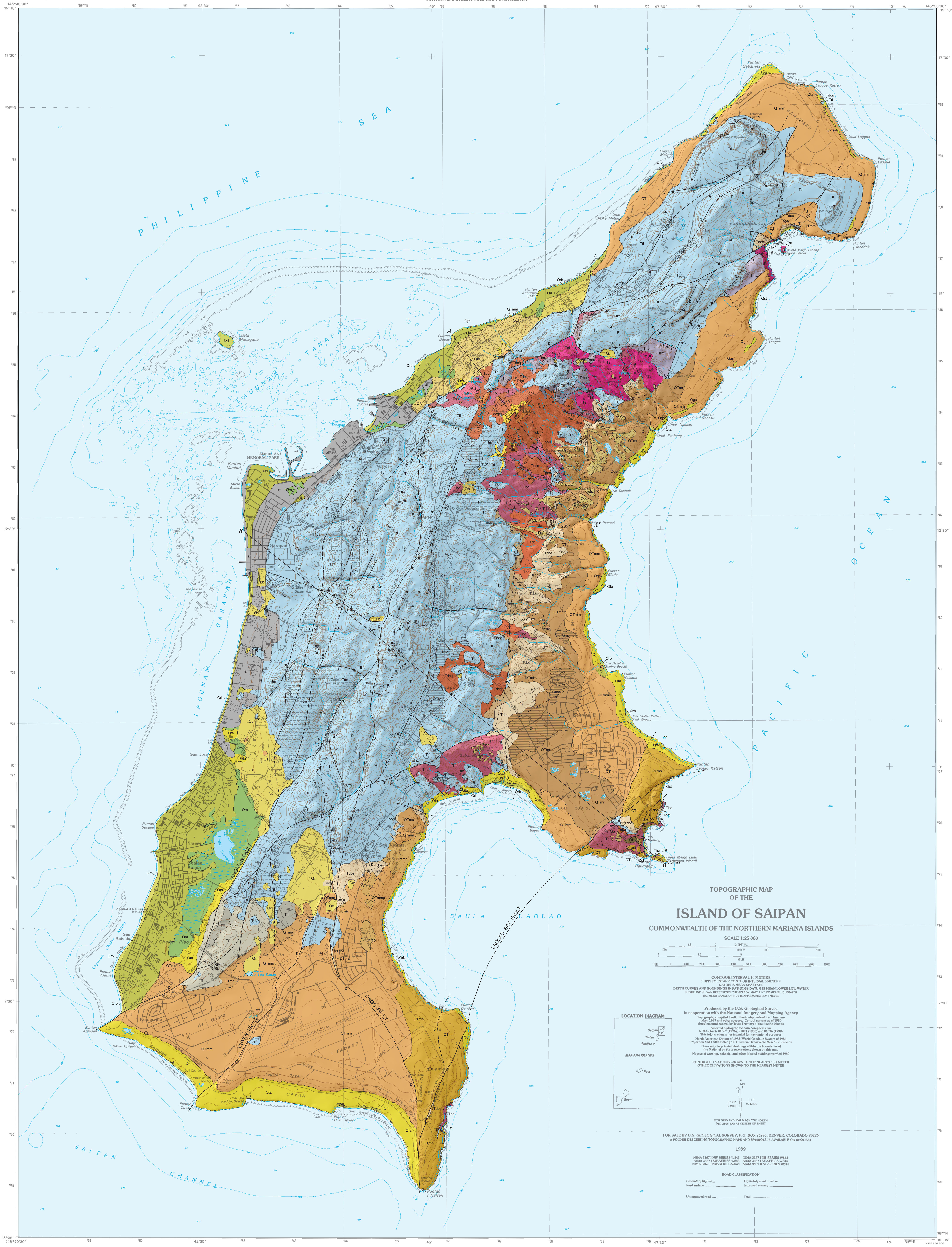
U.S. DEPARTMENT OF DEFENSE
NATIONAL IMAGERY AND MAPPING AGENCY



Geology mapped by D.J. Weary and W.C. Burton, 2006–2007
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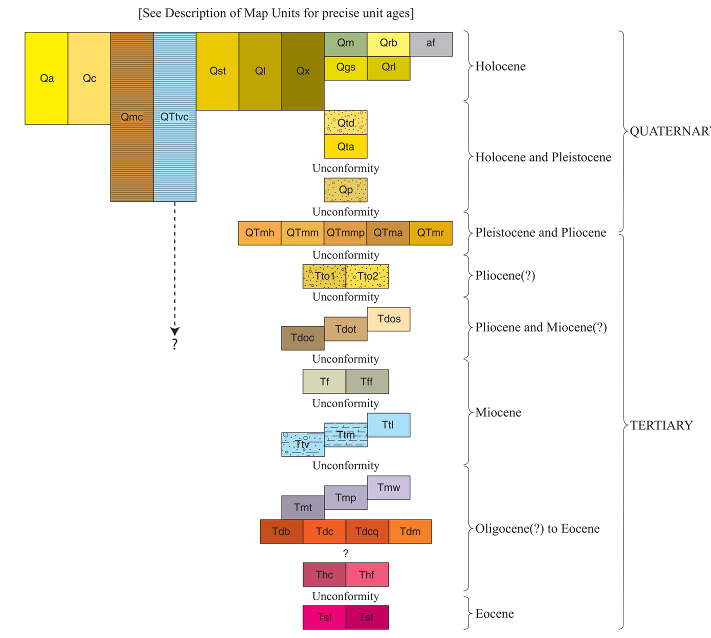
CORRELATION OF MAP UNITS

[See Description of Map Units for precise unit ages]



DESCRIPTION OF MAP UNITS

af **Artificial fill**—Chiefly limestone rubble and sandy material. Principally located in central-western coastal plain. Mapped only where extensive or where geologic map-unit contacts are obscured

Qrb **Beach deposits (Holocene)**—Sand, gravel, beach rock, and patches of recently emerged coralline and algal limestone

Qgs **Gravel and sand in emerged moats (Holocene)**—Calcareous shell-and-coral gravel and carbonate sand, apparently washed up by recent storms and forming a veneer on emerged reef moats in the top surface of either the Tanapag or Mariana Limestones. Restricted to the northeastern part of the island and elevations less than 12 m

Qm **Marsh deposits (Holocene)**—Soft, sticky, bluish-gray to grayish-brown clay. Observed in depressions adjacent to the western coastal plain

Qrl **Emerged carbonate sands (Holocene)**—Very fine to very coarse grained, locally gravelly, carbonate sand. Contains abundant mollusk shells and foraminifera. Emerged to as much as 6 m above sea level, chiefly on western coastal plain

Alluvium (Holocene and Pleistocene)

Qa **Clay and gravel**—Deposited by streams that drain valleys

Qc **Clay wash**—Reworked residual clay, characteristically containing ferruginous and manganiferous pellets, deposited in closed depressions and over broad outwash areas

Mass-wasting deposits (Holocene and Pleistocene)

Qst **Shoreline talus deposits**—Talus consisting of limestone blocks or blocks of both limestone and volcanic rocks deposited along steep areas of the eastern coastline

Ql **Landslide deposits**—Mixture of large and small blocks of Donni formation (informal name) sandstone and the Tagpochau (Ttl) and Mariana (QTmh) Limestones. Mapped only in one area near Puntan Hakmang

Qx **Offset residual and slumped limestone blocks**—Mostly large (up to 18 m across) blocks derived from massive beds of both the Mariana Limestone (QTmh) and the Tagpochau Limestone (Ttl). This deposit has resulted from slow downhill creep (with little rotation) of these blocks over a surface underlain by the Hagman Formation (Thc). Conglomerate and sandstone of the Hagman Formation is locally exposed between blocks. Mapped only in one area near Puntan Hakmang

Qtd **Younger terrace deposits (Holocene and Pleistocene)**—Tuffaceous sands and gravels of lowest terrace above emerged carbonate sands (Qrl). Mapped only in one area near the central part of the northwestern coast

Qmc **Residual clay derived from the Mariana Limestone (Holocene and Pleistocene?)**—Mottled yellowish- to dark-brown and gray clay. Developed over rubbly (QTmr) and massive (QTmm) facies of the Mariana Limestone. Maximum thickness about 12 m

Qta **Tanapag Limestone (Pleistocene)**—Dirty-white to brown emergent fringing coral reef limestone (bafflestone to framestone) occurring below 30 m elevation. Contains abundant, well-preserved fossil corals and coralline algae. Maximum thickness about 15 m

Qp **Terrace deposits younger than Mariana Limestone (Pleistocene)**—Iron-stained, locally quartz-rich, reworked tuffaceous sands and minor gravels at elevations between 30 and 171 m. Clastic material is derived from erosion of older volcanic units. Maximum thickness 3 m

QTtvc **Residual clay derived from the Tagpochau Limestone (Holocene to Pliocene?)**—Mottled and banded clay, either light gray and white or reddish brown and yellowish brown. Developed over the Tagpochau Limestone (either the marly or the tuffaceous facies). Maximum thickness at least 12 m

Mariana Limestone (Pleistocene and Pliocene)—Limestone, commonly coralline and algal, partly argillaceous. Maximum inferred thickness more than 152 m

QTmh ***Halimeda*-rich facies**—Dirty-white and brown massive to bedded, bioclastic limestone (packstone to grainstone) rich in *Halimeda* joints and impressions. Mapped to the east of massive facies (Qmm) and intergrades with it over a large area

QTmm, **QTmmp** **Massive facies**—Dirty-white or pink, generally massive and cavernous, bioclastic limestone. Coral- and algae-rich reef and rubble limestone (floatstone, bafflestone, and rudstone) common in southern Saipan. Dull-pink algae-rich limestone (Qmmp) locally mapped within Qmm. Deep weathering of this facies resulted in development of clay deposits (Qmc)

QTma ***Acropora*-rich facies**—Argillaceous limestone (floatstone to bafflestone) rich in *Acropora*, most of which is fragmented but some of which is intact and in life position. Commonly weathers to thick residual clay. Contact with massive facies (Qmm) is gradational (generalized on map)

QTmr **Rubbly facies**—Highly argillaceous limestone (floatstone); includes large amounts of broken and displaced coral

Tto2, **Tto1** **Older terrace deposits (Pliocene?)**—Reworked argillaceous, locally quartz-rich sand and gravel. Tto1 includes highest and oldest deposits, between 171 and 216 m elevation. Tto2 includes lowest and youngest deposits, between 152 and 177 m elevation

Donni formation (informal name) (Miocene and Pliocene?)—Calcareous and tuffaceous marine sandstone, conglomerate, and tuffaceous limestone. Total inferred thickness about 58 m

Tdos **Sandstone member**—Light- and dark-brown or yellowish- to olive-gray, thin-to medium-bedded, tuffaceous, calcareous sandstone, siltstone, marl, shale, and pebble-and-granule conglomerates. Commonly rich in smaller foraminifera, particularly globigerinids. Overlies informally named Machegit conglomerate member and the transitional facies. Maximum thickness 58 m (Cloud and others, 1956)

Tdot **Transitional facies**—Calcareous conglomerate and tuffaceous limestone and sandstone, commonly with abundant larger foraminifera (possibly reworked from the Tagpochao Limestone). Sediments transition upward or laterally into the sandstone member. Maximum thickness in outcrop of about 12 m

Tdoc **Conglomerate member**—Boulder and cobble conglomerate of reworked volcanic materials. Resembles conglomerates of Densinyama Formation. Locally contains decalcified blocks derived from the Tagpochau Limestone. Possibly a nonmarine deposit. Maximum thickness of at least 12 m

Tf, **Tff** **Fina-sisu Formation (Miocene)**—Interlayered andesitic marine tuffs and basalt flow rocks. Tuffs locally rich in planktonic foraminifera. Includes separately mapped flow (Tff). Maximum thickness at least 122 m

Tagpochau Limestone (Miocene)—White to pink, locally variegated, massive to bedded, locally fossiliferous limestone. Locally rich in clasts of volcanic rocks or fine-grained argillaceous material derived from erosion of older formations. Most common unit exposed in the higher cliffs and uplands of central Saipan. Deep weathering over marly and tuffaceous facies resulted in development of clay deposits (Ttvc). Maximum inferred thickness about 305 m

Ttl **Limestone member**—Massive to well-bedded, relatively pure, sparsely to abundantly foraminiferal limestone (mudstone to grainstone))

Ttm **Marly facies**—Massive to well-bedded, argillaceous limestone

Ttv **Tuffaceous facies**—Massive to well-bedded, impure limestone containing argillaceous material and clasts of volcanic rock

Ttu **Tagpochau Limestone, undivided**—Shown in cross sections only

Matansa Limestone (Eocene?)—Pure to earthy, well-indurated, inequigranular, clastic foraminifera-bearing limestone. Inferred aggregated thickness about 152 m

Tmw **White facies**—White, massive- to well-bedded, relatively pure, sparsely foraminiferal limestone (mudstone to wackestone). Locally may be black, gray, pink, or reddish-brown owing to presence of manganese oxide or magnetite particles. Cements are typically equigranular

Tmp **Pink facies**—Pink, massive to locally well-bedded, foraminiferal limestone (wackestone to packstone). Cements are typically inequigranular

Tmt **Basal transitional facies**—Tuffaceous limestone and calcareous conglomerate. Noncarbonate clasts include andesite particles, siliceous rock fragments, quartz and feldspar grains, and clay minerals. Vertically transitional from underlying Densinyama Formation

Densinyama Formation (Eocene?)—Andesitic breccias and conglomerate, tuffaceous sandstone, tuffaceous limestone, and calcareous conglomerate. Maximum inferred thickness about 244 m

Tdm **Limestone and conglomerate facies**—Thick- to thin- bedded, coarse-grained impure limestone and calcareous conglomerate. Mapped as lens-shaped bodies and irregular beds within upper part of the conglomerate and sandstone facies (Tdc). Contains many quartz grains and small pebbles, granules, and grains of andesite, chert, and silicified pyritic rocks. Lithically and faunally similar to overlying basal transitional facies (Tmt) of Matansa Formation

Tdc **Conglomerate and sandstone facies**—Thick-bedded, largely or wholly marine conglomerate and tuffaceous sandstone deposited as discontinuous, intertonguing bodies. Conglomerate consists of subangular to well-rounded fragments of andesite, dacite, chert, and silicified pyritic rocks. Little or no free quartz grains visible

Tdcq **Quartzose conglomerate and sandstone facies**—Thick-bedded, largely or wholly marine conglomerate and tuffaceous sandstone deposited as discontinuous, intertonguing bodies. Free quartz grains common. Conglomerate consists of subangular to well-rounded fragments of andesite, dacite, chert, and silicified pyritic rocks. Bare soils in areas underlain by Tdcq sparkle in sunlight due to abundant quartz

Tdb **Breccia facies**—Massive, heterogeneous breccia consisting of coarse, angular to rounded rock fragments. Clasts are dominantly andesitic but also contain abundant siliceous rocks. Clasts range up to 1.2 m in diameter. Basal facies of Densinyama Formation

Hagman Formation (Eocene)—Andesite lava flows and andesitic volcaniclastic sedimentary rocks. Maximum exposed thickness about 335 m

Thc **Conglomerate and sandstone**—Massive to irregularly bedded (beds up to 3 m thick), poorly sorted, volcaniclastic conglomerates consisting of subangular to rounded pebbles, cobbles, and boulders of porphyritic andesite in sandy to silty matrix. Interlayered with beds (up to 1 m thick) of moderately to well-sorted, locally crossbedded, volcaniclastic sandstone. Probably represents volcaniclastic debris flows and other related sedimentary deposits. Deposits exposed at tip of Kagman Peninsula are finer grained and appear more distal than deposits to the north and west

Thf **Andesite lava flow**—Dark-gray, buff-weathering, porphyritic andesite lava flows. Typically about 3 m thick. Interfingers with conglomerates (Thc), except on Kagman Peninsula, where flows are absent

Thu **Hagman Formation, undivided**—Shown in cross sections only

Sankakuyama Formation (Eocene)—Rhyolite flows, flow breccias, and ash-flow tuffs. Thickness at least 500 m. $^{40}Ar/^{39}Ar$ age of 45.1 ± 0.3 Ma (Reagan and others, 2008)

Tst **Tuff**—White to buff-weathering, fine-grained, irregularly bedded rhyolite ash-flow tuff. In island interior, layers are up to 9 m thick and are intercalated with flows and breccias. In cliffs under Bird Island overlook, up to 30 m thick and laterally interfingers with rhyolite flows and breccia (Tsf); on Bird Island, grades upward into massive, white matrix-supported breccia with angular gray clasts up to 0.5 m in diameter

Tsf **Rhyolite lava flow and breccia**—Gray to white to locally reddish, fine-grained rhyolite flow rock. On outcrop scale, interfingers with massive to locally flow-banded, autoclastic breccia consisting of welded, angular rhyolite clasts. Phenocrysts of quartz and plagioclase up to 2 mm length locally common in both flows and breccias

Tsu **Sankakuyama Formation, undivided**—Shown in cross sections only

EXPLANATION OF MAP SYMBOLS

Contact—Approximately located

Faults—Solid where location is accurate; dashed where location is approximate; short dashed where inferred; dotted where location is concealed. U (up) or D (down) indicate relative motion

PLANAR POINT FEATURES

[May be combined with other point features at point of observation]

Strike and dip of bedding

26 Inclined

Horizontal

Strike and dip of joints

60 Inclined

Vertical

OTHER FEATURES

Area of brecciated rock; chiefly found within the Tagpochau Limestone

• S662 **Sample locality referred to in text**

INTRODUCTION

This map provides an update and reinterpretation of the geology of the island of Saipan. The geology of the island was previously documented by the U.S. Geological Survey (USGS) in Cloud and others (1956), which includes a geologic map at a scale of 1:20,000. The fieldwork for this project was performed in 2006 and 2007. In addition, our interpretation of data, both our own as well as that of various studies completed since the publication of the 1956 map, requires changes to rank, nomenclature, and stratigraphic order for some of the Miocene map units. Some of the details supporting these changes are discussed below.

No attempt was made to repeat the detailed observation and massive data collection of the earlier study (Cloud and others, 1956); rather, only modest additions were made to the existing data, and some limited reinterpretations of the geology were made. Most of the map-unit delineations and designations from Cloud and others (1956) were retained; any significant changes are noted below. The original 1956 map, which was plotted on a World War II-era topographic base (U.S. Navy, 1944), was scanned and georegistered to a new topographic base map (U.S. Geological Survey, in cooperation with the National Imagery and Mapping Agency, 1999) and hand digitized into a geographic information system (GIS) format. Because of differences in the geographic projection and the scale between the base maps, as well as the small amount of error introduced in the digitization process, some small spatial distortions of the original data have inevitably occurred. The changes to the map-unit contacts and fault locations are based on our field observations. Both the original structural data published by Cloud and others (1956) (including bedding and joint orientations) and the new data that were measured and recorded in 2006 and 2007 are displayed on this map. These data are available as part of the GIS dataset. Most of the stratigraphic names used in this map are attributed to Tayama (1938), with the exception of the informally named Machegit conglomerate member of the now informally named Donni formation (an explanation of this change in status is included below). The spelling of the geographic names and features on Saipan has changed over the years, resulting in potential confusion. This map retains the original spellings used for the stratigraphic units, most of them based on a gazetteer of place names prepared by Cloud (1949). In cases where the native Chamorro language is used for geographic features (bay, beach, mountain, and so on) on the new topographic base map (U.S. Geological Survey, 1999), the English equivalent is provided in parenthesis.

The island of Saipan is located in the Mariana Islands, between the Philippine Sea and the Pacific Ocean, at about latitude 15°12′30″N., longitude 145°45′00″E. (fig. 1). Saipan is about 193 kilometers (km) northeast of the island of Guam (a U.S. territory). Politically, Saipan 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. The CNMI consists of 15 principal islands, of which only Saipan, Tinian, and Rota have significant populations. The 2000 U.S. Census count for the island of Saipan was 62,292. The island is about 23 km long and 10 km wide at its widest point. Elevations range from sea level up to 466 meters (m) at the peak of Okso Takpochao (Mount Takpochao).

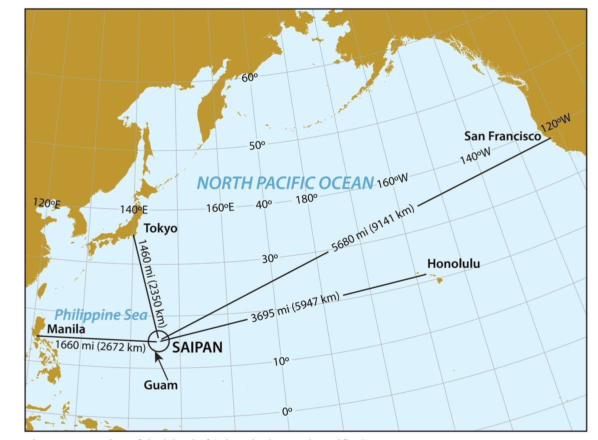


Figure 1. Location of the island of Saipan in the North Pacific Ocean.

STRATIGRAPHY

The oldest rocks exposed on Saipan are Eocene volcanic rocks associated with the inception and evolution of the Izu-Bonin-Mariana (IBM) arc system (Karig, 1971; Taylor, 1992; Cosca and others, 1998). Saipan, which is located on the frontal arc of this system, has been subjected to sporadic episodes of both tectonic uplift and subsidence since the Eocene (Karig, 1971). This history of vertical movement resulted in the deposition (above a volcanic basement) of subaerial and subaqueous sequences; the latter consists of both shallow and deeper marine volcaniclastic and carbonate sedimentary rocks. Cloud and others (1956) relied heavily on biostratigraphy for the age assignments of the stratigraphic units on Saipan. Much data was collected and reported; however, theirs was reconnaissance sampling, no complete sections of individual stratigraphic units were systematically sampled, and little effort was made to precisely define stratigraphic-unit boundaries. There is still a need for detailed, modern, biostratigraphic studies of all of the marine sedimentary units on Saipan.

Sankakuyama Formation

The oldest rock unit exposed on Saipan, the Sankakuyama Formation, is a sequence of Eocene rhyolitic lava flows produced by volcanism during the proto-arc phase of the Izu-Bonin-Mariana (IBM) arc system (Pearce and others, 1999; Reagan and others, 2008). The unit was named for exposures on Okso Achugoa (Mount Achugao) in north-central Saipan (Tayama, 1938). Outcrops of the Sankakuyama Formation chiefly occur in the north-central part of the island, on Okso Achugao, and in areas to the east and southeast of the mountain. Two additional, smaller outcrops are on Isleto Maigo Fahang (Bird Island) and the flanking sea cliffs of southwestern Unai Fañonchuluyan (Fañonchuluyan Beach). The radiometric analysis of samples from the Sankakuyama indicated an age of about 45 Ma (millions of years, or mega-annum), using both the potassium-argon method (Cosca and others, 1998) and the Ar40/Ar39 method (Reagan and others, 2008). An earlier study had reported a potassium-argon age about 5 Ma younger (Meijer and others, 1983). The 45 Ma age is consistent with the middle Eocene relative age assigned by Cloud and others (1956).

The Sankakuyama Formation was divided into four facies-based units by Cloud and others (1956): flow rock (Tsf), breccias (Tsb), tuff (Tst), and mixed pyroclastic rocks (Tsp). Since 1956, these volcanic rocks have been reclassified as rhyolitic rather than andesitic (Meijer and others, 1983; Cosca and others, 1998; Reagan and others, 2008).

We have simplified the subdivision of the Sankakuyama into two map units, a tuff unit (Tst) and a rhyolite lava flow and breccia unit (Tsf), which we believe better reflect the common genesis and interfingering nature of the facies.

Hagman Formation

The Hagman Formation, originally called the "Hagman andesite" by Tayama (1938), was named for exposures in the cliffs of the Hagman Peninsula (now alternatively spelled Hakmang) (Cloud and others, 1956). The Hagman Formation consists of andesitic volcanic rocks and volcaniclastic rocks that were deposited during the first-arc phase of development along the Mariana fore arc (Gill and others, 1994; Reagan and others, 2008). The Hagman was divided into three facies-based map units by Cloud and others (1956): an andesite flow rock, a breccia-tuff facies, and a conglomerate-sandstone facies. We consider both the breccia-tuff facies and the conglomerate-sandstone facies to represent volcanic debris-flow (lahar) and associated reworked deposits. Consequently, the Hagman rocks have been divided herein into only two facies: an andesite lava flow (Thf) and a conglomerate and sandstone unit (Thc).

The potassium-argon ages for the Hagman range from about 28 to 26 Ma (Cosca and others, 1998). The age places these rocks in the late Oligocene, which is much younger than the late Eocene biostratigraphic age assigned earlier by Cloud and others (1956). Further isotopic dating may resolve this discrepancy.

Densinyama Formation

The Densinyama Formation is a sequence of andesitic breccias and conglomerates, tuffaceous sandstones, quartzose conglomerates and sandstones, tuffaceous limestones, and polymictic conglomerates consisting of andesite and limestone pebbles and cobbles. The unit was originally called the "Densinyama beds" after the Japanese name for the ridge that is now called Okso Talafofo (Mount Talafofo) in the north-central part of the island (Tayama, 1938; Cloud and others, 1956). The formation is discontinuously exposed from the vicinity of Bobo Achugao (Achugao Spring), in the western part of north-central Saipan, to areas near the village of Papago, about 6.5 km to the south-southwest. The Densinyama Formation was divided into four facies-based map units by Cloud and others (1956), a subdivision that is retained herein with some modification to the facies names: a breccia facies (Tdb), a conglomerate and sandstone facies (Tdc), a quartzose conglomerate and sandstone facies (Tdcq), and a limestone and conglomerate facies (Tdm).

The Densinyama Formation overlies the Hagman Formation; therefore, it must be younger. The late Oligocene potassium-argon radiometric age for the Hagman assigned by Cosca and others (1998) conflicts with the chiefly Eocene to possibly early Oligocene ages assigned to the Densinyama by Cloud and others (1956) on the basis of larger foraminifera. We have assigned a tentative Eocene age to this unit.

Matansa Limestone

The Matansa Limestone is a sedimentary sequence that transitions upward and laterally from an impure carbonate into a pure-white, shallow-marine limestone. The Matansa Limestone was originally called the "Matansya beds" for exposures near what was called the "Matansya district" by the Japanese (Tayama, 1938). The exposures are located in the west-facing cliffs (Laderan Papao, or the Papao Cliffs) just southeast of the present village of San Roque. The Matansa only crops out in a few limited areas on the northern part of the island. The Matansa was subdivided into three facies-based map units by Cloud and others (1956), which are herein retained in this map: the basal transitional facies (Tmt), the pink facies (Tmp), and the white facies (Tmw).

Like the underlying Hagman and Densinyama Formations, the Matansa Limestone contains larger foraminifera that indicated a late Eocene age (Cloud and others, 1956). Because it overlies both the Densinyama and the Hagman Formations, the late Oligocene potassium-argon radiometric age for the Hagman assigned by Cosca and others (1998) is again problematic when compared to the paleontologic data. We have assigned a tentative Eocene age to this unit.

Tagpochau Limestone

The Tagpochau Limestone is the second most (to the Mariana Limestone) areally extensive rock unit exposed on the island and marks a period of complete submergence of Saipan beneath the sea. The unit is a complex of primarily carbonate rocks with a relatively minor amount of clastic rocks. The Tagpochau Limestone was originally named the "Tappocho Limestone" by Tayama (1938) for outcrops on what was then called Mount Tappocho. The name was later revised to Tagpochau Limestone by Cloud and others (1956) to better fit the English spelling of the Chamorro usage. The name of the geographic feature was changed to Okso Takpochao (Mount Takpochao) on our 1999 USGS topographic base map. In addition to the spelling change, the Tagpochau Formation of Cloud and others (1956) combined the former Toppocho and Laulau Limestones of Tayama (1938) and subdivided the composite formation into two members and six lithic facies. The two members were the Donni Sandstone Member and the Machegit Conglomerate Member. The lithic facies units were (1) the transitional facies, (2) the tuffaceous facies, (3) the marly facies, (4) the inequigranular facies, (5) the equigranular facies, and (6) the rubbly facies. They also mapped various areas in the southern part of the island as undivided Tagpochau Limestone (their map unit Tt).

In our scheme, the Tagpochau Limestone consists of three map units: a tuffaceous facies (Ttv), a marly facies (Ttm), and a limestone member (Ttl). The tuffaceous and marly facies are basal units containing significant amounts of terrigenous material derived from the weathering and erosion of older formations. The limestone member is a composite unit that includes the inequigranular and equigranular facies of Cloud and others (1956) as well as areas that they mapped as undivided Tagpochau Limestone. The cleaner carbonates (that is, cleaner relative to the tuffaceous and marly facies) of the limestone member represent a period of time when the whole of Saipan had subsided beneath sea level, shutting off subaerial erosion and the supply of clastic sediments. The equigranular facies represents local areas where the inequigranular facies recrystallized to an equant-grained cement under meteoric diagenesis.

Following our examination of the rocks formerly assigned to the rubbly facies, we concluded that these rocks are tectonic breccias marking the traces of normal faults in the Tagpochau Limestone, not a fore-reef talus facies as had been suggested by Cloud and others (1956). The brecciated rocks have been assigned to the limestone member of the Tagpochau (Ttl) and are indicated by an overlay pattern on the geologic map. Similar cataclastic breccia zones occur on the nearby island of Guam (Tracey and others, 1964). The breccias of the limestone member are chaotic and mosaic breccias according to the fault-breccia classification of Woodcock and Mort (2008).

We assign the remaining transitional facies, the Donni Sandstone Member, and the Machegit Conglomerate Member as informal members of the informally named Donni formation, which is discussed in more detail below.

The Tagpochau Limestone is early Miocene based on the larger foraminifera species recovered from it (Cloud and others, 1956; Cole, 1975).

Fina-Sisu Formation

The Fina-sisu Formation was named by Cloud and others (1956) for exposures of calcareous marine tuff (Tf) and interbedded volcanic flow rocks (Tff) in the vicinity of the Fina Sisu hills located near the small village of As Lito in the western part of southern Saipan. They were the only known exposures of the formation and covered an area of about 0.6 square kilometers (km2) according to Cloud and others (1956), but the exposures were not successfully located during our mapping; therefore, the following descriptions are based chiefly on those of Cloud and others (1956) except as noted. Exposures of relatively fresh rock are reported to occur only in a few tunnels under the southern part of the Fina Sisu hills (Fuller and others, 1980). The tuffs are well bedded and locally contain abundant planktonic foraminifera. Sparse calcareous nannofossils also are present (Bramlette, 1957). The tuffs closely resemble lithologies found in parts of the underlying Hagman Formation and also in parts of the overlying informally named Donni formation. The volcanic flow rock was described as a light- to dark-olive-gray and greenish-gray, vesicular, aphanitic to finely porphyritic augite andesite. More recent workers have classified the rock as basalt (Meijer and others, 1983). Most of the flows are less than 6 m thick; however, at least one flow may exceed 30 m in thickness. The Fina-sisu typically is highly weathered, and areas of outcrop have become overgrown with vegetation since the 1940s.

Todd and others (1954) reported a probable late Oligocene age for the Fina-sisu Formation based on planktonic foraminifera. On the basis of this age and inferred field relations, they thought that the Fina-sisu was both partially coeval with and also overlain by the Tagpochau Limestone; however, later study of the associations of larger and smaller foraminifera from the Fina-sisu and a comparison of the Fina-sisu with other stratigraphic units in the Indo-Pacific region led to a reassignment of its age to the middle Miocene and a stratigraphic position definitively above the Tagpochau Limestone (Cole, 1975). A subsequent potassium-argon analysis of basalt from the Fina-sisu produced an absolute age of about 13 Ma, or middle Miocene age (Meijer and others, 1983).

Four planktonic foraminifera species recovered from the Fina-sisu Formation were reported from two closely spaced (essentially the same) localities (C85 and S662 of Cloud and others, 1956) by Todd (1957). These sample locations are plotted on the map. The recovered taxa were *Globigerinatella insueta*, *Globigerinoides bispherica*, *G. subquadrata*, and *Orbulina suturalis*. *Globigerinodes bispherica* has since been gender corrected to *G. bispericus,* and *G. subquadrata* is now synonymized with *G. ruber* (Bolli and Saunders, 1985). Their stratigraphic ranges suggest an age of latest early Miocene (upper *Praeorbulina glomerosa* zone), which is equivalent to the uppermost N8 and lowermost N9 planktonic foramanifera Zones and the uppermost NN4 and lowermost NN5 calcareous nannofossil Zones. The absolute age range is about 14.8 to 15 Ma.

Bramlette (1957) analyzed calcareous nannofossil samples from the same two localities (C85 and S662 of Cloud and others, 1956) and reported a sparse flora that included the species *Discoaster aster, D. brouweri, D. challengeri* var., and *D. woodringi*. The only biostratigraphically reliable species in these collections probably are *D. brouweri* and *D. challengeri*, which range from the latest middle Miocene into the latest middle Pliocene. By comparison, the calcareous nannofossil ages reported from the same samples are incompatibly younger than the planktonic foraminifera ages. The Discoaster age range for these Fina-sisu samples is, however, compatible with the Discoaster and planktonic foraminifera ages of samples from the informal Donni formation (discussed later). More biostratigraphic work is needed to resolve this apparent conflict.

Donni formation (informal name)

Strata that were originally called the "Donny beds" by Tayama (1938) were raised in status to the Donni Sandstone Member of the Tagpochau Limestone by Cloud and others (1956). The unit was named for exposures on the eastern side of Saipan, in the hills to the east of the village of I Donni (now I Denni on the topographic base map). The type section was designated as exposures along a traverse located near the intersection of the Cross-Island Connecting Highway with the East Coast Highway (Cloud and others, 1956); the location is now a pronounced curve in the Talofofo Road. Cloud and others (1956) suggested that the Donni Sandstone Member was stratigraphically positioned near the middle of the Tagpochau Limestone and interfingered with the other Tagpochau facies. The new field mapping (which included a re-examination of the field relations between the Donni Sandstone Member and adjoining map units) and the available biostratigraphic evidence point to a distinctly younger age and higher stratigraphic position for this unit than was reported by Cloud and others (1956); therefore, we are raising the rank of the Donni to that of an informal formation on this map.

The informal Donni formation includes three subdivisions that previously were included in the Tagpochau Limestone by Cloud and others (1956): the conglomerate member, which includes sediments previously assigned to the Machegit Conglomerate Member of the Tagpochau Limestone (Tdoc); the transitional lithofacies (Tdot); and the sandstone member (Tdos). The Donni formation is a transgressive sequence of sediments that were deposited over an irregular topographic surface of older sedimentary and igneous rocks. The conglomerate member is a localized, coarse-grained, subaerial or nearshore deposit. The transitional facies is a basal transgressive conglomerate that grades upward into the neritic, foraminifera-rich deposits of the sandstone member.

Cloud and others (1956) mapped several small areas of the Donni on the slopes about 0.8 km southeast of the peak of Okso Tipo Poli (Mount Tipo Poli). Two of their map polygons were attributed with queries (Ttd?); however, after a careful field check of that map area, no outcrops of the Donni were revealed. The original uncertain map designation of these areas probably was based on soil composition. Because no bedrock evidence of the Donni was found and because the stratigraphic position at these localities appears to be inconsistent with other known Donni exposures, these areas are reassigned herein to the limestone member of the Tagpochao (Ttl).

The informal Donni formation laps over the top of the early Miocene Tagpochau Limestone and other older formations in angular unconformity; therefore, the deposition of the Donni must postdate the Tagpochau. The conglomerate member of the Donni formation contains no reported fossils and, therefore, is not dated biostratigraphically; however, its basal or contemporaneous lateral facies association with both the transitional facies and the sandstone member suggests that it is about the same age as the rest of the Donni formation.

The transitional facies of the informal Donni formation contains a sparse fauna of planktonic foraminifera and locally larger foraminifera. All of the planktonic foraminifera species recovered from the transitional facies also are found in the sandstone member (Todd, 1957). Following our cursory examination and comparison of published planktonic foraminifera data (Todd, 1957) to the modern foraminiferal zonation scheme for the lower latitudes of the Pacific Ocean (Bolli and others, 1985), we suggest a probable early Pliocene age assignment for the samples from the transitional facies. Specifically, we assign the transitional facies to the *Globorotalia magaritae* Zone, which occurs within planktonic foraminifera Zones N18 to N19. The early Miocene larger foraminifera reported from these rocks (Cloud and others, 1956; Cole, 1958) are likely reworked from the underlying Tagpochau Limestone. Cloud and others (1956, p. 72) report their appearance as local "…concentrations of larger Foraminifera, as layers or channel-filling lenses."

The sandstone member of the informal Donni formation contains abundant planktonic foraminifera and shows more species diversity than the transitional facies. Again, following our cursory examination and comparison of published planktonic foraminifera data (Todd, 1957) to the modern foraminiferal zonation scheme for the lower latitudes of the Pacific Ocean (Bolli and others, 1985), we suggest a late Miocene to early Pliocene age assignment for the sandstone member. Three of the species originally reported from the Donni by Todd (1957) have known ranges that do not occur within this age interval. Todd (1957) identified the foraminifera *Globorotalia hirsuta*, which occurs in both the transitional facies and in the sandstone member of the Donni and ranges in age from early Pleistocene to Holocene; further examination indicates that these specimens are instead probably *G. margarita*, which has an early to middle Pliocene age (see Bolli and Saunders (1985, p. 220) for a discussion of these taxa). Specimens identified by Todd (1957) as *Hastigerina aequilateralis* in the sandstone member range in age from late Pliocene to modern; further examination indicates that these specimens actually may be *H. siphonifera*, which ranges in age from middle Miocene to modern (see Bolli and Saunders (1985, p. 253) for a discussion of these species' synonymies). The last biostratigraphic outlier species is *Globigerinoides mitra*, which Todd (1957) reported from several localities in the sandstone member. Its middle Miocene biostratigraphic range is older and thus incompatible with the ranges of the rest of the Donni foraminifera and with other foraminifera recovered from the same samples. Todd (1957) named this species, so the identification is probably valid. The incompatibility raises the possibility that the specimen was contained in reworked sediments or that there may have been intersample contamination.

A single sample of the informal Donni formation collected by the authors and analyzed for calcareous nannofossils by Jean Self-Trail (U.S. Geological Survey, written commun., 2010) yielded a sparse flora of chiefly Discoaster species. This sample (field number 2057, see map for location) was collected from near the base of the sandstone member. The identified specimens include *Discoaster braarudii, D. brouweri, D. challengerii*, and *D. loeblichii*. All of these species are limited to either the Miocene or the Pliocene, but *D. braarudii* (calcareous nannofossil Zones NN5 to NN10) is limited to the Miocene, and both the first and last occurrence of *Discoaster loeblichii* is limited to the late Miocene (upper part of calcareous nannofossil zone NN10). The background specimens include *Reticulofenestra* spp., *Coccolithus pelagicus*, *Calcidiscus leptoporus*, and *Sphenolithus abies*; all of these species' ages are consistent with a late Miocene age.

Todd (1966) noted the occurrence of the Miocene to Pliocene planktonic foraminifer species *Globigerina nepenthes* in the Janum Formation on the island of Guam as well as in the transitional facies and the Donni Sandstone Member of the Tagpochau Limestone on Saipan (both now parts of the informal Donni formation). On the basis of these observations, Todd (1966, p. 21) suggested that the Donni Sandstone Member might be stratigraphically separate from and younger than the Tagpochau Limestone. The partially shared foraminiferal fauna suggests that the Janum Formation and the now informal Donni formation may be at least partly coeval. The Janum Formation is a tuffaceous, globigerinid-rich limestone that is found only in sea-cliff exposures in the northeastern part of Guam. The similarities in age and lithology, as well as their topographic positions relative to their respective islands, suggest that both the informal Donni formation and the Janum Formation were influenced by similar tectonic activity that created a relatively deep marine depositional environment on the eastern sides of both Saipan and Guam during late Miocene and early Pliocene time. This timing coincides with a period of quiescence along the Mariana subduction zone and the submergence of the frontal arc posited by Karig (1971).

Younger Stratigraphic Units

The occurrence of a variety of both bedrock and surficial stratigraphic units that are younger than the informal Donni formation are shown on the map. The map-unit names and ages for these units were retained from the work of Cloud and others (1956). Brief descriptions may be found in the Description of Map Units. For more detailed descriptions, see Cloud and others (1956).

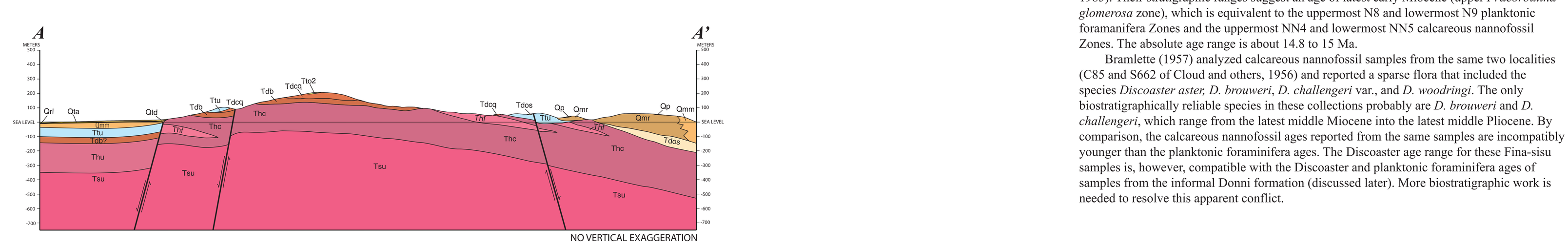
STRUCTURAL GEOLOGY

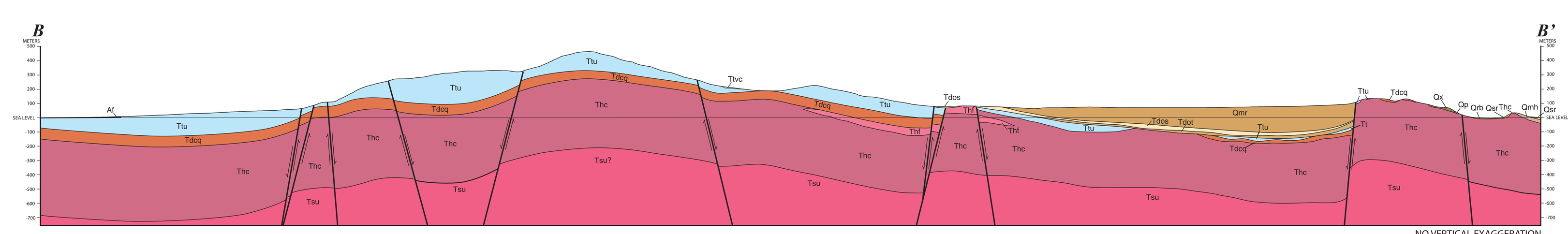
According to Cloud and others (1956), the rock units on Saipan are cut by a number of normal faults, most of which trend northeast to southwest and have a down-to-the-west sense of motion. Cloud and others (1956) observed westward-dipping surfaces that displayed slickensides along some of the major faults, such as the Angingan fault, which juxtaposes older volcanic rocks of the Fina-sisu Formation against younger limestones. They deduced offsets on these faults ranging from a few meters to as much as a hundred or more meters, although no strata showing offsets of the latter magnitude were observed. Some of the faults, such as the Obyan fault, display evidence of relatively recent movement inasmuch as they offset the late Pleistocene Tanapag Limestone. Some of the faults presumably were active as far back as the Oligocene, as indicated by the profound unconformity between the Eocene volcanic rocks and the Miocene Tapogchau Limestone (Cloud and others, 1956). A combination of faulting and erosion undoubtedly accounts for the removal of the volcanic vents for the volcanic rocks, which were located to the west and northwest of the present exposures.

Our identification of tectonic breccias and the interpretation of additional fault traces has led to a reinterpretation of the faulting on Saipan, which we now consider to be more extensive and throughgoing than depicted by Cloud and others (1956). The elongate body of breccia east of Okso Takpochao (Mount Takpochao) is now thought to mark a normal fault with an east-side-down sense of motion; this fault likely played a role in the uplift of the central part of the island during middle Tertiary time.

Our map suggests that the Agingan, Obyan, and Dago faults (mapped by Cloud and others (1956) at the south end of the island) are part of an anastomosing network that passes on either side of the central highlands and connects to faults cutting Laderan Bañadaru (Suicide Cliffs) and Bahia Fañonchuluyan (Fañonchuluyan Bay). Most of the faults on Saipan trend north to northeast, and all are thought to be normal with both east-side- and west-side-down senses of motion. Most of them are reflected in the topography, and the cross sections suggest offsets that are mostly in the range of tens of meters. The Laulau Bay fault of Cloud and others (1956) has a west-side-down sense of motion and extends from the Hakmang Peninsula across Bahia Laulau (Laulau Bay) to the southern tip of the island and possibly onward to the island of Tinian about 12 km to the southwest. Other faults trend more east to west (connecting the north-to-south strands) and are less well understood, except that they are possibly also steeply dipping normal faults.

Fault activity has extended from the middle Tertiary to the present, with even the youngest Holocene formations showing offsets (Cloud and others, 1956). A north-trending belt of the informal Donni formation just northwest of the Hakmang Peninsula rests variously on the Densinyama and Hagman Formations as well as the Tagpochau Limestone. This implies that differential erosion (possibly triggered by middle Tertiary fault movement) removed most of the Tagpochau Limestone (or prevented its deposition) before the Donni formation was deposited. Accordingly, a fault that offsets the Hagman Formation against the Tagpochau Limestone just west of the Hakmang Peninsula is shown on this map as extending northward underneath the Donni; we suggest that this segment of the fault was active only before the Donni was deposited.





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Preliminary Geologic Map of the Island of Saipan, Commonwealth of the Northern Mariana Islands

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2011

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