in 1948–1949. These studies, sponsored by the U.S. Army Corps of Engineers, resulted in several reports and USGS Professional Paper 280 “Geology of Saipan Mariana Islands,” which was published in four separate parts from 1956 to 1959 and includes chapters by various authors on general geology, petrology, soils, paleontology, submarine topography, and shoal-water ecology (refer to Cloud and others [1956], Schmidt and others [1957], Johnson and others [1957], and Cloud [1959]) . Part 1, “General Geology,” includes detailed descriptions of geologic units of Saipan Island and a geologic map at 1:20,000 scale (Cloud and others, 1956). Many years later, a chart showing correlation of stratigraphic units among the high islands of the Guam region, including Saipan Island, was compiled by Siegrist and Reagan (2008) as part of their generalized geologic map of Guam. Weary and Burton (2011) mapped selected areas of Saipan Island, field-checked earlier mapping by Cloud and others (1956), and digitized and compiled the results onto modern base maps and a GIS-based digital geologic map at a scale of 1:25,000.

Previously Established Neogene Stratigraphic Framework of Saipan Island

The geologic studies by Cloud and others (1956) resulted in establishment of a formal nomenclature and an interpreted stratigraphic sequence for the rocks of Saipan Island. Their interpretations, based on field mapping and what was known of invertebrate biostratigraphy at the time and developed without a full understanding of plate tectonic theory, are incorrect in part. In their scheme, sediments were composed, from oldest to youngest, of the Eocene and Oligocene Fina-sisu Formation and the Miocene Tagpochau Limestone (sensu lato). The Fina-sisu Formation included two separate map units: marine tuffs and interlayered thin lava flow rocks, and massive lava flow rocks. The Tagpochau Limestone (sensu lato) contained the Machegit Conglomerate and Donni

Sandstone Members as well as several interfingering limestone lithofacies map units, which included the transitional facies, the tuffaceous facies, the marly facies, the inequigranular facies, the equigranular facies, and the rubbly facies. The vertical and lateral relationships of the Fina-sisu Formation and Tagpochau Limestone, as presented by Cloud and others (1956), are illustrated in the stratigraphic column on figure 3. We now know that these units are Neogene in age.

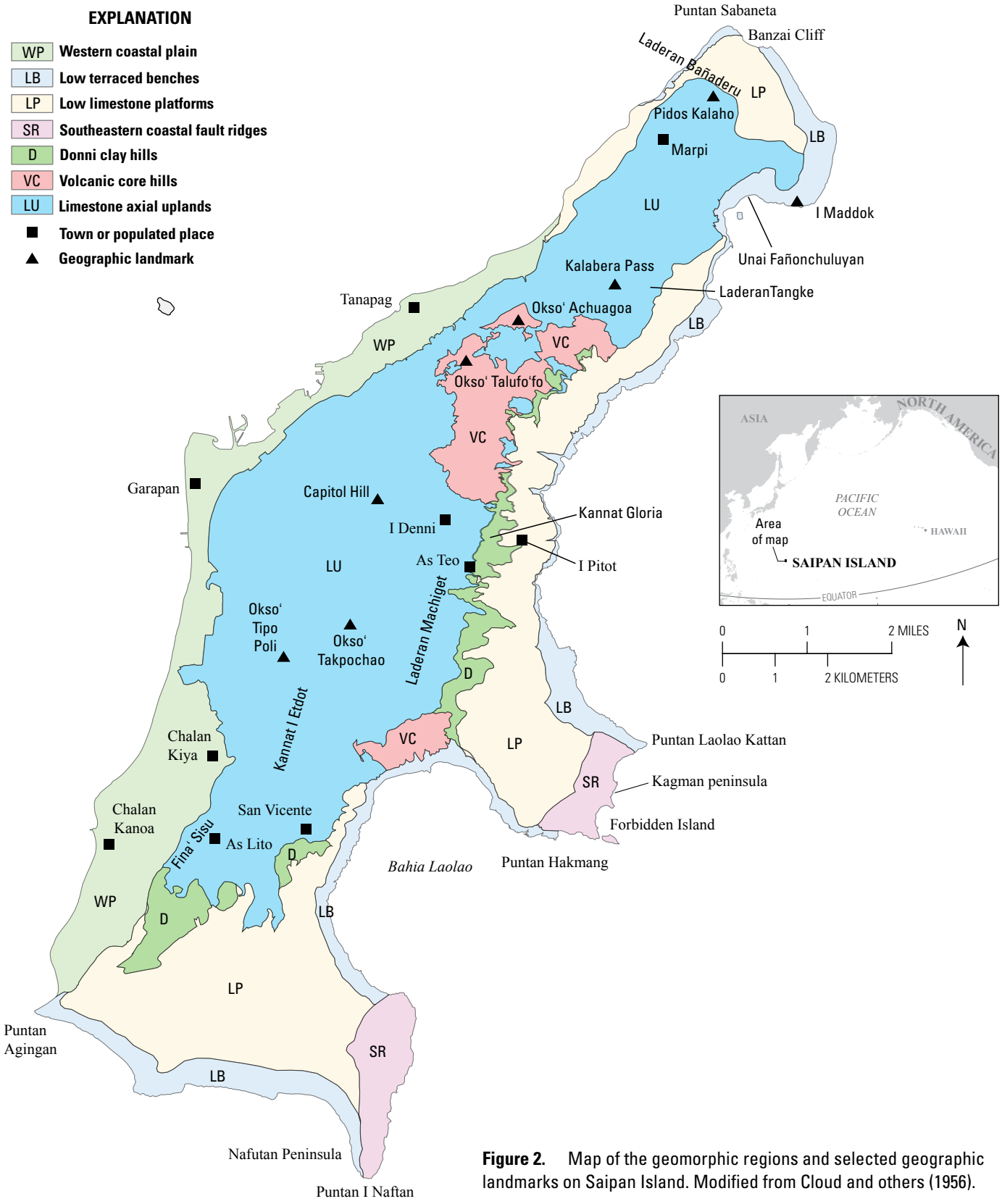


Figure 2. Map of the geomorphic regions and selected geographic landmarks on Saipan Island. Modified from Cloud and others (1956).

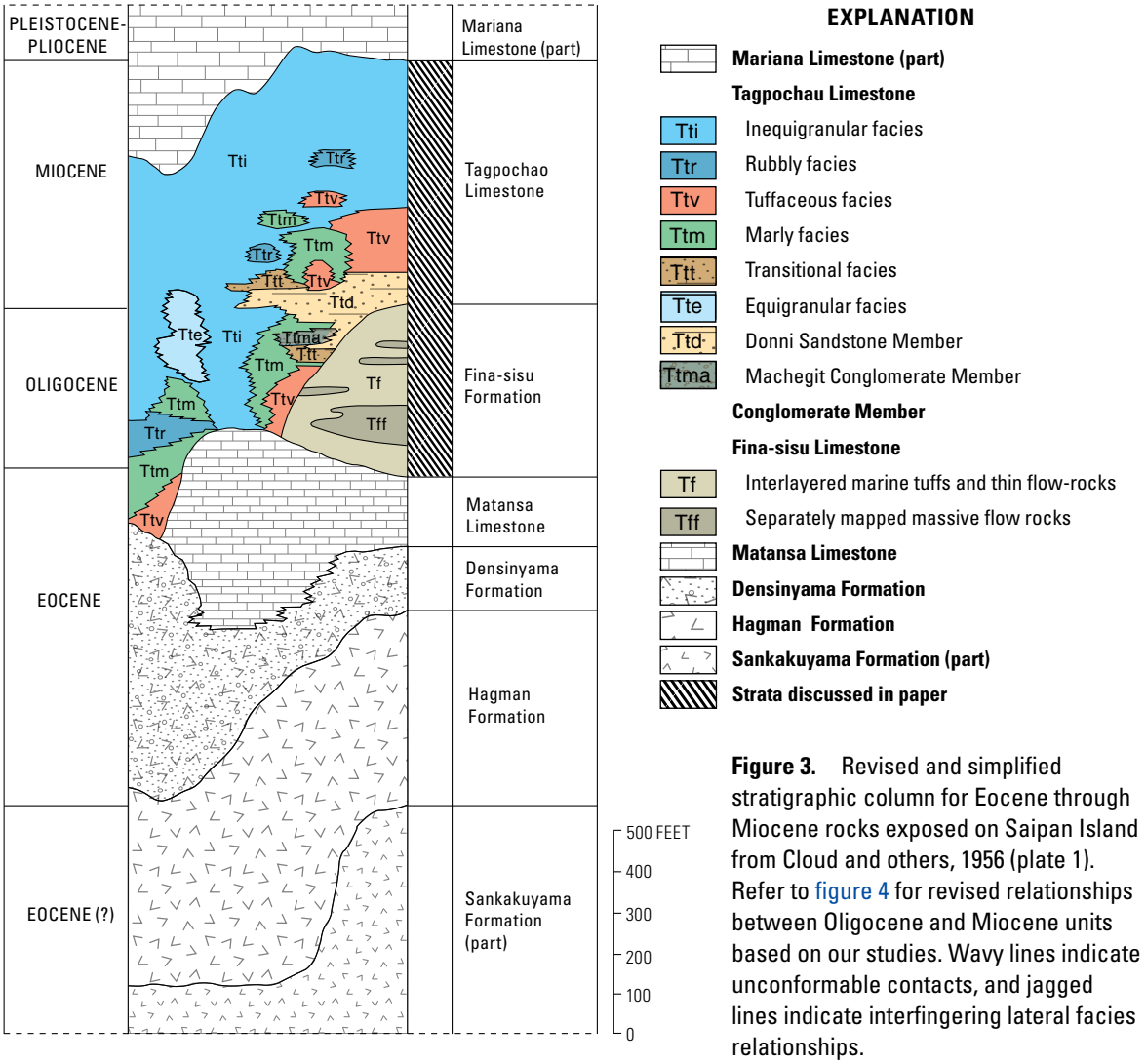


Figure 3. Revised and simplified stratigraphic column for Eocene through Miocene rocks exposed on Saipan Island from Cloud and others, 1956 (plate 1). Refer to figure 4 for revised relationships between Oligocene and Miocene units based on our studies. Wavy lines indicate unconformable contacts, and jagged lines indicate interfingering lateral facies relationships.

Geographic and Lithostratigraphic Name Conventions

The English spelling of geographic place names on Saipan Island has evolved since the end of Japanese administration of the island in 1944. Because formal lithostratigraphic unit names are derived from geographic names, there is now incongruence between the spelling of some stratigraphic unit names and the modern spelling of place names. To alleviate confusion, we have continued the lithostratigraphic unit spelling of Cloud and others (1956), who established most of the stratigraphic nomenclature for the island, even if the spelling of the geographic name has since changed. Many place names derive from the local Chamorro language, and where appropriate, the English translation is given in parentheses after the Chamorro term. Some examples are the Fina-sisu Formation, which is named for Fina‘ Sisu (herein called Fina-sisu hills), the Tagpochau Limestone, which is named for Okso‘ Takpochao (Mount Takpochao); the Machegit Conglomerate Member, which is named for Laderan Machiget (Machiget Cliffs); and the Hagman Formation, which is named for Puntan Hakmang (Hagman Point).

Methods

Age control for this stratigraphic revision is provided by biostratigraphy and stratigraphic relationships observed during field mapping (Weary and Burton, 2011). Age determination for the Tagpochau Limestone (sensu stricto) is based on the ranges of larger foraminifera species reported in earlier studies (Cloud and others, 1956; Cole, 1958) compared with the biozones of Adams (1984).

Reported occurrences of planktonic foraminifera and calcareous nannofossil species from the Fina-sisu and Gloria Formations (Cloud and others, 1956; Bramlette, 1957; Todd, 1957) were compiled. Rock samples of the Gloria Formation collected by D. Weary in 2006 and 2007, in support of geologic mapping (Weary and Burton, 2011) were submitted for processing and analysis of calcareous nannofossils to J. Self-Trail in 2010 and 2012 respectively. Smear slides for calcareous nannofossil examination were made using the techniques of Bown and Young (1998) and mounted using Norland Optical Adhesive 61. Slides were examined on a Zeiss Axioplan 2 light microscope at 1,250x magnification under cross polarized light. Samples were dated using the

calcareous nannoplankton zonation scheme of Martini (1971). The results of those investigations are reported herein.

Biostratigraphic ranges for planktonic foraminifera species recovered from the Fina-sisu and Gloria Formations were determined by comparison with planktonic foraminiferal biohorizons of Raffi and others (2006), low-latitude planktonic foraminifera biozones from Wade and others (2011), and Neogene and Paleogene planktonic foraminifera biozones from Blow (1969). Biostratigraphic ranges of calcareous nannofossil species recovered from these rocks were compared with calcareous nannofossil biozones from Martini (1971).

Ranges of the recovered planktonic foraminifera and calcareous nannofossil species from the Fina-sisu and Gloria Formations were correlated with the International Commission of Stratigraphy chronostratigraphic chart (Raffi and others, 2020) to determine relative and numerical ages.

Revised Neogene Stratigraphy on Saipan Island

We herein revise the Neogene stratigraphy of Saipan Island to include, from oldest to youngest, the Tagpochau Limestone, the Fina-sisu Formation, and the (new) Gloria Formation. These formations were deposited during the Miocene, and deposition of the Gloria probably extended into the early Pliocene. Figure 4 illustrates a synopsis of this revised stratigraphy. Discussion of the supporting evidence is found in the following subsections.

Tagpochau Limestone

The oldest Neogene unit, the Miocene Tagpochau Limestone, is second only to the Pliocene and Pleistocene Mariana Limestone in areal exposure on Saipan Island.

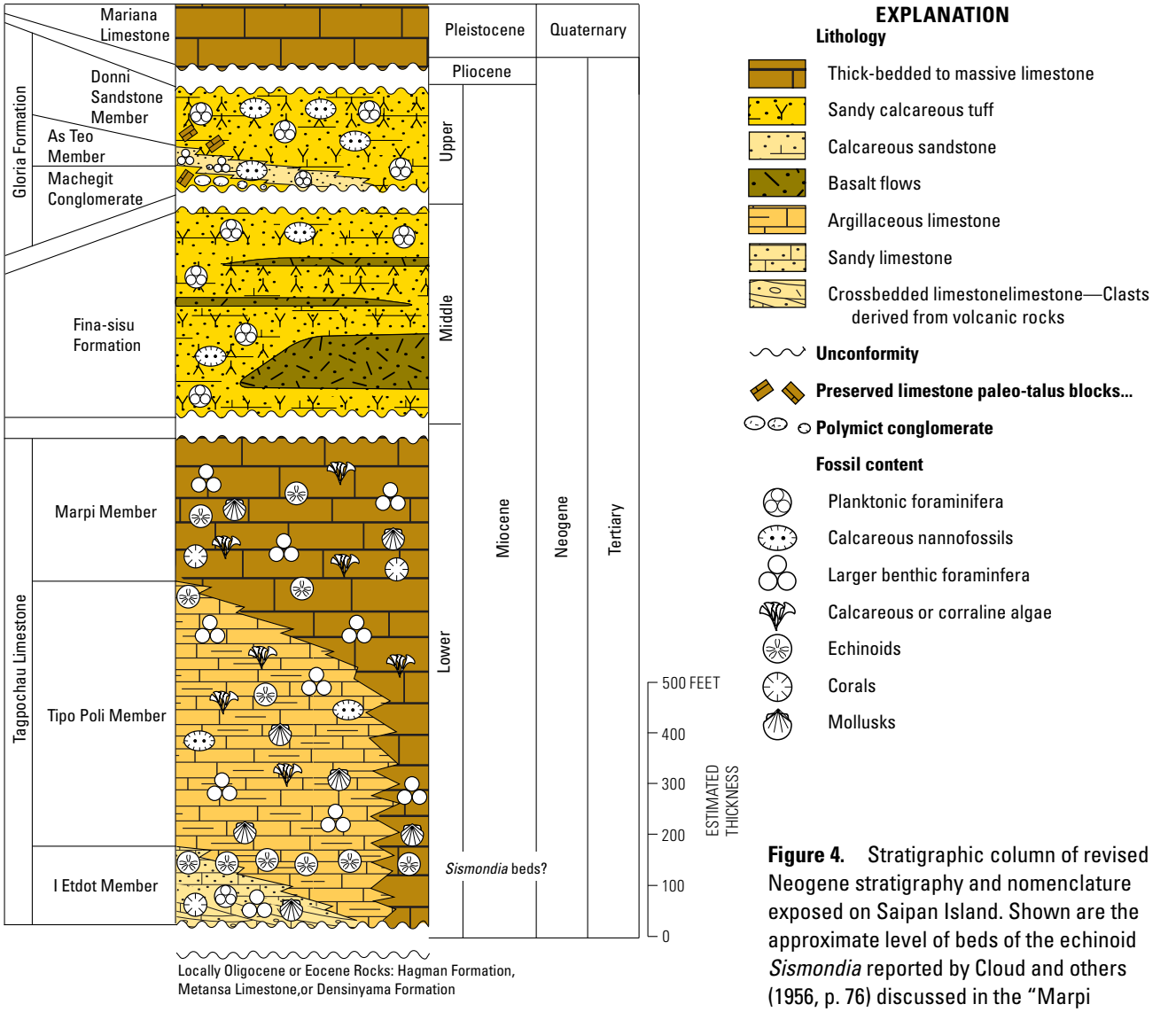


Figure 4. Stratigraphic column of revised Neogene stratigraphy and nomenclature exposed on Saipan Island. Shown are the approximate level of beds of the echinoid *Sismondia* reported by Cloud and others (1956, p. 76) discussed in the "Marpi Member" subsection.

Outcrops of the Tagpochau form prominent cliffs in the limestone axial uplands of the island (figs. 2, 5). The Tagpochau Limestone was originally named the "Tappocho Limestone" by Tayama (1936) for outcrops on what was then called Mount Tappocho. Cloud and others (1956) also included rocks previously designated the Laulau Limestone by Tayama (1936) within the Tagpochau. The spelling was later revised to Tagpochau Limestone (Cole and Bridge, 1953; Cloud and others, 1956) for a better fit with the English spelling of the native Chamorro language. They also established a type section for the formation, which is shown on figure 6. Although the spelling of the formation's type section area is now Okso' Takpochao (Mount Takpochao) on the 1999 USGS topographic map of the island, we are retaining the spelling "Tagpochau" for the formation name because it has more than half a century of usage in the geologic literature.

The Tagpochau Limestone is a complex of chiefly shallow-water limestone lithofacies with relatively minor amounts of siliciclastic material that were derived from the weathering of older volcanic and clastic units. Deposition of the Tagpochau across the entire island indicates a period of complete submergence of Saipan Island beneath the sea. This was one of several episodes of submergence that have occurred on Saipan Island since the development of the Mariana subduction zone in the early Eocene (Karig, 1971).

Stratigraphic Redefinition of the Tagpochau Limestone

In the new stratigraphic scheme presented herein, the Tagpochau Limestone consists of three formal members, which are each equivalent to the informal map units used by Weary and Burton (2011). These informal map units were the (1) tuffaceous facies (their unit Ttv), (2) marly facies (their unit Ttm), and (3) limestone member (their unit Ttl). These units, which have stratigraphic significance and reach significant thicknesses, merit being formally defined as members of the Tagpochau Limestone. These three new members are the I Etdot, Tipo Poli, and Marpi. Figure 5 shows the aerial extent of these members on Saipan Island. The

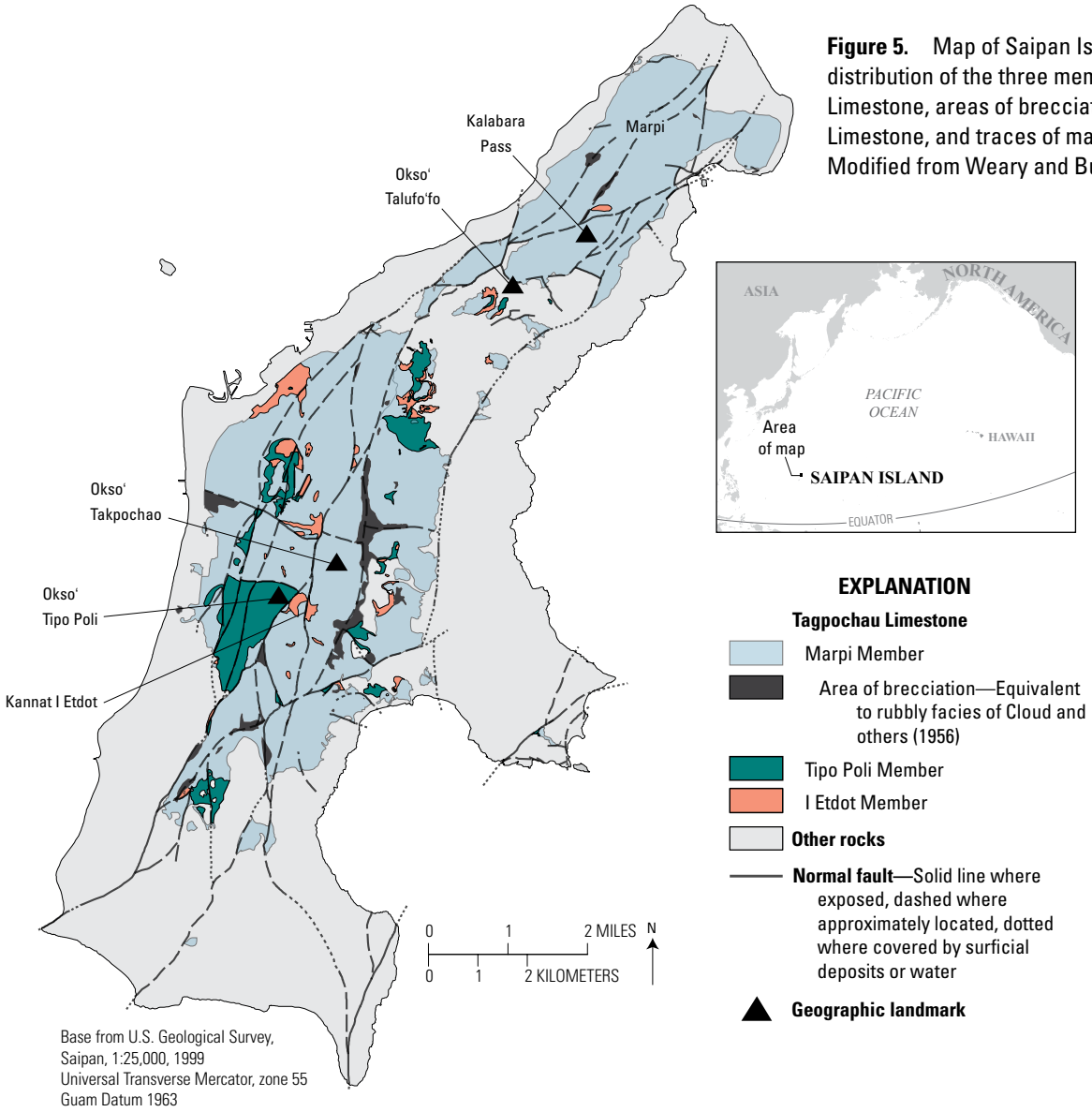


Figure 5. Map of Saipan Island showing the distribution of the three members of the Tagpochau Limestone, areas of brecciated Tagpochau Limestone, and traces of mapped normal faults. Modified from Weary and Burton (2011).

original Tagpochau Limestone type section, which includes outcrops of the Marpi and the Tipo Poli Members, is on the eastern slopes of Okso‘ Takpochao (Mount Tagpochao) and is shown on figure 6 (Cloud and others, 1956).

The I Etdot and Tipo Poli Members of the Tagpochau Limestone are basal units or marginal to the basal part of the overlying Marpi Member. Regardless of which member is at the base of the formation locally, the Tagpochau Limestone

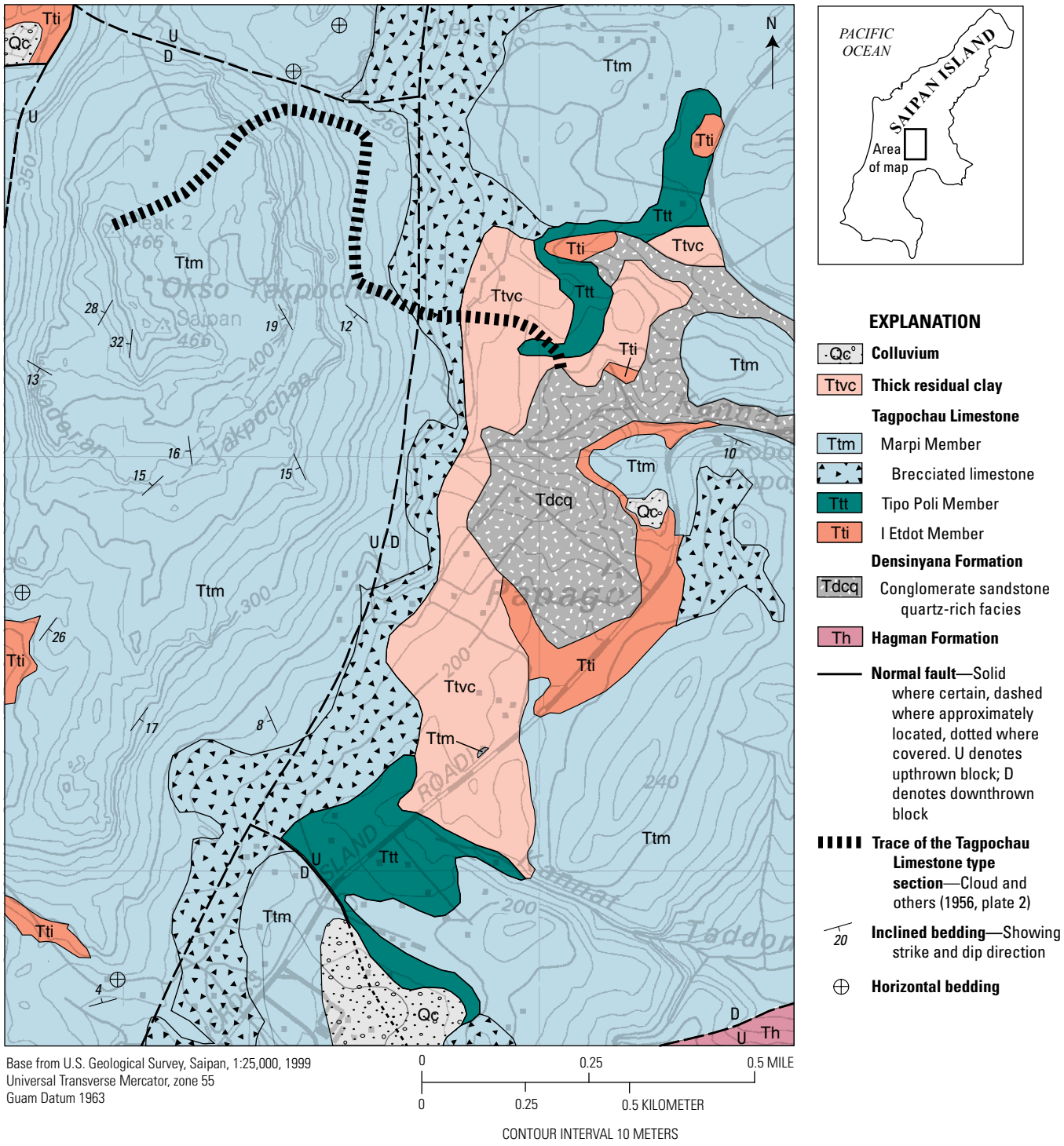


Figure 6. Geologic map showing the overlapping relationship between the basal members of the Tagpochau Limestone and the underlying Densinyama Formation in southeast-central Saipan Island. An erosional window in the east-central part of the area exposes the conglomeratic sandstone quartz-rich facies of the Densinyama Formation (unit Tdcq). It is unconformably overlain locally by the I Etdot (unit Tti), Tipo Poli (unit Ttt), and Marpi (unit Ttm) Members of the Tagpochau Limestone. Geologic map modified from Weary and Burton (2011). Note that the Tagpochau Limestone type section of Cloud and others (1956) crosses a newly mapped normal fault that offsets the section downward to the east.

has an unconformable contact with older formations of Eocene or Oligocene age. Both the I Etdot and Tipo Poli Members contain significant amounts of siliciclastic material that was derived from the weathering and erosion of older volcanic and volcaniclastic units, such as the Eocene Sankakuyama Formation and the Oligocene Hagman and Densinyama Formations. The lithologies of both basal members grade laterally and upward, becoming less enriched in siliciclastic materials and more predominantly composed of the purer limestone, typical of the Marpi Member. The I Etdot or the Tipo Poli Member usually forms the basal lithology where the Tagpochau Limestone crops out. Lithologic descriptions from water wells that penetrate the Tagpochau in the east-central part of the limestone axial uplands also confirm the positions of those members at the base of the formation in the subsurface (Ayers, 1981). The I Etdot Member, which is rich in coarse volcanic material, was deposited more proximally to exposed areas of the older volcanic rocks than the finer grained, more argillaceous Tipo Poli Member. Outcrops at the land surface of these two basal members are indicative of local post-depositional, erosional removal of the thick, overlying Marpi Member.

The Marpi Member comprises relatively pure light-colored limestone that was apparently deposited when the whole of Saipan Island was submerged beneath the sea surface, which subsequently shut off subaerial erosion of the older volcanic rocks and eliminated the supply of terrigenous clastic sediments. The Tagpochau Limestone unconformably overlies, and locally may be found in contact with, any of the older strata on Saipan Island.

Early Miocene I Etdot Member

The I Etdot Member of the Tagpochau Limestone is commonly planar-bedded and fossiliferous, locally crossbedded limestone to calcareous sandstone and conglomerate. The I Etdot locally contains as much as 90 percent volcanically derived clasts but usually much less. The unit is reddish brown to dark yellowish orange. Fossils include larger and smaller foraminifera and fragments of echinoids, mollusks, and *Acropora* (staghorn coral). The unit is less resistant to weathering than the other members of the Tagpochau Limestone and because of this it is not well exposed. The unit is best developed and thickest in the west-central part of the limestone axial uplands and in an area about 1 km (0.6 mi) southwest of Okso‘ Talu‘fo‘fo (Mount Talu‘fo‘fo) (fig. 2). The area of most complete exposure of these rocks is on the flank of Okso‘ Takpochao (Mount Takpochao) about 0.5 mi north-northwest of the peak (fig. 2). It is also exposed in areas at the head of the Kannat I Etdot (I Etdot Ravine) and along the trace of the original Tagpochau Limestone type section (figs. 5 and 6). Kannat I Etdot was chosen as the type section and as the name for this new member. Thickness of the I Etdot Member ranges from zero to at least 170 ft (52 m), and it typically grades upward and laterally into the Tipo Poli Member. For additional lithologic information on the I Etdot Member refer to descriptions of the Tagpochau Limestone tuffaceous facies in Cloud and others (1956).

Early Miocene Tipo Poli Member

The Tipo Poli Member is a locally fossiliferous, fine-grained, moderately indurated, thin- to medium-bedded limestone, typically containing greater than 10 percent argillaceous material. The rock is tan to yellowish white or yellowish orange. Fossils include larger and smaller foraminifera, fragments of echinoids, mollusk shells, and joints of *Halimeda* (calcareous algae). Scarce calcareous nannofossils were reported from this member by Bramlette (1957, table 1, p. 251), and none are biostratigraphically diagnostic, although the presence of the nannofossil *Discoaster saipanensis* indicates reworking of some material from older, Eocene sedimentary rocks. This member ranges in thickness from zero to about 500 ft (150 m) at a section exposed on the west flank of Okso Tipo Poli (Mount Tipo Poli), which provides the geographic part of the name of this unit (fig. 2).

Early Miocene Marpi Member

The Marpi Member, named for extensive outcrops on the peaks and cliffs of the Marpi area in the northern part of Saipan Island, is the thickest and most aerially extensive part of the Tagpochau Limestone. The Marpi Member stratigraphically overlies both the I Etdot and Tipo Poli Members.

The Marpi Member comprises strata of the inequigranular, equigranular, and rubbly facies map units of Cloud and others (1956). This member is a cliff former and underlies most of the high peaks and ridges along the limestone axial uplands of Saipan Island (figs. 2, 5). Rocks of the Marpi Member are a fine- to coarse-grained, very well indurated, indistinctly bedded to massive, foraminiferal limestone containing less than 10 percent argillaceous material. The unit is usually pink, white, yellowish, gray, or variegated. The calcite matrix of the rock commonly has an inequigranular fabric but may be equigranular locally. Equigranular fabrics are common in the discontinuous outcrops of the Tagpochau Limestone that occur in areas of western and northern Saipan Island (Cloud and others, 1956). These outcrops commonly overlie rocks with inequigranular fabrics and are probably exposure surfaces where inequigranular cements have recrystallized to equant-grained cements under meteoric diagenesis. These rocks seem to be less fossiliferous than those in the inequigranular facies possibly because recrystallization of the rocks has obscured many of the smaller fossils.

Bodies of brecciated Tagpochau Limestone were mapped as the “rubbly facies” by Cloud and others (1956), who interpreted these rocks as fossil fore-reef talus. Some of the moderately steeply dipping brecciated limestone beds exposed in the quarries just south of Okso‘ Takpochao superficially resemble classic fore-reef beds exposed in the Permian Capitan Limestone in Texas and New Mexico, including within Carlsbad Caverns (Lloyd, 1929; King, 1948; Hose and Queen, 2006). They also contain several slickensided fault planes. Following our field examination of these rocks, we concluded that they are probably tectonic breccias along the

traces of normal fault zones, a possibility alluded to by Cloud and others (1956, p. 74). This does not preclude the possibility that some of the breccia bodies on Saipan Island are reef-related sedimentary breccias. Similar breccia zones occur in limestones on the nearby island of Guam and were interpreted by Tracey and others (1964) as cataclastic in origin. In most instances, the breccias are developed in the Marpi Member of the Tagpochau, the most brittle lithology of the formation. Many of the limestone quarries on Saipan Island are in these breccia bodies because the tectonized rock is soft enough to be excavated with mechanical digging equipment (fig. 7). The breccias of the Marpi Member are, for the most part, chaotic and mosaic breccias according to the fault-breccia classification of Woodcock and Mort (2008).

Fossils in the Marpi Member include sparse to abundant orbitoid and miogypsinid foraminifera, coralline algae, mollusks, echinoids, and occasional coral fragments. A possibly stratigraphically significant interval rich in the echinoid *Sismondia* ("*Sismondia* beds") was reported by Cloud and others (1956, p. 76) and was included as a possible stratigraphic datum in their geologic map of Saipan Island. This apparent acme zone seems to occur low in the Marpi Member and laterally in both the I Etdot and Tipo Poli Members (fig. 4). The fact that this fossil is restricted to the rocks of our revised Tagpochau Limestone lends support to our more limited (compared to Cloud and others, 1956) definition of the formation. The *Sismondia* beds were not examined during mapping by Weary and Burton (2011).

Cloud and others (1956, p. 76) reported an estimated thickness of at least 900 ft (275 m) of Marpi Member rocks in a composite of two sections. One is located just east of Kalabera Pass at Laderan Tangke (Tangke Cliffs) and the other at Laderan Bañaderu (Bañaderu Cliffs in the northern part of the island, fig. 2).

Age of the Tagpochau Limestone

An early Miocene age for the Tagpochau Limestone is based on the larger foraminifera species reported in earlier studies (Cloud and others, 1956; Cole, 1958). However, the interpretive columnar section of Cloud and others (1956, plate 1) (fig. 3) graphically shows that basal parts of the Tagpochau are as old as latest Eocene. This relationship was required because they erroneously believed that the Fina-sisu Formation was Oligocene in age and that it was positioned somewhere above the base of the Tagpochau Limestone, perhaps a deep-water lateral facies equivalent (Todd and others, 1954; Cloud and others, 1956). An Oligocene Fina-sisu Formation thus required beds of Tagpochau Limestone occurring below the Fina-sisu to be older. The Fina-sisu Formation was later shown to be middle Miocene in age on the basis of foraminiferal biostratigraphy (Cole, 1975).

The Tagpochau Limestone is underlain locally by the Matansa Limestone (fig. 3) that contains upper Eocene, Tertiary *b* Biozone larger foraminifera (Cole, 1958). There are no biostratigraphically documented Oligocene rocks on Saipan Island. An Oligocene isotope age range of 28–26 Ma from the Hagman Formation was reported by Cosca and others (1998), that was based on K-Ar samples. However, the Hagman Formation contains abundant late Eocene fossils, which indicate that the Oligocene radiometric age of the Hagman is incorrect. A preliminary study of the larger foraminifera of

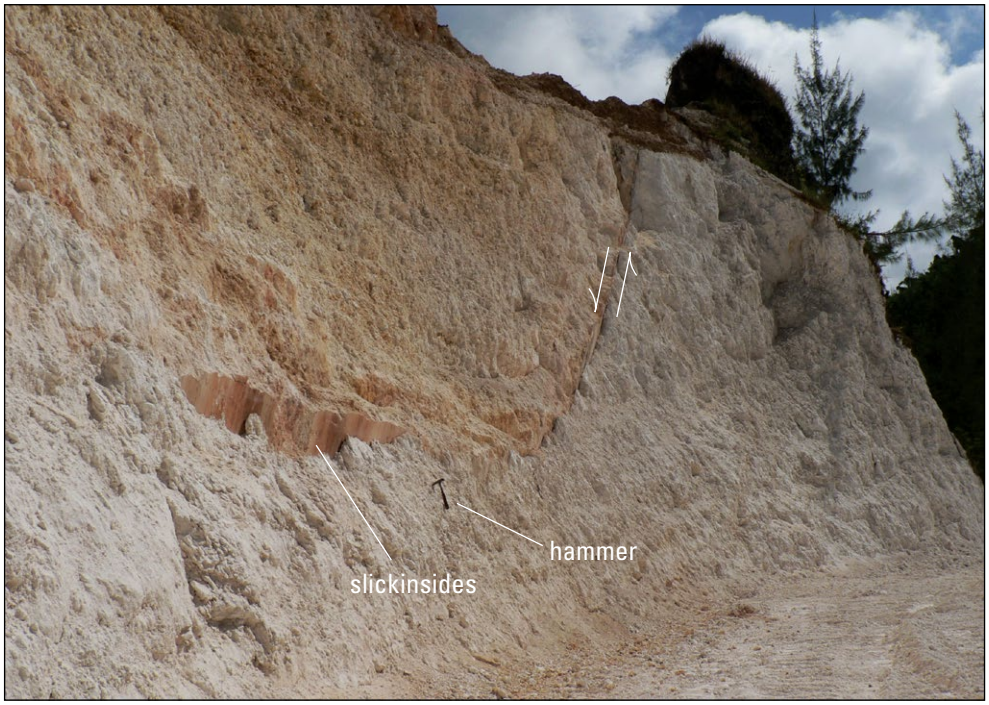


Figure 7. Photograph of a limestone quarry in northwestern Saipan Island showing a normal fault plane cutting rock of the Tagpochau Limestone, Marpi Member. These rocks were mapped as the "rubbly facies" of the Tagpochau Limestone by Cloud and others (1956). Rock hammer in the lower left center measures about 13 in (33 cm) long. Slickensides on the fault plane indicate movement down to the northwest (left side of photograph, relative movement shown by white arrows). Note enhanced weathering and iron staining in rocks of the hanging wall (left of fault) as compared to those in the foot wall (right of fault).

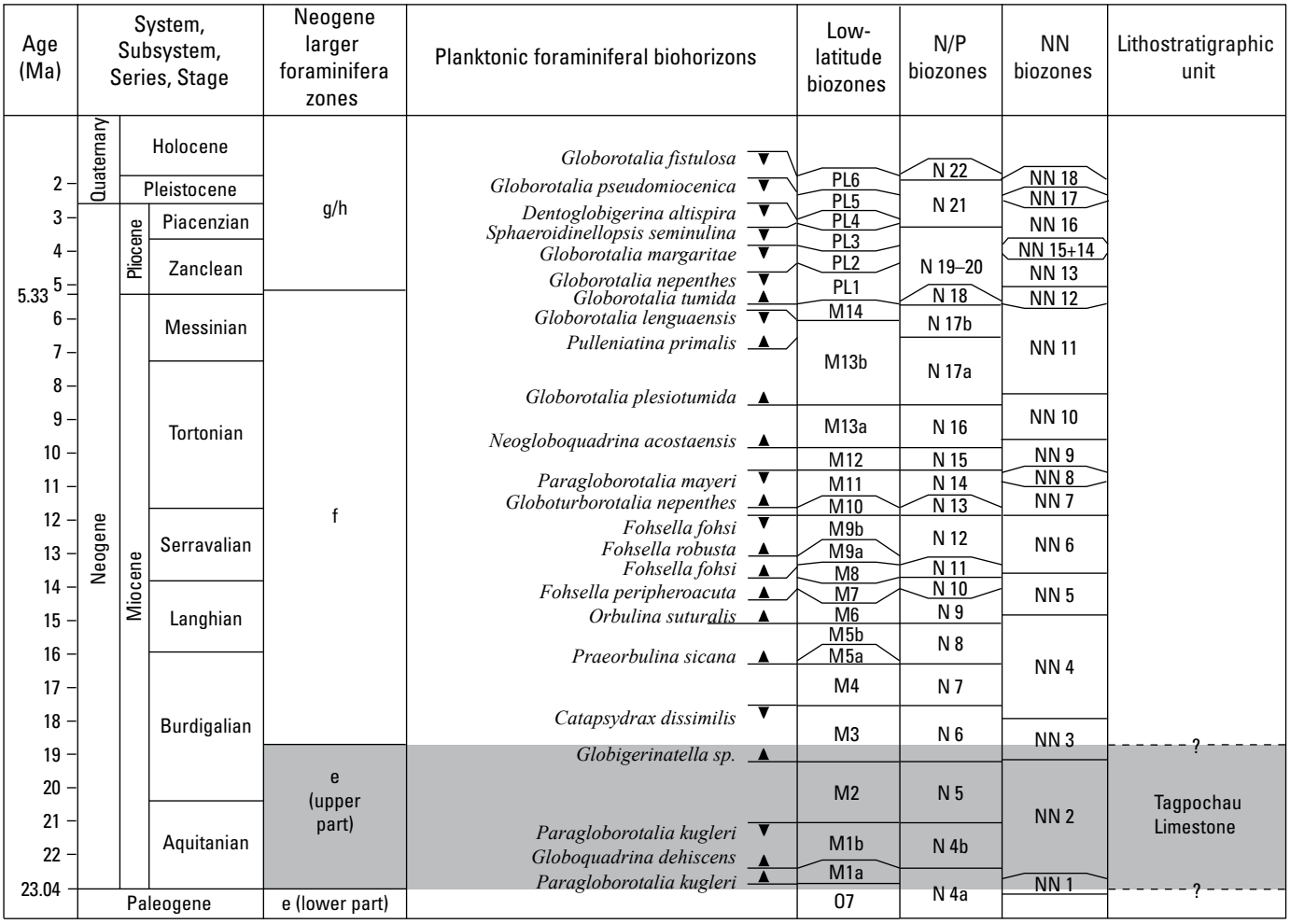
Saipan Island concluded that the upper part of the Tagpochau extended into the foraminifera Tertiary *f* Biozone (Cole and Bridge, 1953). A later, more comprehensive study of larger foraminifera from 426 localities concluded that the entire Tagpochau Limestone probably lies within the larger foraminifera Tertiary *e* Biozone (Cole, 1958), and probably within the Neogene N4 to N6 planktonic foraminifera Biozones of the lower Miocene (Blow, 1969) (fig. 8). This places the Tagpochau Limestone in the lower part of the Miocene in the Aquitanian through about the middle of the Burdigalian Stages and yields a fossil-based numerical age range of about 23–18.7 Ma (fig. 8).

Biostratigraphic evidence of intraformational age relationships between the different members of the Tagpochau Limestone is sparse. Cole (1958) reported that there was no correlation between the distribution of species of larger foraminifera and the different lithofacies of the Tagpochau.

A composite maximum thickness for the entire Tagpochau Limestone, using the maximum estimated thicknesses for its constituent members, is about 1,570 ft (479 m). However, the formation probably seldom exceeds 1,000 ft (305 m) in thickness at any one locality.

Middle Miocene Fina-sisu Formation

The Fina-sisu Formation was named by Cloud and others (1956) for outcrops of calcareous marine tuff and interbedded volcanic flow rocks in the vicinity of the Fina-sisu hills near the small village of As Lito in the western part of southern Saipan Island (figs. 2, 9). These are the only known outcrops



EXPLANATION

Age range of Tagpochau Limestone

Unit boundary—Inferred and uncertain

Last occurrence of foraminifera species

First appearance of foraminifera species

Figure 8. Correlation chart showing estimated age range for the Tagpochau Limestone using reported larger foraminifera species (Cloud and others, 1956; Cole, 1958, 1975). Geologic divisions are in conformance with those of Raffi and others (2020), larger foraminifera biozones from Adams (1984), planktonic foraminiferal biohorizons from Raffi and others (2006), low-latitude planktonic foraminifera biozones modified from Wade and others (2011) with emended M14, Neogene and Paleogene (N/P) planktonic foraminifera biozones modified from Blow (1969), and calcareous nannofossil NN biozones from Martini (1971).

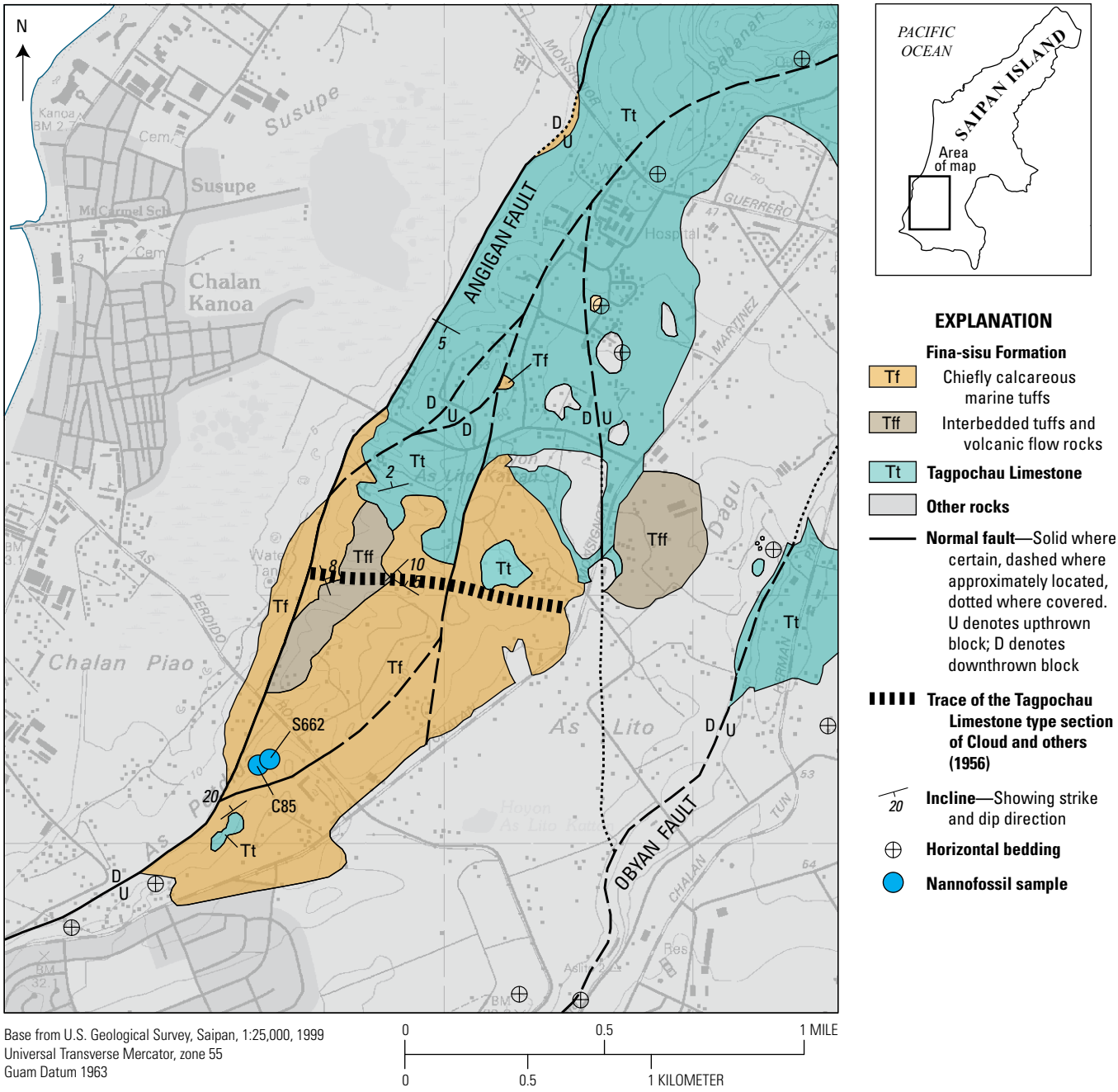


Figure 9. Generalized geologic map showing areas of outcrop of the Fina-sisu Formation and Tagpochau Limestone in southern Saipan Island. Geologic map modified from Weary and Burton (2011). Foraminifera and calcareous nannofossil sample localities C85 and S662 were reported in Bramlette (1957), Cloud and others (1956), and Todd (1957).

of the formation, and they cover an area of about 1 square mile (mi^2; 0.6 km^2) (fig. 9). These rocks have been mapped as two separate informal units: (1) chiefly calcareous marine tuffs and (2) interbedded tuffs and volcanic flow rocks (Cloud and others, 1956; Weary and Burton, 2011) (fig. 9). The tuffs closely resemble lithologies found in parts of the underlying Hagman Formation and in parts of the overlying Gloria Formation. Because of the similarity in lithology with the Gloria Formation, areas underlain by the Fina-sisu Formation share a similar physiography and are classified as the Donni clay hills geomorphic region (fig. 2; Cloud and others, 1956). The tuffs of the Fina-sisu are bedded and locally contain abundant smaller foraminifera. Sparse calcareous nannofossils are also present (Bramlette, 1957).

The volcanic flow rock of the second informal map unit was initially described as a light- to dark olive-gray and greenish-gray, vesicular, aphanitic to finely porphyritic augite andesite (Cloud and others, 1956). Subsequent workers redefined the rock as basalt (Meijer and others, 1983). Most of the basalt flows are less than 20 ft (6 m) thick, although at

least one flow may exceed 100 ft (30 m) in thickness (Cloud and others, 1956). The Fina-sisu Formation is typically highly weathered, and areas of outcrop have become overgrown with vegetation since the 1940s. The only known outcrops of relatively fresh rock occur in tunnels under the Fina-sisu hills (Cloud and others, 1956; Fuller and others, 1980). The maximum exposed thickness of the Fina-sisu Formation is about 400 ft (122 m).

The Fina-sisu Formation unconformably overlies the Tagpochau Limestone at the surface but may also overlie other, older formations in the subsurface. The map pattern of the outcrop area in southern Saipan Island supports our interpretation of a relatively younger Fina-sisu Formation deposited over an erosional surface at the top of the older Tagpochau Limestone (fig. 9). A few isolated areas of Tagpochau Limestone protrude through the Fina-sisu Formation demonstrating the topographically irregular surface at the top of the limestone (fig. 8). The Fina-sisu is, in turn, overlain locally by the unconformably onlapping Pliocene and Pleistocene Mariana Limestone or possibly elsewhere, in the subsurface, by the Miocene and Pliocene(?) Gloria Formation. Cloud and others (1956, p. 70) described cuttings from a well in southern Saipan Island where there seemed to be about 5 ft of Fina-sisu Formation between the underlying Eocene Densinyama Formation and the overlying Donni Sandstone Member of the Tagpochau Limestone (now part of the Gloria Formation).

Cole (1975) suggested that the tuffaceous beds of the Fina-sisu Formation as a whole might be a part of the Donni Sandstone Member of the Tagpochau Limestone because of their lithologic resemblance and that both units are younger than the Tagpochau Limestone. That idea is rejected herein because of the distinctive difference in reported foraminifera species assemblages (and resulting biostratigraphic age difference) between the Fina-sisu and the Donni Sandstone Member of the Gloria Formation (Todd, 1957), the presence of basalt flows only in the Fina-sisu, and the lack of detrital quartz in the Fina-sisu Formation compared to the Gloria Formation.

Age of the Fina-sisu Formation

The age of the Fina-sisu Formation is poorly constrained. Extensive biostratigraphic sampling that occurred in the 1940s (Cloud and others, 1956) was not systematic, and little attempt was made to collect samples in measured sections across unit contacts. The Fina-sisu Formation was initially assigned a probable late Oligocene age by Todd and others (1954) that was based on planktonic foraminifera, which indicated the *Globigerinatella insueta* Biozone. The *insueta* Biozone is now known to be upper lower Miocene (Bolli and Saunders, 1985; fig. 10). The Oligocene age assignment and observed field relations caused Cloud and others (1956) to believe that the Fina-sisu was older than most but coeval with the basal parts of the Tagpochau Limestone (see fig. 3). A later study of larger and smaller foraminifera from the Fina-sisu, and comparison with other stratigraphic units in the Indo-Pacific region, led to a reassignment of its age to the Miocene and a stratigraphic position definitively above that of the Tagpochau Limestone (Cole, 1975). Subsequent K-Ar analysis of a basalt sample from the Fina-sisu produced an isotopic age of 12.9±0.3 Ma, which indicates a middle Miocene age (Meijer and others, 1983). This age, younger than the biostratigraphic age, is the basis for a separate, higher stratigraphic position for the Fina-sisu basalt flows unit on the Mariana Islands stratigraphic chart of Siegrist and Reagan (2008).

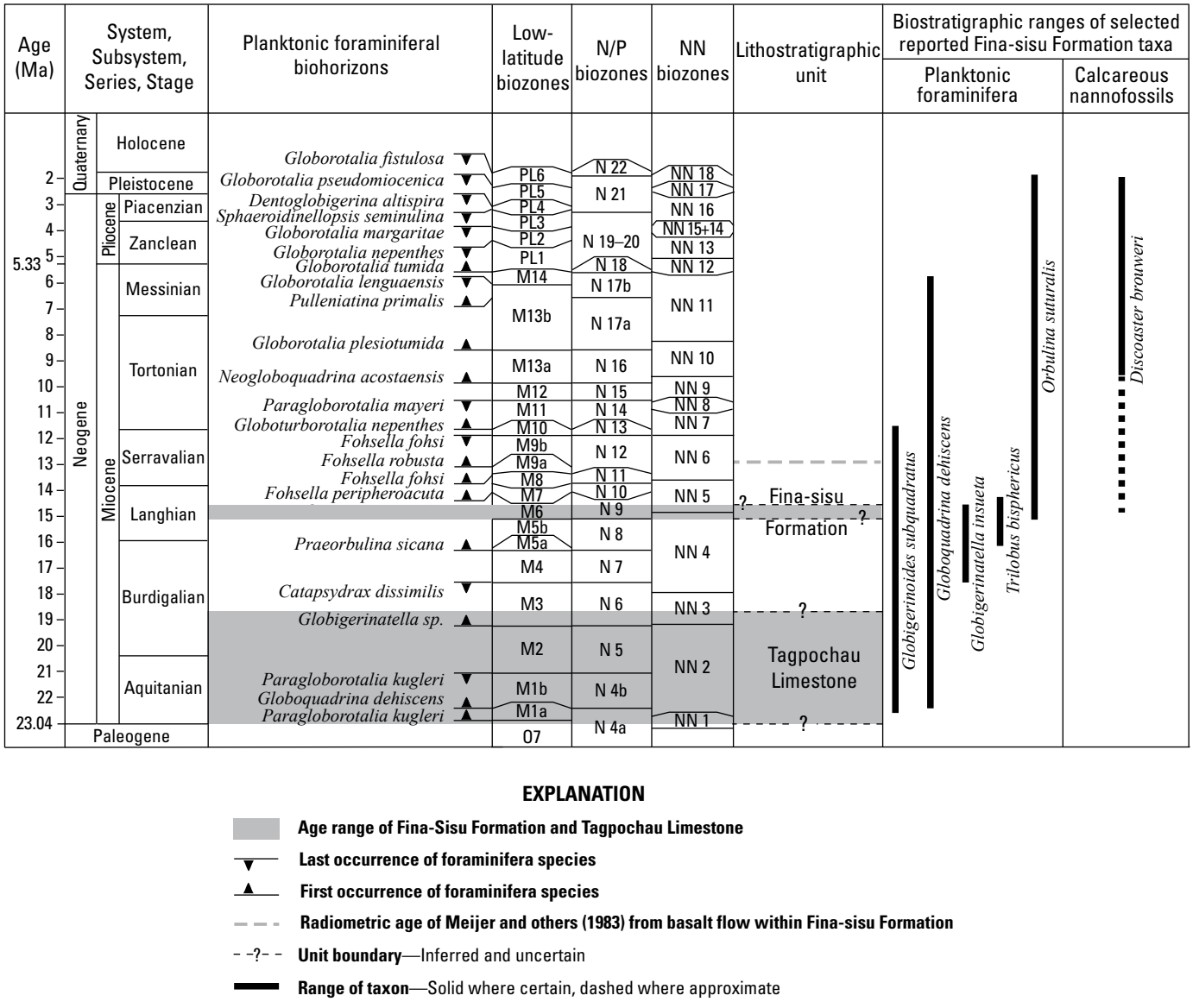
Five planktonic foraminifera species were reported from the Fina-sisu Formation at two very closely spaced localities by Todd (1957, table 2, p. 273) (nannofossil sample locations C85 and S662 shown on fig. 9). These taxa were identified as *Globigerinatella insueta*, *Globigerinoides bispherica*, *G. subquadrata*, *Globoquadrina dehiscens* and *Orbulina suturalis*. Since the original study, *Globigerinoides bispherica* has been reassigned as *Trilobus bisphericus* (Bolli and Saunders, 1985). The stratigraphic ranges of these species as documented by the online database Pforams@microtax (Huber and others, 2017) are summarized in Figure 10. The concurrent range suggests an age of latest early Miocene, upper part of the *Praeorbulina glomerosa* Biozone for these two samples. This is equivalent to the uppermost N8 and lowermost N9 planktonic foraminiferal biozones, and uppermost NN4 and lowermost NN5 calcareous nannofossil biozones. The numerical age range for these zones is about 15.2 to 14.6 Ma., or slightly older than the K-Ar age of the Fina-sisu basalt sample. This indicates Fina-sisu Formation is the uppermost lower Miocene (Langhian) (fig. 10). Because the foraminifera samples were not collected from measured sections, and the precise stratigraphic relationships between them and the top or bottom of the formation are unknown, it is impossible to have a narrow constraint for the maximum and minimum age of the Fina-sisu Formation at this time. Where it is exposed, the Fina-sisu unconformably overlies the Tagpochau Limestone. Therefore, it is reasonable to assume that the maximum age of the Fina-sisu Formation is younger than the minimum age of the Tagpochau Limestone.

Bramlette (1957, table 1, p. 251) analyzed samples from the same two localities as the foraminifera (C85 and S662) and reported a sparse calcareous nannofossil assemblage. These included the *Discoaster* species *D. aster*, *D. brouweri*, *D. challengeri* var., and *D. woodringi*. Probably the only biostratigraphically diagnostic species in this collection is *D. brouweri*. The first occurrence of *D. brouweri* is reported by Browning and others (2017) at about the top of the NN8 calcareous nannofossil biozone or about 10.3 Ma (fig. 10), although sporadic occurrences of an older age have been documented (refer to Nannotax3; Young and others [2022]). This age is incompatibly young compared to the age range from the planktonic foraminifera reported from the same sample localities and is also significantly younger than the K-Ar age for the Fina-sisu Formation basalt sample (12.9±0.3 Ma). The *Discoaster*-based age for these Fina-sisu(?) samples is, however, compatible with both the *Discoaster* and planktonic foraminifera ages of samples from the overlying

Gloria Formation. This coincidence indicates the possibility that there was a labeling or handling error of samples from locations C85 and S662 between field collection in 1948 or 1949 by P. Cloud and R. Schimdt, respectively (Cloud and others, 1956) and publication of the final nannofossil report by Bramlette (1957). Gross lithologic similarity between the Fina-sisu Formation and the Donni Sandstone Member of the Gloria Formation makes it understandable that hand samples might have been inadvertently switched between the collections from those units.

Late Miocene Gloria Formation (New Unit)

The newly named Gloria Formation comprises three members: Machegit Conglomerate Member, As Teo Member, and Donni Sandstone Member. Rocks of all three members were originally defined as subunits of the Tagpochau Limestone (Cloud and others, 1956) and are revised herein. These strata previously were in the same order: Machegit Conglomerate Member, informal "transitional lithofacies," and Donni Sandstone Member (Cloud and others, 1956).



EXPLANATION

- **Age range of Fina-Sisu Formation and Tagpochau Limestone**
- **Last occurrence of foraminifera species**
- **First occurrence of foraminifera species**
- **Radiometric age of Meijer and others (1983) from basalt flow within Fina-sisu Formation**
- **Unit boundary**—Inferred and uncertain
- **Range of taxon**—Solid where certain, dashed where approximate

Figure 10. Correlation chart showing estimated age range for the Fina-sisu Formation and stratigraphic relationship to the Tagpochau Limestone using reported planktonic foraminifera species from nannofossil localities C85 and S662 (fig. 9; Todd, 1957). Also shown are ranges of calcareous nannofossils species that were purported to be from the same sample localities by Bramlette (1957). Chart is scaled to equal-interval planktonic foraminifera biozones. Geologic divisions are in conformance with those of Raffi and others (2020), planktonic foraminiferal biohorizons from Raffi and others (2006), low-latitude planktonic foraminifera biozones from Wade and others (2011) with emended M14, Neogene and Paleogene (N/P) planktonic foraminifera biozones from Blow (1969), and calcareous nannofossil NN biozones from Martini (1971).

The Machegit Conglomerate and the Donni Sandstone Members retain their original names but are reassigned from the Tagpochau Limestone to the Gloria Formation. The new formation is named for Kannat Gloria (Gloria Ravine) in central eastern Saipan Island, which exposes rocks of all three members, and is the type section for the Gloria Formation. These outcrops are about 0.5 mi (0.8 km) south-southwest of the original type section of the Donni Sandstone Member and 0.1 mi (0.2 km) north of the type section for the Machegit Conglomerate Member (Cloud and others, 1956) (figs. 11, 12). The original type sections as designated by Cloud and others (1956) are retained.

Cloud and others (1956) erroneously assigned the rocks of the three members of the Gloria Formation to the middle part of the Tagpochau Limestone (refer to their fig. 3). Our field mapping and examination of the spatial relations of the Gloria strata and adjacent map units and examination of available borehole data (Cloud and others, 1956; Ayers, 1981; van der Brug, 1985; Carruth, 2003) and biostratigraphic evidence (Cloud and others, 1956; Todd (1957); this report) supports assignment to a distinctly higher stratigraphic position and younger age than that of the Tagpochau Limestone.

The Gloria Formation occurs chiefly in a discontinuous belt bordering the limestone axial uplands along the east side and southern part of the island (figs. 2, 11). Weathering and erosion of the tuffaceous sandstones within the Gloria Formation results in a physiography of low rounded hills, which have been called the Donni clay hills geomorphic region (Cloud and others, 1956; fig. 2). The Gloria is also found in a few outcrops in cliffs along the peninsula north of Bahia Laolao (Laolao Bay) herein called the Kagman peninsula, Nafutan Peninsulas, cliffs facing Unai Fañonchuluyan (Fañonchuluyan Beach), and within a few karst sinkholes at the north end of the island, most notably

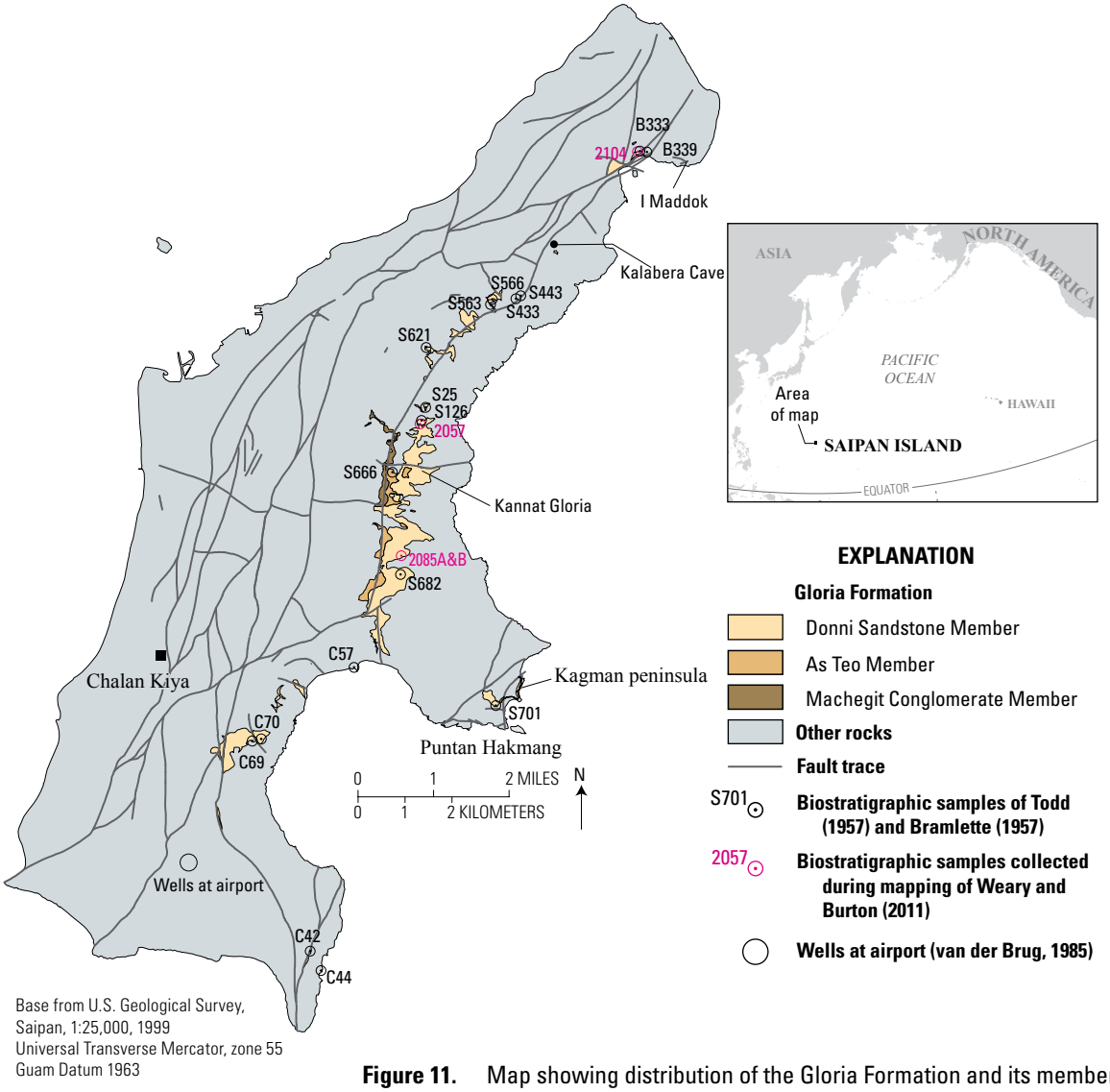


Figure 11. Map showing distribution of the Gloria Formation and its members on Saipan Island and the locations of biostratigraphic samples discussed herein.

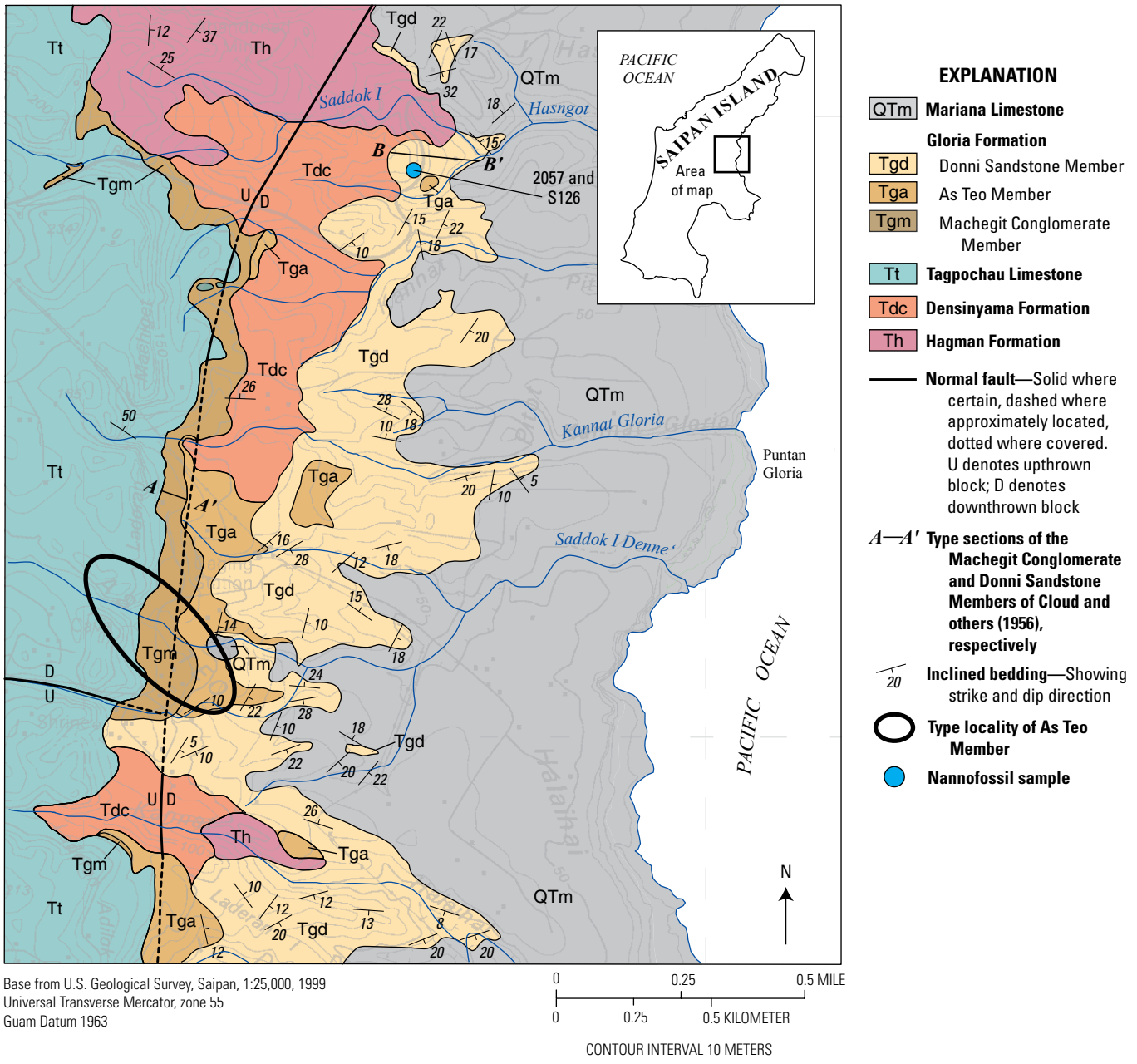


Figure 12. Geologic map of the type sections and areas of the Gloria Formation (new unit) and its members on Saipan Island. Geologic map modified from Weary and Burton (2011).

within I Madok (figs. 2, 11). The Gloria Formation may have been deposited only along the east side of the island or more broadly deposited and subsequently removed from western areas by later erosion. The top of the Gloria Formation is unconformably overlain by shallow water carbonates of the Pliocene and Pleistocene Mariana Limestone.

We interpret the Gloria Formation to be a transgressive sequence of shallow to chiefly deep-water marine sediments deposited over a topographically irregular erosion surface above the Tagpochau Limestone and older sedimentary and igneous rocks. The Machegit Conglomerate Member is a localized, coarse, subaerial or steep shoreface deposit. The As Teo Member is a shallow-water, basal transgressive conglomerate that grades upward into the finer grained, neritic, foraminifera- and calcareous nannofossil-rich deposits of the Donni Sandstone Member (fig. 13).

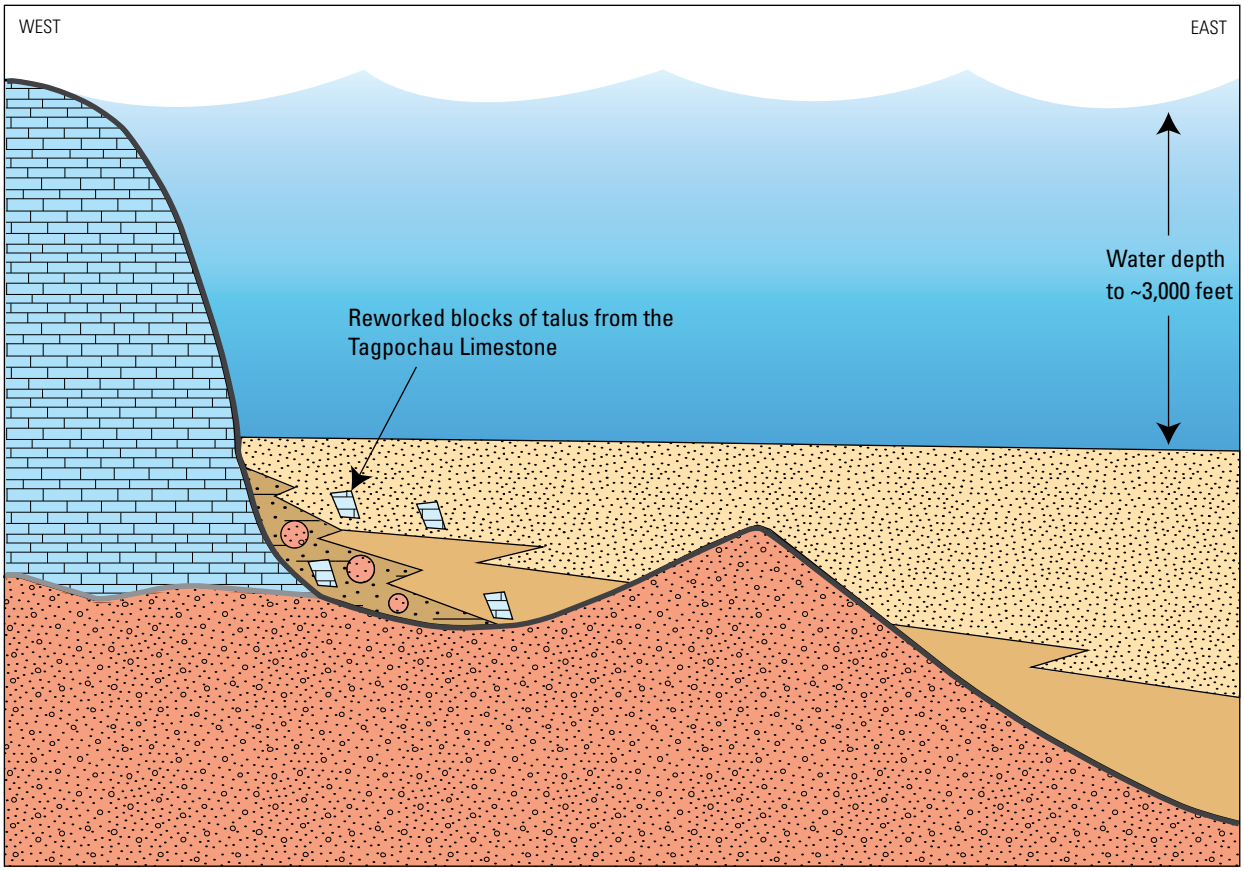


Figure 13. Conceptual diagram of the Gloria Formation (new unit) depositional sequence. The Machegit Conglomerate Member contains conglomerate clasts derived from volcanic units older than the Tagpochau and was deposited on an erosional surface seaward (eastward) of cliffs in the Tagpochau Limestone. The As Teo Member was deposited more distally than the Machegit Conglomerate Member. The planktonic foraminifera-rich Donni Sandstone Member was deposited in a neritic environment with water depths estimated as much as 3,000 feet. All three members locally contain reworked, silica-replaced talus blocks of Tagpochau Limestone. These reworked limestone blocks are concentrated along the west edge of the Gloria Formation outcrop area.

Late Miocene Machegit Conglomerate Member

The Machegit Conglomerate Member of the Gloria Formation is known to occur only in a relatively narrow belt of outcrops just east of the Laderan Machiget (Machiget Cliffs; note new spelling) (figs. 2, 11, 12). The type section originally described by Cloud and others (1956) is along an east to west traverse with easting (e) and northing (n) endpoint coordinates in Universal Transverse Mercator (UTM), Zone 55N, of 367,247e, 1,680,785n meters and 367,331e, 1680760n meters. This east to west traverse includes outcrops of rocks they called the transitional facies of the Tagpochau Limestone (now the As Teo Member of the Gloria Formation), the Machegit Conglomerate Member, and rocks of the informal inequigranular facies of the Tagpochau Limestone (now the Marpi Member of the Tagpochau Limestone) (fig. 12).

The Machegit Conglomerate Member was thought by early mappers to be interlayered with beds of the Tagpochau Limestone that it abutted to the west. This was the reason it was considered a unit within the Tagpochau (Cloud and others, 1956). We assert that the Machegit Conglomerate Member of the Gloria Formation and the overlying As Teo and Donni Sandstone Members onlap, from east to west, over an erosion surface at the top of the Tagpochau Limestone, and other,

older units abut laterally against a scarp in the Tagpochau Limestone (Laderan Machiget) (figs. 12, 13). This scarp is the westward terminus of deposition of the Gloria Formation in this area. The Laderan Machiget probably approximates a late Miocene sea-cliff paleo shoreline. Lithologic logs from several test wells, which are located about 0.3 mi (0.5 km) to the west of the Machegit Conglomerate Member outcrop belt and that penetrate most of the thickness of the Tagpochau Limestone, show no indication of any of the three members of the Gloria Formation in the subsurface (Ayers, 1981).The lack of the Gloria Formation within these wells supports our assertion that the Gloria Formation is not interlayered with, nor a part of, the Tagpochau Limestone.

The Machegit Conglomerate Member is a coarse, polymict conglomerate of deeply weathered, well-rounded andesite boulders and cobbles, sparse rounded cobbles of quartz-rich rock (perhaps dacite), and scattered boulders and smaller clasts of silica- and iron-oxide-replaced limestone blocks. The replaced limestone blocks are concentrated near the base of the conglomerate and were suggested by Cloud and others (1956, p. 71) to be derived from their transitional facies of the Tagpochau Limestone. These blocks are likely relict talus from the cliffs of Tagpochau Limestone (Laderan Machiget) located just to the west of the Machegit Conglomerate Member outcrop belt (figs. 12, 13). A modern analogue exists on Saipan Island where similar talus blocks of the Pleistocene Mariana Limestone are being shed into the Pacific Ocean along the eastern sea cliffs of Saipan Island (Cloud and others, 1956; Weary and Burton, 2011). Clast size in the Machegit Conglomerate Member fines upwards, and the boulders of andesite in the basal part have a maximum diameter of 3 ft (1 m) whereas those in the upper parts only about 1 ft (0.3 m). Unlike the other members of the Gloria Formation, no fossils have been reported from the Machegit Conglomerate Member.

Cloud and others (1956, p. 72) suggested that the volcanic rock clasts in the Machegit Conglomerate Member may have been reworked from older conglomerates in the Eocene (?) Densinyama Formation exposed in some unknown area to the west of the Machegit Conglomerate outcrop belt. Apparently, no such area exists. It is more likely that the volcanic clasts are derived from outcrops of the Eocene Hagman and Densinyama Formations like those currently exposed near the north and south ends of the Machegit Conglomerate outcrop belt, and that also may underlie areas now covered by rocks overlying the Machegit Conglomerate to the east (fig. 12). Given the complex tectonic and erosional history of the island, it is possible that some areas to the east of the outcrop belt were topographically higher during the late Miocene, forming a trough between the Tagpochau Limestone cliffs to the west and exposed volcanic rocks to the east. This scenario would allow deposition, in a narrow belt, of volcanic rock material derived from the north, south, and east with the inclusion of the occasional limestone talus from the west (fig. 13). The Machegit Conglomerate Member may be a subaerial deposit like a fanglomerate, but no sedimentary structures such as imbrication of the clasts have been reported. The Machegit Conglomerate Member ranges in thickness from zero to at least 40 ft (12 m).

Late Miocene As Teo Member

The As Teo Member of the Gloria Formation is named for the community of As Teo where it is exposed just east of the Laderan Machiget (figs. 2, 12). Strata composing the As Teo Member are equivalent to strata previously mapped as the informal transitional facies of the Tagpochau Limestone by Cloud and others (1956). The As Teo Member crops out in two narrow belts in eastern Saipan Island and in a very small area at the south end of a coastal reentrant on the east side of the Naftan Peninsula in the southern part of the island (fig. 11, sample locality C44). One of the outcrop belts partly parallels the outcrop area of the Machegit Conglomerate Member (fig. 12), and the other is exposed in the sea cliffs of Puntan Hakmang (figs. 14–16).

The As Teo Member comprises calcareous tuffaceous sandstone, marl and locally, calcareous andesitic conglomerate. The unit is sparsely fossiliferous but does contain both smaller and larger foraminifera (Todd, 1957; Cole, 1958) and sparse calcareous nannofossils. The larger foraminifera are commonly concentrated into lag layers or channel-filling lenses, suggesting reworking from older units, particularly the underlying Tagpochau Limestone. The As Teo Member reaches a maximum thickness in outcrop of about 40 ft (12 m).

Cloud and others (1956) suggested that the strata comprising the As Teo Member (their transitional facies) represented a lateral sedimentary facies gradation from their "inequigranular facies" of the Tagpochau Limestone into the Donni Sandstone Member and vice versa. Cloud and others (1956, p. 61) wrote: "Strata referred to the transitional facies itself although typically intervening between the Donni Member and more typical calcareous facies of the Tagpochau, may occur either above or below the Donni beds." Outcrop spatial relationships (figs. 11, 12) and planktonic foraminifera and age affinities with the Donni Sandstone Member of the Gloria Formation leads us to interpret the As Teo Member as a basal transgressive conglomerate, deposited over an erosional surface located above the Tagpochau Limestone and other, older bedrock units, and also onlapping over the Machegit Conglomerate Member (fig. 13). It is the basal part of a deepening-upward depositional sequence that culminates with accumulation of the deep-water sediments of the Donni Sandstone Member into which it grades upwards and laterally. In the outcrop belt just east of the Machiget Cliffs, the As Teo Member clearly laps onto the Machegit Conglomerate Member, which itself laps onto an erosion surface formed on the Tagpochau Limestone (figs. 12, 13). The As Teo Member is, in turn, lapped over from the east by the Donni Sandstone Member.

On the Puntan Hakmang, the As Teo Member lies unconformably above older rocks of the Eocene Hagman Formation in the northern part of its exposure and then

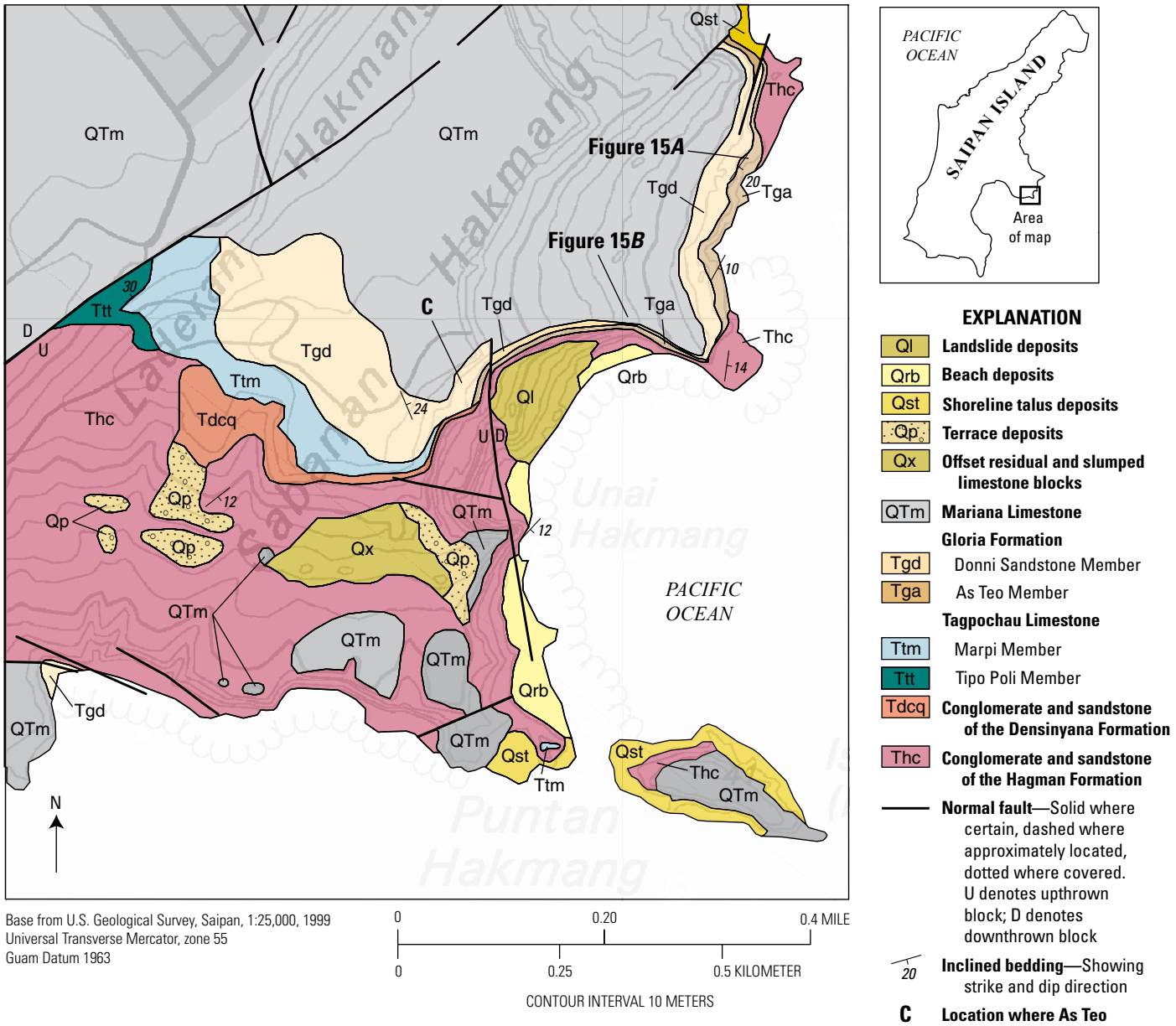


Figure 14. Geologic map of the Puntan Hakmang area showing spatial relationships between the As Teo and Donni Sandstone Members of the Gloria Formation (new unit) and other subjacent and superjacent units. Geology modified from Weary and Burton (2011).

pinches out to the southwest near outcrops of the Tagpochau Limestone (figs. 14, 15). Cloud and others (1956, p. 72) reported that what they thought were local unconformities below the beds of their transitional facies (herein the As Teo Member) were common in the Puntan Hakmang area. They also speculated that these beds graded to the north into their inequigranular facies (herein the new Marpi Member) of the Tagpochau Limestone. In actuality, the As Teo Member grades laterally into beds of the Donni Sandstone Member that overly the Tagpochau Limestone in that area (fig. 14).

Late Miocene Donni Sandstone Member

Strata originally called the Donny beds by Tayama (1936) and the Donni tuff by Cole and Bridge (1953) were formally assigned to the Donni Sandstone Member of the Tagpochau Limestone by Cloud and others (1956). The unit was named for outcrops in the hills to the east of the village of I Donni, now spelled I Denni, on the eastern side of Saipan Island where it forms rounded hills and gullies (fig. 2). Cloud and others (1956) designated a type section for the Donni Sandstone Member between Kannat I Hasngot and Kannat I Pitot (I Hasngot ravine and I Pitot ravine) (fig. 12). The base of the section is in contact with the underlying Densinyama Formation just west of the intersection of the Talafofo Road (formerly the Cross-Island Connecting Highway) and the old East Coast Highway (no longer extant, trace is the access trail to Unai I Hasngot [Hasngot Beach]; coordinates 368,03e,1,681,908n meters; UTM Zone 55N).

The top of the section is a contact with the overlying Mariana Limestone along the trace of the old East Coast Highway about 800 ft (245 m) east-southeast of the intersection (endpoints coordinates 368,251e, 1,680,785n and 367,331e, 1,681,839n meters). Weary and Burton (2011) took these strata out of the Tagpochau Limestone and assigned these rocks to the informal sandstone member map unit of their informal Donni formation. We herein formally reassign these strata to the Donni Sandstone Member of the Gloria Formation and retain the original type section.

Although more widespread than either the Machegit Conglomerate or As Teo Members, outcrops of the Donni

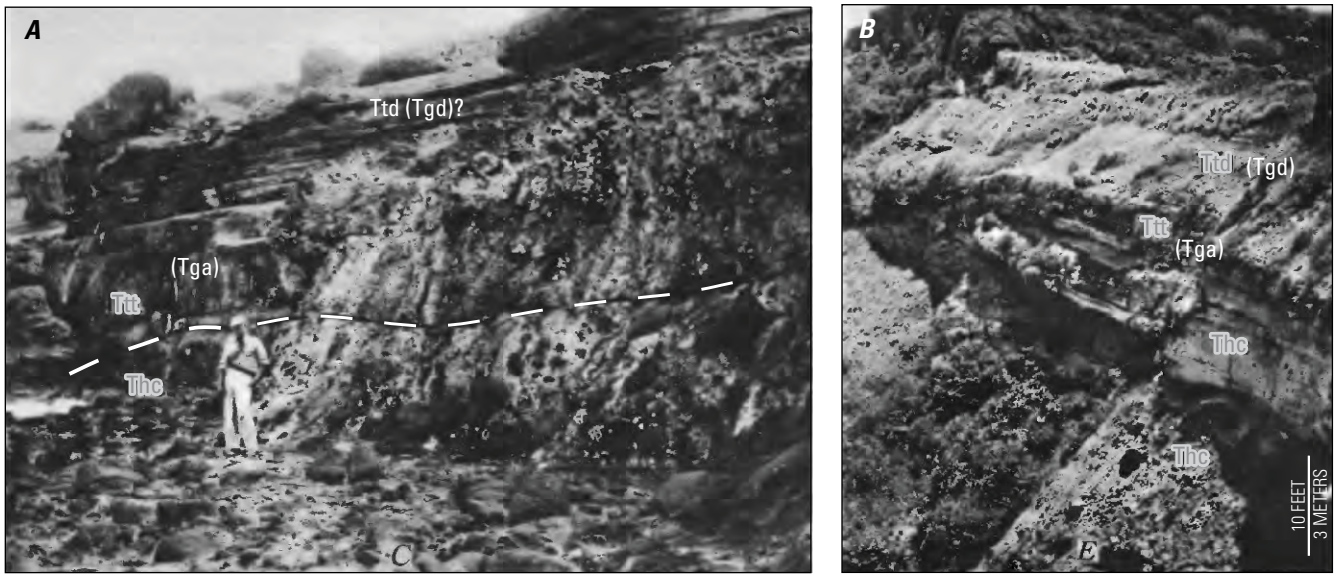


Figure 15. Annotated historical photographs of outcrops of the Hagman Formation (unit Thc) underlying the As Teo and Donni Sandstone Members (units Tga and Tgd, respectively) of the Gloria Formation (new unit) near Puntan Hakmang modified from Cloud and others (1956). Refer to figure 14 for locations of photographs and Cloud and others (1956, plates 7C and 6E respectively) for original captions. *A*, Andesitic conglomerate of Hagman Formation north of Hagman beach underlies the thin-bedded limestone and calcareous conglomerate of the transitional facies of Tagpochau Limestone (unit Ttt). Human figure for scale. *B*, Conglomerate-sandstone facies of Hagman Formation that underlies the transitional facies and Donni Sandstone Member of Tagpochau Limestone in the bluffs of Unai Hakmang (Hagman Beach). White unit labels in parts *A* and *B* indicate the current stratigraphic divisions of the As Teo and Donni Sandstone Members of the Gloria Formation (unit Ttd on part *A* of the Tagpochau Limestone [sensu lato]), whereas dark unit labels are those of Cloud and others (1956). White dashed line in part *A* marks the unconformable contact between the coarse conglomerates of the Hagman Formation and the overlying As Teo Member of the Gloria Formation, which then grades into well-bedded sandstone of the Donni Sandstone Member on the slopes above. Photograph viewpoint of part *B* indicated on figure 16.

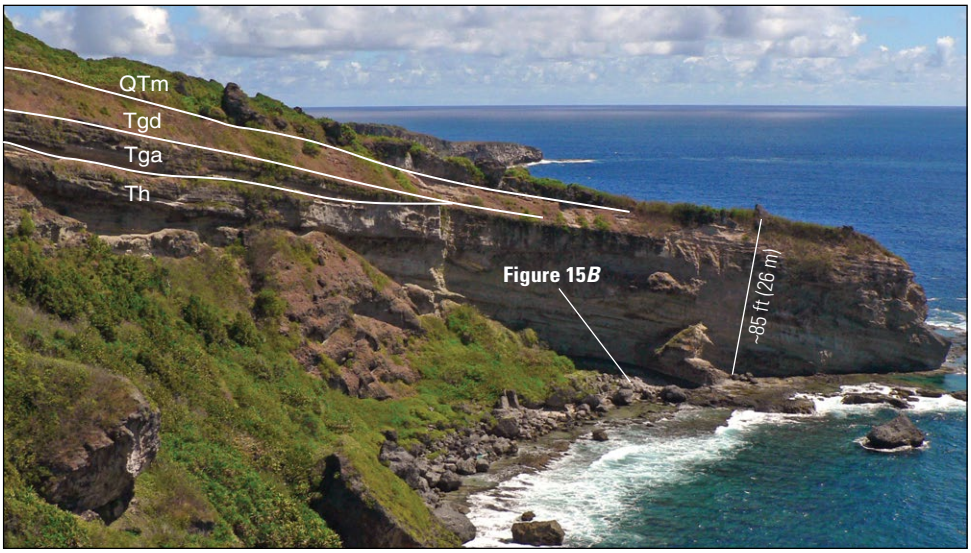


Figure 16. Photograph of bedrock outcrops at north end of Unai Hakmang (Hakmang Beach). View is toward the north. At this locality, the Hagman Formation (unit Th) is unconformably overlain by the As Teo (unit Tga) and the Donni Sandstone (unit Tgd) Members of the Gloria Formation. The Donni Sandstone Member is then overlain unconformably by massive Mariana Limestone (unit QTm). Large, rotated blocks of Mariana Limestone are visible in landslide deposits comprising the slope in the left foreground. Photograph taken in 2007 by D. Weary.

Sandstone Member are still chiefly confined to the east side of Saipan Island (fig. 11). As much as 110 ft of Donni Sandstone Member was encountered in a well drilled at the village of Chalan Kiya on the west side of the island (Cloud and others, 1956; table 8, p. 70) (refer to figures 2 and 11 for location of village). Logs from several wells drilled in the vicinity of the Saipan Island International Airport (fig. 11) document tuffaceous sandstone that may be either the Donni Sandstone Member of the Gloria Formation or the underlying Fina-sisu Formation (van der Brug, 1985). Weathered sandstone slabs, assumed to be the Donni Sandstone Member, were also reported in a deep underground passage near the village of Kalabera (locally known as Kalabera Cave) in the northeastern part of the island (Wexel, 2006) (fig. 11).

The Donni Sandstone Member comprises thin to medium bedded tuffaceous, calcareous, sandstone, siltstone, marl, shale, and pebble and granule conglomerates commonly rich in smaller foraminifera, particularly globigerinids. This member also contains sparse to common calcareous nannofossils, particularly discoasters (Bramlette, 1957). The Donni Sandstone Member is usually light and dark brown or yellowish to olive gray in color. Clasts are dominantly volcanic in origin, chiefly andesites and dacites, and were probably reworked from the older volcanic units. The Donni Sandstone Member locally contains large angular blocks, as much as 3 ft (1 m) in diameter, of fossiliferous Tagpochau Limestone. The presence of these blocks was taken as evidence for penecontemporaneous deposition of the Tagpochau Limestone and the Donni Sandstone Member (sensu lato) by Cloud and others (1956). However, these limestone blocks, like those in the As Teo Member, are probably talus from Tagpochau Limestone paleo-sea cliff outcrops located to the west of the Donni outcrop belt that fell off and were deposited along with the neritic and pelagic sediments of the Donni Sandstone Member. The Donni Sandstone Member ranges in thickness from zero up to 190 ft (58 m).

Although they recognized its deep-water foraminiferal content, Cloud and others (1956) speculated that the sediment of the Donni Sandstone Member must not have been deposited in waters much deeper than 100 fathoms (600 ft; 183 m). This speculation was based on their interpretation that the Donni Sandstone Member was a facies of the Tagpochau Limestone. An examination of the present-day bathymetric profile off the eastern coast of Saipan Island shows nearby offshore water depths of between about 600 and 3,000 ft (180–900 m). These depths are consistent with those of the foraminifera-rich shelf to pelagic limestone facies in the frontal arc slope of the paleo-Mariana arc system conceptual model of Garrison and others (1975, fig. 8, p. 61) and a reasonable analogue for depths of deposition of the foraminifera recovered from the Donni Sandstone Member.

Age of the Gloria Formation

Beds of the Gloria Formation lap over the top of the lower Miocene Tagpochau Limestone in angular unconformity and so must significantly postdate that formation. The Machegit Conglomerate Member contains no reported fossils. However, its close spatial association with both the As Teo and Donni Sandstone Members suggests that it is a basal or lateral equivalent to those units and thus is either slightly older or about the same age as the rest of the basal Gloria Formation.

Microfossil Biostratigraphy

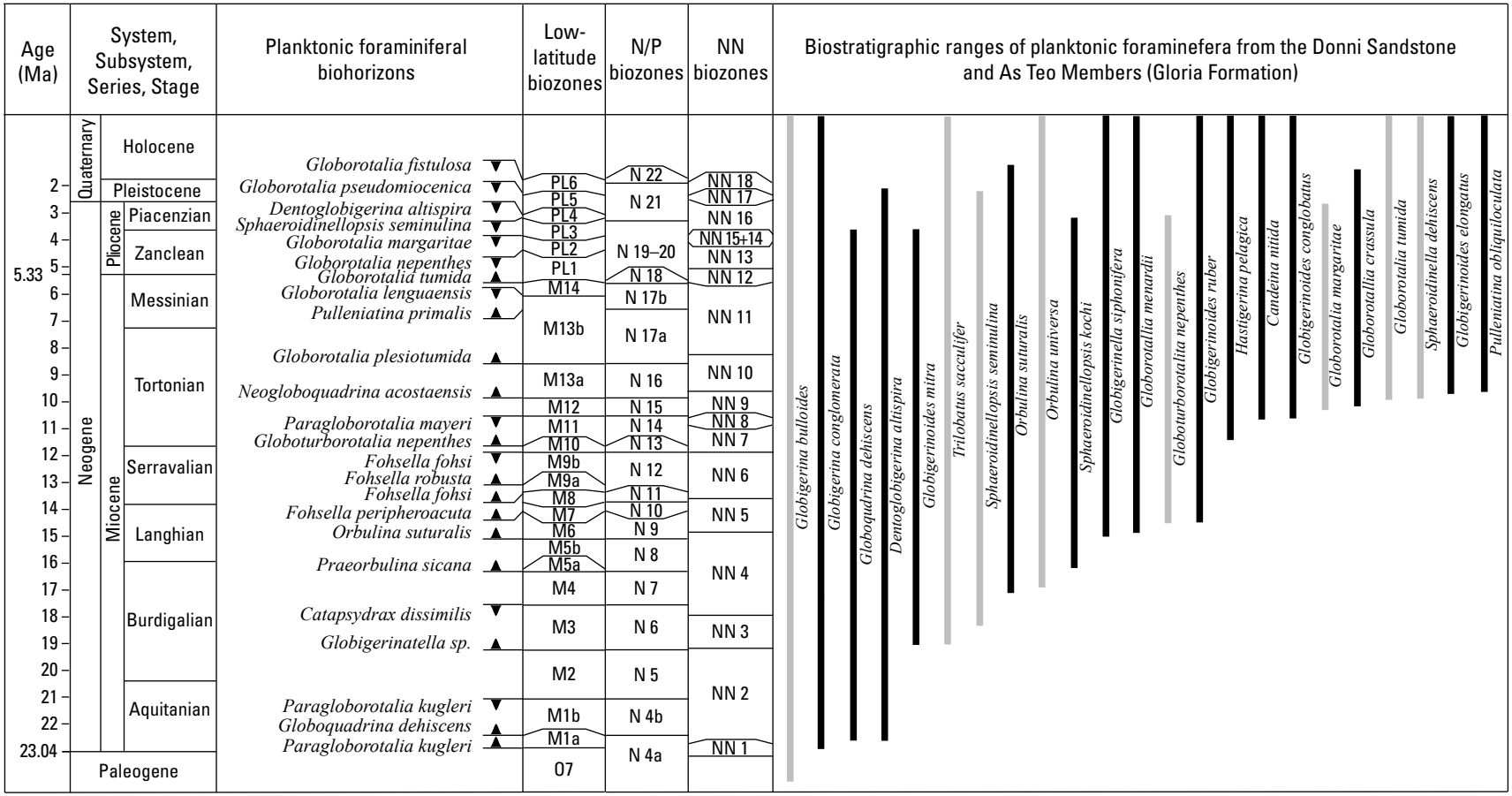
As a part of this study, an analysis was made of available microfossil biostratigraphic data from the Gloria Formation. This includes published data from Cloud and others (1956) and Todd (1957), as well as new data from rock samples collected during field mapping by Weary and Burton (2011). None of these samples were systematically collected along measured sections and so do not precisely constrain the ages of the lower or upper contacts or the timing of depositional events internal to the formation. The results, however, are sufficient to clearly differentiate the age of the Gloria Formation from the underlying Fina-sisu Formation and the Tagpochau Limestone, as well as the overlying Mariana Limestone.

Planktonic Foraminifera

No microfossils are reported from the basal Machegit Conglomerate Member of the Gloria Formation (Cloud and others, 1956; Todd, 1957; Weary and Burton, 2011).

Based on incorrect assumptions of physical interfingering of the Donni Sandstone Member (now part of the Gloria Formation) with the larger foraminifera-bearing inequigranular facies of the Tagpochau Limestone, and the state of knowledge of foraminiferal biostratigraphy of the time, R. Todd assigned an early Miocene age to the Donni Sandstone Member (Todd, 1957, p. 280). As a part of this study, we re-evaluated the ranges of planktonic foraminifera species reported from Saipan Island strata by Todd (1957). These ranges were plotted against modern equatorial Pacific biostratigraphic schemes (for example, Bolli and Saunders, 1985) to constrain the age of the Gloria Formation. Species identifications made by Todd (1957) were accepted, and no attempt was made to reexamine her photographs, collections, or type specimens. Variance between the biostratigraphic interpretations and conclusions reached in this report and those of Todd (1957) are almost entirely the result of over 65 years of advancement and refinement in our knowledge of planktonic foraminifera lineages, ranges, zonal biostratigraphic frameworks, and the geologic time scale.

The As Teo Member of the Gloria Formation contains a sparse fauna of planktonic foraminifera and, locally, larger foraminifera. Todd (1957, table 3, p. 277) reported smaller foraminifera from four samples collected from the As Teo Member (C44, C57, S666, and S701, fig. 11). Only sample S666 yielded biostratigraphically diagnostic planktonic foraminifera. The known ranges of those taxa indicate an early Pliocene age and are placed within the *Globorotalia magaritae* Biozone (N18 to N19 Zone of Bolli and Saunders, 1985) (figs. 17, 18). All the reported planktonic foraminifera species recovered from the As Teo Member are also found in the overlying Donni Sandstone Member, suggesting both age and environmental affinities between the two units (Todd, 1957).



EXPLANATION

- **Range of species that occur in Donni Sandstone and As Teo Members**
- **Range of species that occur only in Donni Sandstone Member**
- **Last occurrence of foraminifera species**
- **First occurrence of foraminifera species**

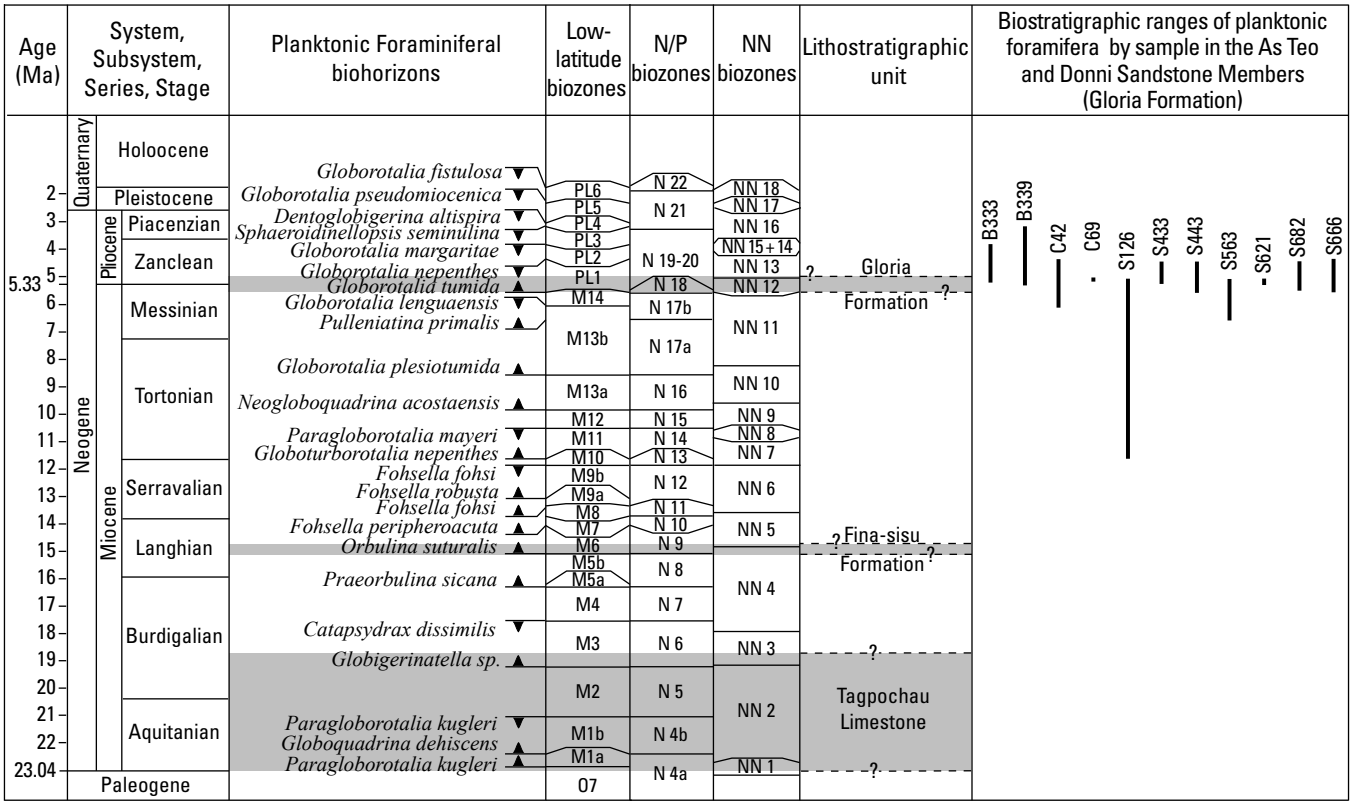
Figure 17. Chart showing biostratigraphic ranges of planktonic foraminifera reported from the Gloria Formation (occurrence data from Todd, 1957). Species ranges conform to those reported in the online database Pforams@mikrotax (Huber and others, 2017). Refer to Todd (1957) table 3 on p. 279 for reported species occurrences and p. 281 for range chart of the same species. Geologic divisions are in conformance with those of Raffi and others (2020), planktonic foraminiferal biohorizons from Raffi and others (2006), low-latitude planktonic foraminifera biozones after Wade and others (2011) with emended M14, planktonic foraminifera Neogene and Paleogene (N/P) biozones after Blow (1969), and calcareous nannofossil NN biozones from Martini (1971).

Larger foraminifera reported from the As Teo Member (Cole, 1958) are also early Miocene in age (Tertiary *e* Biozone). As mentioned previously in this report, these fossils are probably lag deposits reworked from the underlying Tagpochau Limestone and therefore not age diagnostic for the Gloria Formation.

The Donni Sandstone Member contains abundant planktonic foraminifera and shows more species diversity than the As Teo Member. Todd (1957, table 3, p. 279) reported planktonic foraminifera from samples collected from 13 sites on Saipan Island (fig. 11).

Table 1 lists planktonic foraminifera species recovered from the Gloria Formation, As Teo and Donni Members as reported by Todd (1957) and updated to modern equivalent names.

Figure 17 shows a summary of the planktonic foraminifera species recovered from all Gloria Formation samples and their known stratigraphic ranges. Integration



EXPLANATION

- **Age range of the Gloria Formation, Fina-sisu Formation, and Tagpochau Limestone**
- **Range of sample**
- **Last occurrence of foraminifera species**
- **First occurrence of foraminifera species**
- **Unit boundary**—Inferred and uncertain

Figure 18. Chart showing composite planktonic foraminifera age ranges by sample from the Gloria Formation based on occurrence data reported by Todd (1957). Only sample S666 yielded diagnostic foraminifera from the As Teo Member, the remainder of the samples shown are from the Donni Sandstone Member. Sample locations are shown in figure 11. Geologic divisions are in conformance with those of Raffi and others (2020), biozones planktonic foraminiferal biohorizons from Raffi and others (2006), low-latitude planktonic foraminifera biozones after Wade and others (2011) with emended M14, planktonic foraminifera Neogene and Paleogene (N/P) biozones after Blow (1969), and calcareous nannofossil NN biozones from Martini (1971).

Table 1. Planktonic foraminifera species identified by R. Todd (1957) and updated synonymous names.

[Species listed in order of known biostratigraphic first occurrence, as reported by the online database Pforams@mikrotax (Huber and others, 2017)]

Planktonic foraminifera species as reported by R. Todd (1957) from Saipan Island strata now assigned to the Gloria Formation	Revised species names (where necessary) and taxonomic and stratigraphic notes
Globigerina bulloides D'Orbigny	*Globigerina bulloides* D'Orbigny
Globigerinoides sacculifera Brady	*Trilobatus sacculifer* (Brady) Species assigned to new genus (Spezzaferri and others, 2015).
Sphaeroidinella dehiscens Parker and Jones	*Sphaeroidinella dehiscens* Parker and Jones

Table 1. Planktonic foraminifera species identified by R. Todd (1957) and updated synonymous names —Continued.

[Species listed in order of known biostratigraphic first occurrence, as reported by the online database Pforams@mikrotax (Huber and others, 2017)]

Planktonic foraminifera species as reported by R. Todd (1957) from Saipan Island strata now assigned to the Gloria Formation	Revised species names (where necessary) and taxonomic and stratigraphic notes
Globoquadrina altispira Cushman and Jarvis	*Dentoglobigerina altispira* (Cushman & Jarvis) Assignment to *Dentoglobigerina* opinion of Kennett & Srinivasan (1983).
Globoquadrina dehiscens Chapman, Parr & Collins	*Globoquadrina dehiscens* Chapman, Parr & Collins
Globigerinoides mitra Todd, n. sp.	*Globigerinoides mitra* Todd Upper part of stratigraphic range from (Waterman and others, 2012; Poag,1972; Witrock, 2017). Lower part of stratigraphic range from Bolli and Saunders (1985)
Sphaeroidinella seminulina (Schwager)	*Sphaeroidinellopsis seminulina* (Schwager)
Orbulina suturalis Bronnimann	*Orbulina suturalis* Bronnimann
Orbulina universa D'Orbigny and *O. bilobata* D'Orbigny	*Orbulina universa* D'Orbigny *O. bilobata* is now considered a variant of *O. universa* (Kennett & Srinivasan, 1983)
Sphaeroidinella kochi (Caudri)	*Sphaeroidinellopsis kochi* (Caudri)
Globigerinella aequilateralis (Brady)	*Globigerinella siphonifera* (d'Orbigny) Synononimized with *G. siphonifera*, Banner and Blow (1960)
Globorotalia menardii (D'Orbigny)	*Globorotalia menardii* (Parker, Jones & Brady, 1865 after d'Orbigny, 1826 nomen nudum)
Globigerina nepenthes Todd n. sp. 1957	*Globoturborotalita nepenthes* (Todd)
Globigerinoides rubra D'Orbigny	*Globigerinoides ruber* (D'Orbigny) Species gender corrected to match genus.
Hastigerina pelagica (D'Orbigny)	*Hastigerina pelagica* (D'Orbigny)
Candeina nitida D'Orbigny	*Candeina nitida* D'Orbigny
Globigerinoides conglobata Brady	*Globigerinoides conglobatus* (Brady)
Globorotalia hirsuta (D'Orbigny)	*Globorotalia margaritae* Bolli and Bermúdez (1965). *Gr. margaritae* is ancestral to *Gr. hirsuta*. See Bolli and Saunders (1985, p. 216 and 220) for a discussion of these taxa
Globorotalia crassula Cushman and R.E. Stewart	*Globorotalia crassula* Cushman and R.E. Stewart belongs to the *Globorotalia crassiformis* complex. Ranges Pliocene through to Holocene. Bolli and Saunders (1985, p. 231)
Globorotalia tumida (Brady)	*Globorotalia tumida* (Brady)
Globigerinoides elongata D'Orbigny	*Globigerinoides elongatus* (D'Orbigny)
Pulleniatina obliquiloculata (Parker and Jones)	*Pulleniatina obliquiloculata* (Parker and Jones)
Globigerina eximia Todd, n. sp.	*Globoquadrina conglomerata* (Swager) Todd (1964) synonomized Globigerina eximia with *Globigerina conglomerata* (Swager) and reported it ranging from Oligocene to Holocene

of the species occurrence data that was reported by Todd (1957) with a modern zonation scheme for the low-latitude Pacific Ocean (Bolli and others, 1989; Wade and others, 2011) suggests an early Pliocene age for the deposition of the Gloria Formation sediments, probably confined to the *Globorotalia margaritae* Biozone (Bolli and others, 1989) and within the PL1 Biozone of Wade and others (2011). This is based on the overlap of *Globoquadrina dehiscens*, which has its last occurrence at the top of the N18 Zone; *G. margaritae*, which has its first occurrence at the base of N18 Zone; and *G. nepenthes*, which had its last occurrence at the top of the PL1 Zone (figs. 17, 18).

The biostratigraphic range of the species *Globigerinoides mitra* Todd (fig. 17) requires some discussion. This species was described and named by Todd (1957) from specimens recovered from two Saipan Island localities (samples S126 and S621 from the Donni Sandstone Member of the Gloria Formation; fig. 11). *Globigerinoides mitra* has been reported

to occur only within the Miocene in the equatorial Pacific Ocean region (for example, Bolli and Saunders, 1985). However, at least two biostratigraphic charts indicate a range into the lower Pliocene in the Gulf Coast region (Waterman and others, 2012; Witrock and others, 2017), and *G. mitra* is also reported to range into the N18 Zone in the western North Atlantic Ocean region (Poag, 1972). The species holotype specimen (USNM 624038), designated by Todd (1957), was collected on Saipan Island from the Donni Sandstone Member at locality S621 (fig. 11). Based on its co-occurrence on Saipan Island with other species with well-defined ranges, the species holotype, long considered Miocene, is most likely early Pliocene in age (fig. 17).

Figure 18 summarizes the new planktonic foraminifera age ranges determined for each Gloria Formation sample from data reported by Todd (1957). Biostratigraphic ranges of the individual samples fall chiefly within the upper Miocene Messinian Stage and the lower Pliocene, Zanclean Stage.

Calcareous Nannofossils

Rock samples containing calcareous nannofossils from the Gloria Formation were collected from either the transitional facies of the Tagpochau Limestone or the Donni Sandstone Member during mapping by Cloud and others (1956). As with the foraminifera samples, these were spot collections that were not systematically related to the tops or bottoms of the stratigraphic units and so poorly constrain the ages of the lowermost and uppermost parts of these units. Bramlette (1957, table 1, p. 251) published a list of calcareous nannofossil species recovered from nine samples within the Gloria Formation. Of the taxa reported, *Discoaster brouweri*, *D. challengeri* (now considered to be *D. variabilis*), and *D. pentaradiatus* are biostratigraphically significant, constraining those samples to an age no older than late Miocene or ~ 9.1 Ma or position no lower than the NN10 Biozone (Raffi and others, 2006) (fig. 19).

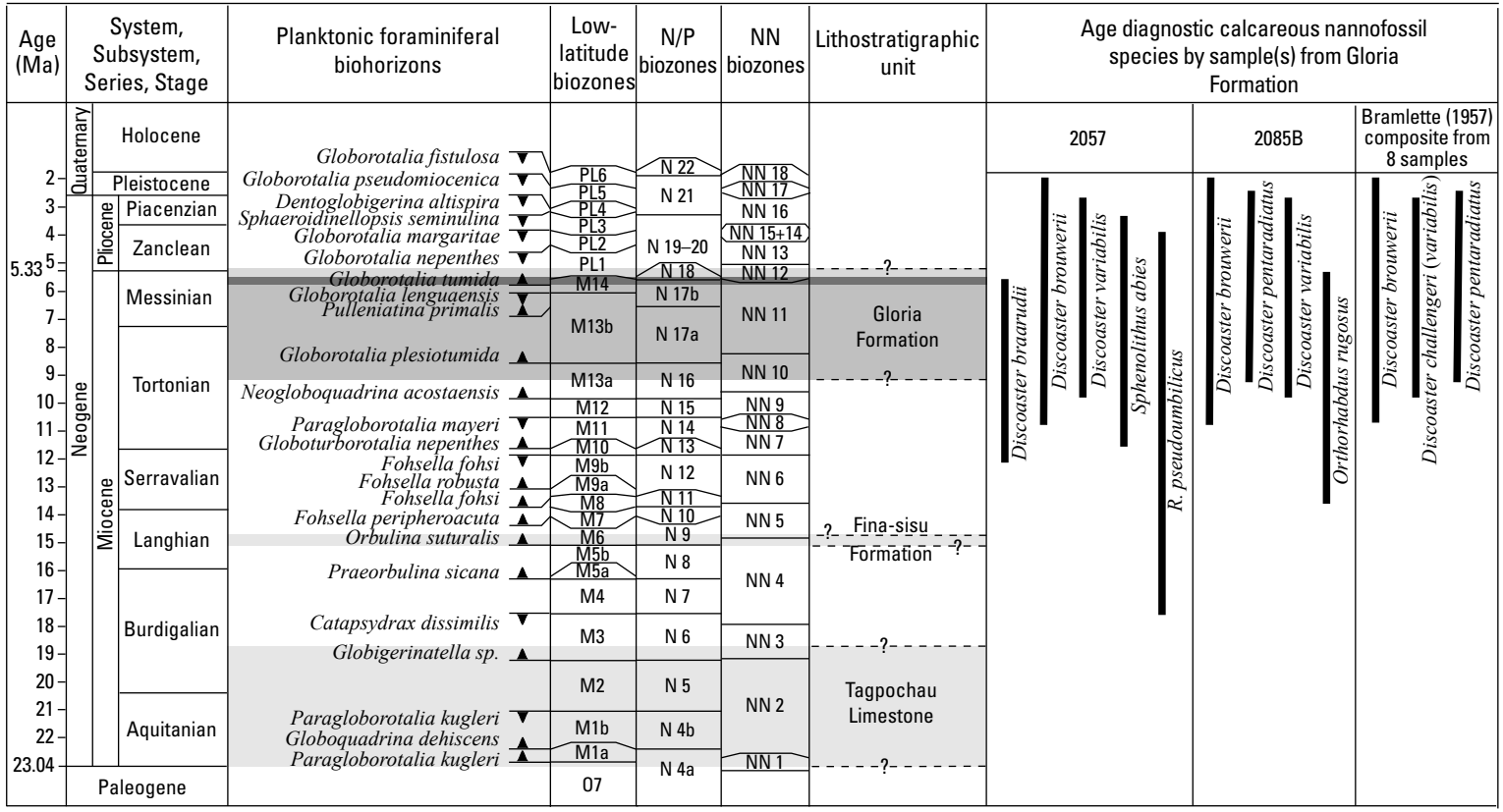
Four rock samples of the Gloria Formation (Donni Sandstone Member) collected during mapping by D. Weary in 2006 and 2007, were analyzed for calcareous nannofossils and yielded common to sparse flora of chiefly *Discoaster* species. The northernmost sample, locality 2104 (fig. 11), yielded a few non-age diagnostic specimens.

Sample locality 2057 from the central-eastern part of the island (fig. 11), collected from near the middle of the Donni Sandstone Member, yielded a sparse nannofossil flora (table 2). All these species are either Miocene or Pliocene in age, but *D. braarudii* (NN7–NN11 Biozone) is restricted to the Miocene. Background specimens include *Reticulofenestra pseudoumbilic*us, *Coccolithus pelagicus*, *Calcidiscus leptoporus*, and *Sphenolithus abies*. All these species are consistent with a late Miocene to early Pliocene age.

The sample from locality 2085 was collected from an exposure of the upper part of the Donni Sandstone Member about 1.9 mi (3,000 m) south southwest of locality 2057 (fig. 11). The single hand sample, which comprised laminated coarse- and fine-grained calcareous sandstone and mudstone, was divided into a fine-grained subsample A and a course-grained subsample B. Both samples yielded abundant calcareous nannofossils and shared most of the same species, but subsample B had a slightly more diverse flora. The co-occurrence of *Discoaster* species *D. brouweri*, *D. pentaradiatus*, and *D. variabilis* indicates that the Gloria Formation is no lower than the NN10 Biozone. Additionally,

Table 2. Calcareous nannofossil species recovered from Saipan Island.

Species	Sample locality number			
	2057	2085A	2085B	2104
Calcidiscus leptoporus (Murray & Blackman 1898) Loeblich & Tappan, 1978			X	X
Calcidiscus macintyrei (Bukry & Bramlette 1969) Loeblich & Tappan, 1978		X	X	
Coccolithus pelagicus (Wallich 1877) Schiller, 1930	X	X	X	X
Discoaster braarudii Bukry 1971	X		X	
Discoaster brouweri Tan Sin Hok 1927	X		X	
Discoaster calcaris Gartner 1967			X	
Discoaster deflandrei Bramlette & Riedel 1954		X		
Discoaster neohamatus Bukry & Bramlette 1969			X	
Discoaster pansus (Bukry & Percival 1971) Bukry, 1973		X	X	
Discoaster pentaradiatus Tan Sin Hok 1927		X	X	
Discoaster triradiatus Tan Sin Hok 1927			X	X
Discoaster variabilis Martini & Bramlette 1963	X	X	X	
Discoaster spp.		X		X
Hayaster perplexus (Bramlette & Riedel 1954) Bukry, 1973		X	X	
Helicosphaera carteri (Wallich 1877) Kamptner, 1954		X	X	
Orthorhabdus rugosus (Bramlette & Wilcoxon 1967) Young & Bown, 2014		X		
Reticulofenestra pseudoumbilicus (Gartner 1967) Gartner, 1969	X	X	X	X
Scyphosphaera pulcherrima Deflandre 1942			X	
Sphenolithus abies Deflandre in Deflandre & Fert 1954	X	X	X	
Sphenolithus moriformis (Brönnimann & Stradner 1960) Bramlette & Wilcoxon 1967		X	X	
Sphenolithus verensis Backman 1978			X	



EXPLANATION

- **Composite age range of planktonic foraminifera**
- **Composite age range of planktonic foraminifera collected from samples in fig. 18**
- **Overlap of two age ranges**
- **Range of species**
- **Last occurrence of species**
- **First occurrence of species**
- **Unit boundary**—Inferred and uncertain

Figure 19. Chart showing composite ranges of calcareous nannofossils in the As Teo and Donni Sandstone Members of the Gloria Formation reported from Saipan Island (Bramlette, 1957; this report). Samples 2057 and 2085B were collected by D. Weary in 2007 as part of geologic mapping by Weary and Burton (2011). Composite age ranges of these species are indicated by horizontal gray rectangle. Horizontal lighter gray rectangle indicates composite ranges of planktonic foraminifera also collected from the Gloria Formation, but from different rock samples (refer to fig. 18). The overlap of the two age ranges is darkest gray. Geologic divisions are in conformance with those of Raffi and others (2020), planktonic foraminiferal biohorizons from Raffi and others (2006), low-latitude planktonic foraminifera biozones after Wade and others (2011) with emended M14, planktonic foraminifera Neogene and Paleogene (N/P) biozones after Blow (1969), and calcareous nannofossil NN biozones from Martini (1971).

the presence of *Orthorhabdus rugosus*, which has its last occurrence in the lower NN12 Biozone, restricts sample 2085 to the uppermost Miocene (table 2, fig. 19). Thus, calcareous nannofossil biostratigraphy indicates the Gloria Formation is latest Miocene in age.

Planktonic foraminifera place the Gloria Formation in the upper part of the M14 and lower part of the PL1 Biozones of Wade and others (2011) based on the reported co-occurrence of *Globorotalia tumida tumida* and *Globoturborotalita nepenthes*. Calcareous nannofossils place the Gloria Formation in NN11to lower NN12 Biozones, based on the co-occurrence of *D. braarudii* with *D. variabilis*, *D. brouweri*, and *O. rugosus*. The overlap between the two zonations and fossil groups allows for precise dating of these sediments.

The composite age range for the Gloria Formation is the latest Messinian Age (late Miocene) between approximately 5.8 and 5.5 Ma, based on a combination of planktonic foraminifera and calcareous nannofossil data and correlation to the 2020 geologic time scale (Raffi and others, 2020) (fig. 20).

Regional Correlations

There appear to be rocks similar to, and possibly correlative with, the Gloria Formation on the other large islands of the Mariana archipelago to the south of Saipan Island. Rocks lithologically similar to the Donni Sandstone Member of the Gloria Formation occur on the neighboring Tinian Island about 4 miles (6.5 km) southwest of Saipan Island, where mappers assigned them to the sandy facies of

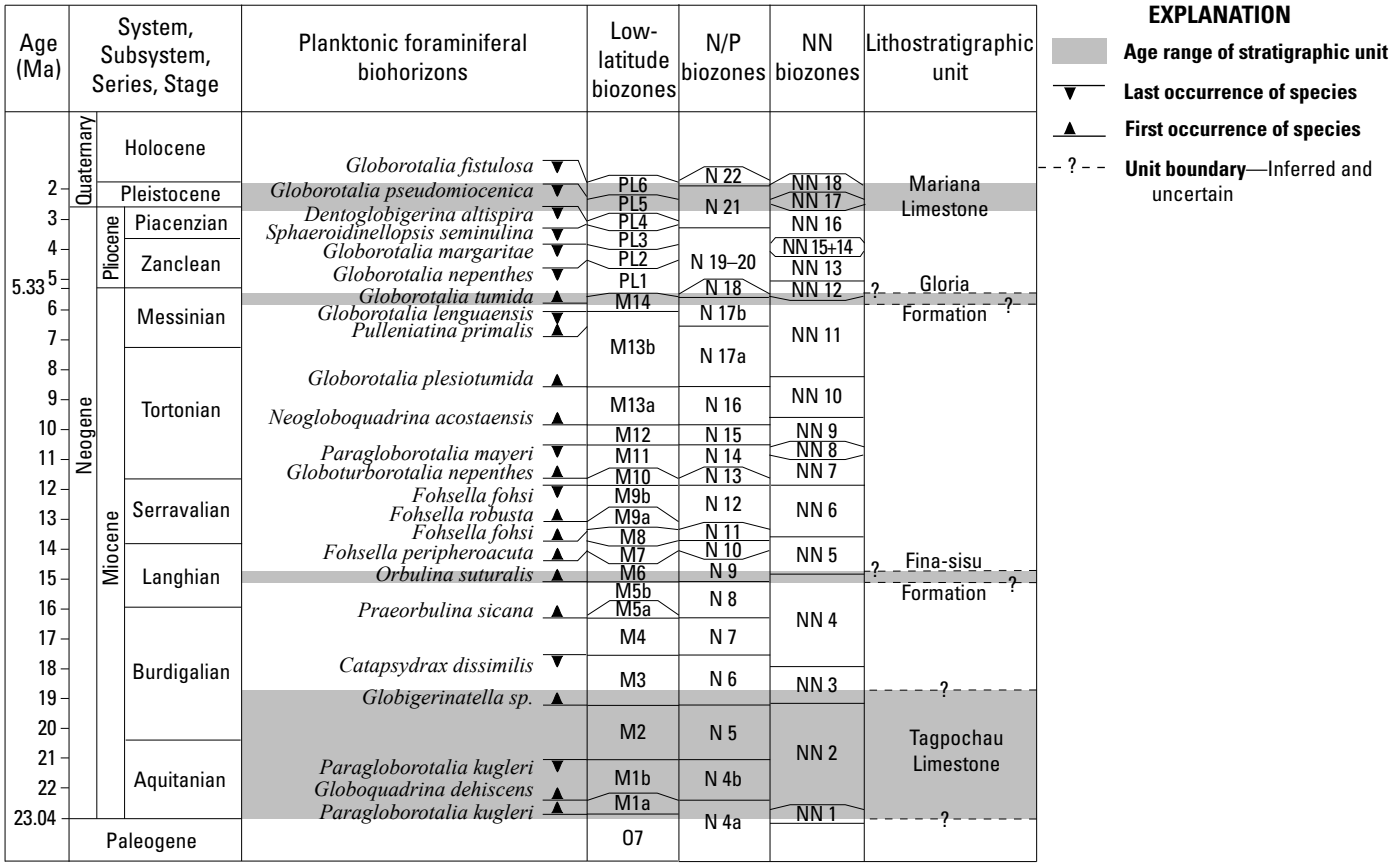


Figure 20. Chart showing the composite planktonic foraminifera and calcareous nannofossil biostratigraphic ranges of the Gloria Formation as well as the overlying Mariana Limestone and underlying Fina-sisu Formation and Tagpochau Limestone for comparison. Planktonic foraminifera data reported by Todd (1957) and calcareous nannofossil data reported by Bramlette (1957) and in this report (figs. 18, 19). Age of the Mariana Limestone from Cloud and others (1956) and Ladd (1966) but was not examined in this study. Geologic divisions are in conformance with those of Raffi and others (2020), planktonic foraminiferal biohorizons from Raffi and others (2006), low-latitude planktonic foraminifera biozones after Wade and others (2011) with emended M14, planktonic foraminifera Neogene and Paleogene (N/P) biozones after Blow (1969), and calcareous nannofossil NN biozones from Martini (1971).

the Tagpochau Limestone (Doan and others, 1960). (Doan and others (1960, p. 63) reported that the sandy facies contains abundant "small foraminifers," but there was no description of what types or species they were. The depositional and local geographic context of these rocks is similar to that of the Gloria Formation on Saipan Island. On Tinian Island, the sandy facies of Doan and others (1960) occurs only on the eastern edge of the island and appears to unconformably overly the argillaceous facies of Doan and others (1960) of the Tagpochau Limestone, and it either overlies or interfingers laterally with, the detrital facies of the Tagpochau (Doan and others, 1960). The sandy facies is, in turn, overlain in angular unconformity by the Mariana Limestone. Doan and others (1960, p. 64) commented that exposure of the contacts they mapped was not adequate to resolve the exact relationship between the sandy facies and their other Tagpochau Limestone map units.

The island of Rota, located 71 mi (115 km) to the southwest of Saipan Island, has not been mapped for geology island wide since a pre-World War II reconnaissance by Sugawara (1934). Like Saipan and Tinian Islands, Gloria Formation equivalent strata are probably present along the south and eastern sea cliffs of Rota. A few of the planktonic foraminifera species, such as *Globoquadrina dehiscens*, *Pulleniatina obliquiloculata*, and *Orbulina universa* are commonly found in the Gloria Formation (table 1) and were also reported from samples of the informal Hirippo and Mariiru limestone units from Rota (Sugawara, 1934; Hanzawa, 1957). Further study could help to determine the exact stratigraphic relationships between these units and other rocks on Rota.

Lithologically similar to parts of the Gloria Formation, the Janum Formation on the island of Guam is a tuffaceous, globigerinid-rich limestone and is only found in sea cliffs in the northeastern part of the island. Todd (1966) noted the occurrence of the species *Globoturborotalita nepenthes* both in the Donni Sandstone Member of the Tagpochau Limestone Formation (now the Donni Sandstone Member of the Gloria Formation) on Saipan Island and in the Janum Formation on Guam about 120 mi (193 km) to the southwest of Saipan Island. Based on the planktonic foraminiferal faunas recovered from the Donni Sandstone on Saipan Island and the Janum Formation on Guam, Todd (1966, p. 21) suggested that the Donni Sandstone might be a unit separate from and younger than the Tagpochau Limestone. The shared foraminiferal taxa suggest that the Janum and the Gloria Formations are similar in age. A probable open-marine shelf environment of deposition for the Janum Formation was discussed and illustrated in a conceptual model of the Mariana Island Arc by Garrison and others (1975, fig. 8, p. 61). Similar ages, lithologies, and fossil content allow us to infer that the Donni Sandstone Member of the Gloria Formation on Saipan Island and the Janum Formation on Guam were deposited penecontemporaneously under similar open-marine shelf conditions.

Relevance to Groundwater Resources

Understanding the stratigraphy is relevant because Saipan Island is highly dependent on extraction of groundwater for human and agricultural uses. For example, both the Fina-sisu and Gloria Formations stratigraphically and physically overlie the Tagpochau Limestone and their low hydrologic transmissivity lithologies (tuffaceous and volcanic units in the Fina-sisu Formation and shales in the Donni Sandstone Member of the Gloria Formation) may act as a hydrologic confining unit for groundwater in the underlying Tagpochau Limestone aquifer in southern and eastern parts of Saipan Island (Hoffman and others, 1998). These aquitards, at least locally, separate confined artesian water in the Tagpochau Limestone aquifer from the overlying, unconfined Mariana Limestone aquifer (Wexel, 2006). The Mariana aquifer, the chief source of fresh groundwater production on Saipan Island, is vulnerable to tidal mixing near the coasts and pumping-induced upconing of salt water at production well sites (Carruth, 2003).

Summary

Early geologic mappers on Saipan Island (Tayama, 1936; Cloud and others, 1956), working under pre-plate tectonic paradigms, established a Neogene stratigraphic framework for the island that failed to recognize the profound impacts of periodic vertical tectonic movements on the sedimentary record. This resulted in development of a lateral-facies conceptual stratigraphic model for the Neogene sedimentary rocks on Saipan Island (fig. 3) and an incorrect conceptualization of the stratigraphic position of the Fina-sisu Formation below the thick, lower Miocene Tagpochau Limestone and inclusion of the Machegit Conglomerate and Donni Sandstone Members (both parts of our new Gloria Formation) as members of the Tagpochau Limestone (fig. 3).

The Tagpochau Limestone (sensu stricto) has been redefined to include only the rocks informally called the tuffaceous, marly, inequigranular, equigranular, and rubbly facies by Cloud and others (1956). These rocks comprise the new formally named I Etdot, Tipo Poli, and Marpi Members of the Tagpochau Limestone. Other strata, previously included in the Tagpochau Limestone by Cloud and others (1956) (the Machegit Conglomerate Member, the informal transitional facies, and the Donni Sandstone Member) are herein removed from the Tagpochau Limestone and assigned to the overlying, newly named, Gloria Formation.

Rather than being Oligocene in age and stratigraphically below the Tagpochau Limestone (Cloud and others, 1956), the Fina-sisu Formation is a younger, latest early Miocene deposit (15.1 to 14.8 Ma) that laps onto an angular unconformity produced by erosion after deposition of the Tagpochau Limestone. This conclusion is based on an analysis of ranges of planktonic foraminifera from these sediments. Analysis of map patterns and field relationships

also supports this interpretation (Weary and Burton, 2011). A published interpretation of radiometric age (13 Ma) for a basalt flow in the Fina-sisu Formation (Meijer and others, 1983) is either slightly too young or suggests that eruption of that lava occurred later in the history of the formation than deposition of the sediments that were sampled for fossils. Either way, the Fina-sisu Formation is demonstrably younger than the Tagpochau Limestone and older than the overlying Gloria Formation.

The latest Miocene Gloria Formation (Machegit Conglomerate, As Teo, and Donni Sandstone Members) is much younger than the underlying early Miocene Tagpochau Limestone and probably represents a separate cycle of chiefly deep-water sedimentation related to tectonic activity along the Mariana Subduction Zone.

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