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A STRATIGRAPHIC STUDY OF LATE MIDDLE EOCENE/EARLY OLIGOCENE VOLCANIC ARC ROCKS OF SOUTHERN GUAM

To my wife, Shirley

A STRATIGRAPHIC STUDY OF LATE MIDDLE EOCENE/EARLY OLIGOCENE VOLCANIC ARC ROCKS OF SOUTHERN GUAM

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ABSTRACT

The Facpi Formation (volcano remnant) and the Alutom Formation (intra-arc basin deposit) form the Late Middle Eocene/Early Oligocene basement rocks of Guam; these units represent elements of the >300km wide Palau-Kyushu-Arc (Fig. 1) that originated in the western equatorial Pacific about Early Eocene time (Fryer, 1992). The Alutom terrain exposes four, coeval rock sequences composed of volcaniclastic, pyroclastic, carbonate and minor flow rock in southcentral and southwest Guam. The sequences are exposed in four major fault blocks (Figs. 2, 3) named Sasa (7,360 ft. +), Tenjo (4,700 ft. +), Tarzan Falls (3,500 ft.), and Bolanos (1,450 ft.). Lithofacies that form the sequences include: (1) turbidites, (2) tuff, (3) interbedded breccia/conglomerate, sandstone and shale, (4) interbedded breccia, pillow lava, sandstone/shale and (5) micrite (oozes)/limestones. Sedimentary processes reflected in the Alutom sequences include turbidity currents, debris flows, and gravitative settling through the water column; cross-bedded units indicate that other forms of bottom currents were present. Downslope movements produced convoluted bedding and large-scale slump folds. A single mappable unit of pillow lava, breccia, sandstone and shale (Unit Av) is the only unit present in all four blocks; its origin may be due to widespread eruptions of pillow lava triggering debris flows that incorporated slabs of flow-rock as they moved downslope.

The blocks are bounded by high-angle faults (Sasa, Atantano-Sigua, Talofofo, and Adelup), apparently normal faults, which exhibit relative vertical displacements up to ~1,000 ft.; other faults typically show vertical displacement of 200-300 ft. Fault striation geometries indicate that some faults have experienced oblique-slip with strike-slip components greater than dip-slip. Each block exhibits a number of anticlines and synclines. The Tenjo, Tarzan Falls and Bolanos micritic-rich sequences show, with few exceptions, substantial correlations among themselves, but the three show little correspondence to the Sasa micritic-poor section, which is juxtaposed against the Tenjo Block along the Sasa Fault. Deformation along the Sasa Fault, coupled with left-lateral stream patterns along its trace, and inability to correlate readily across it, suggests that the Sasa Block is allocthonous, and has moved in a left-lateral direction, possibly in excess of 15-20 miles (Fig.4). The Sasa section was deposited in an intra-arc basin, that was located north of Guam's present site and unconnected to the Tenjo-Tarzan Falls-Bolanos basin.

Unconformities occur in all the fault block sections, some of them showing angular discordance up to 60° indicating that the sequences were subject to frequent uplift, erosion and subsidence during Alutom time. This evidence strongly suggests that faults bounding the main blocks (Sasa, Atantano-Sigua, and Talofofo faults), as well as intra block faults, were active throughout the duration of Alutom intra-arc basin deposition,

and probably were established even earlier, when the Palau-Kyushu-Arc was forming, presumably under strong extensional stresses during the Paleocene/Early Eocene interval. Most or all of the major faults have probably remained active into latest Cenozoic time.

The Alutom sequences, of Late Middle Eocene to Late Eocene age, were deposited in deep marine environments (middle to lower bathyal), ranging in depth from ~4,500 feet (~1,500 m) to, or slightly below, the Eocene Calcite Compensation Depth (~9,600 ft.; 3,200 m). Deposition extended well beyond the present outline of Guam. Stratigraphic distribution of calcareous nannoplankton and radiolaria assemblages suggest that the floor of theTenjo-Tarzan Falls-Bolanos basin deepened northeastwards and that it fluctuated in depth at times. To the southwest, the sea floor apparently shallowed and deposition took place on the flank of the Facpi volcano (Fig. 4). The basin apparently shallowed to upper bathyal depths (450-1,500 ft.; 150-500m) during Early Oligocene time, possibly a precurser to regional uplift of the Facpi/Alutom complex in the Middle Oligocene. Limestone clasts in Alutom conglomerate, containing traces of coral, mollusks, and calcareous algae, indicate nearby reef complexes fringing emergent volcanoes or ridges. Rounded basaltic boulders also indicate a nearby shallow water environment (volcano coastline) where abrasion could take place followed by transport into deep water.

The Late Middle Eocene – Early Oligocene age-span of the Alutom Formation is considerably longer than previously recognized. The virtual age-equivalence of the lower Alutom with the subjacent Facpi suggests that Alutom deposition began almost simultaneous with completion of Facpi accumulation. The Alutom and Facpi arc basement complex is truncated by a Middle Oligocene unconformity (~ 30-32 Ma), the interval apparently coincident with initial splitting of the Palau-Kyushu-Arc, to produce the Palau-Kyushu-Ridge, West Mariana Arc and intervening Parece Vela back-arc basin. Uplift of the Alutom/Facpi arc basement complex during the Middle Oligocene was probably in the order of several thousand feet, or more possibly, producing a slightly emergent arc basement, an embryonic island, on which shallow Late Oligocene/Early Miocene carbonates of the Maemong Limestone Member (Umatac Formation) were deposited. Uplift was accompanied by left-lateral movement along the Sasa Fault and widespread folding of Alutom rocks. The Middle Oligocene uplift marked the cessation of an active Palau-Kyushu-Arc and its conversion to a Ridge (remnant arc). Renewed splitting of the West Mariana Arc (~10 Ma) produced the West Mariana Ridge (remnant arc), the Mariana Trough and the Mariana Ridge. The splitting of the Palau-Kyushu-Arc and the West Mariana Arc enabled elements of the PKA to be translated to their present position where they now form Guam's basement rocks – the Facpi and Alutom formations.

INTRODUCTION

The Late Middle Eocene/Early Oligocene (44-32 Ma) basement rocks of Guam, and those of the same age in the 1,000 mile-long Mariana Ridge (Fig. 1), are inferred to represent a tectonically detached part of the early Tertiary Palau-Kyushu Arc, remnants of which include the Palau-Kyushu Ridge and the West Mariana Ridge (Crawford, et al. 1981; and Hussong and Uyeda, 1982). The island of Guam, the southernmost emergent site on the Mariana Ridge, reveals a substantial thickness and areal extent of these arc rocks and thus is a highly favorable site to study the details of arc history.

Important geologic investigations on Guam were published shortly after World War II, (e.g. Tayama, 1952; Cloud and Cole, 1953). However the first comprehensive study of the island's stratigraphy, structure, and Tertiary history was completed by Tracey et al., (1964) – before the emergence of plate tectonic theory. The latter's work delineated all the major mappable units on the island, including those rock units now believed to be of Palau-Kyushu Arc origin. Subsequently, Meijer (1980) and Reagan and Meijer (1984) provided important additional details concerning the geochronology, petrology and stratigraphic interrelationships of the arc sequence on Guam.

As a result of the foregoing studies, the early Tertiary arc succession on Guam is now defined by two units: the Facpi Formation (Late Middle Eocene) and the Alutom Formation (Late Middle Eocene-Early Oligocene) [Fig. 3]. The Facpi, primarily an eruptive unit, consists mainly of pillow lava and subordinate volcaniclastic rocks intruded extensively by dikes. The Alutom, primarily an intra-arc basin deposit, is characterized by abundant volcaniclastic rocks, minor pillow lava, rare carbonate rocks, tuffs, and a few intrusive rocks.

Although much is known about these arc units, the stratigraphic successions that make up the units are poorly known. To fill this important gap, a field study, primarily focused on the Alutom Formation, was carried out by the chief investigator between 1987 and 1994 with these objectives: (1) to provide a geologic map of the Alutom Formation and work out its stratigraphic record, and (2) to clarify stratal and age relations between the Alutom and Facpi formations. The overall goals of the study are (1) to provide a detailed, paleontologically well-dated geologic column of the Alutom sequence on Guam, to which other sequences of Palau-Kyushu Arc origin in the Philippine Sea region (Fig 1) may be compared and calibrated, and (2) to interpret such details of the geologic history of the Palau-Kyushu arc rocks on Guam (e.g. volcanism, sedimentation, structural development) as the data permit.

I have been greatly aided in the present study by my co-investigators, Dr. Johanna Resig and Dr. John D. Longshore. While I have consulted extensively with them, as well as others, the views and interpretations presented herein are my own.

FIELD METHODS

Field mapping was undertaken at various times between 1987 and 1994. The level of mapping ranged from detailed to reconnaissance depending on the frequency of exposures, access, and vegetative cover. Geological data were plotted on United States Geological Survey (USGS) (7.5') quadrangles (Agat, Apra Harbor, Merizo, Agana, and Talofofo), and interpreted through study of United States Department of Agriculture (USDA) (1975) vertical aerial photographs. Thicknesses of stratigraphic sections were estimated by using hand-leveling methods and quantitative map data. The present investigation involved extensive collecting within the Alutom Formation for microfossils including calcareous nannoplankton, foraminifers and radiolaria. Rock samples were collected for petrographic information. These data are shown in the appendix.

Four distinct stratigraphic sections composed of Alutom deposits were recognized in four fault blocks named Sasa Block, Tenjo Block, Tarzan Falls Block and Bolanos Block (Fig. 2)[Plate D]. Each section was found to be composed of mappable units which were defined in the field using the following lithofacies as criteria: (1) tuff, (2) turbidites, (3) micrite/limestone, (4) interbedded breccia, pillow lava, sandstone/shale, and (5) interbedded breccia/conglomerate, sandstone/shale. Other bases for delimiting units included changes in lithology, mineralogy, topography, color, and unconformities. Tracey et al. (1964) established the Mahlac Member as the highest stratigraphic unit in the Alutom, but he left un-

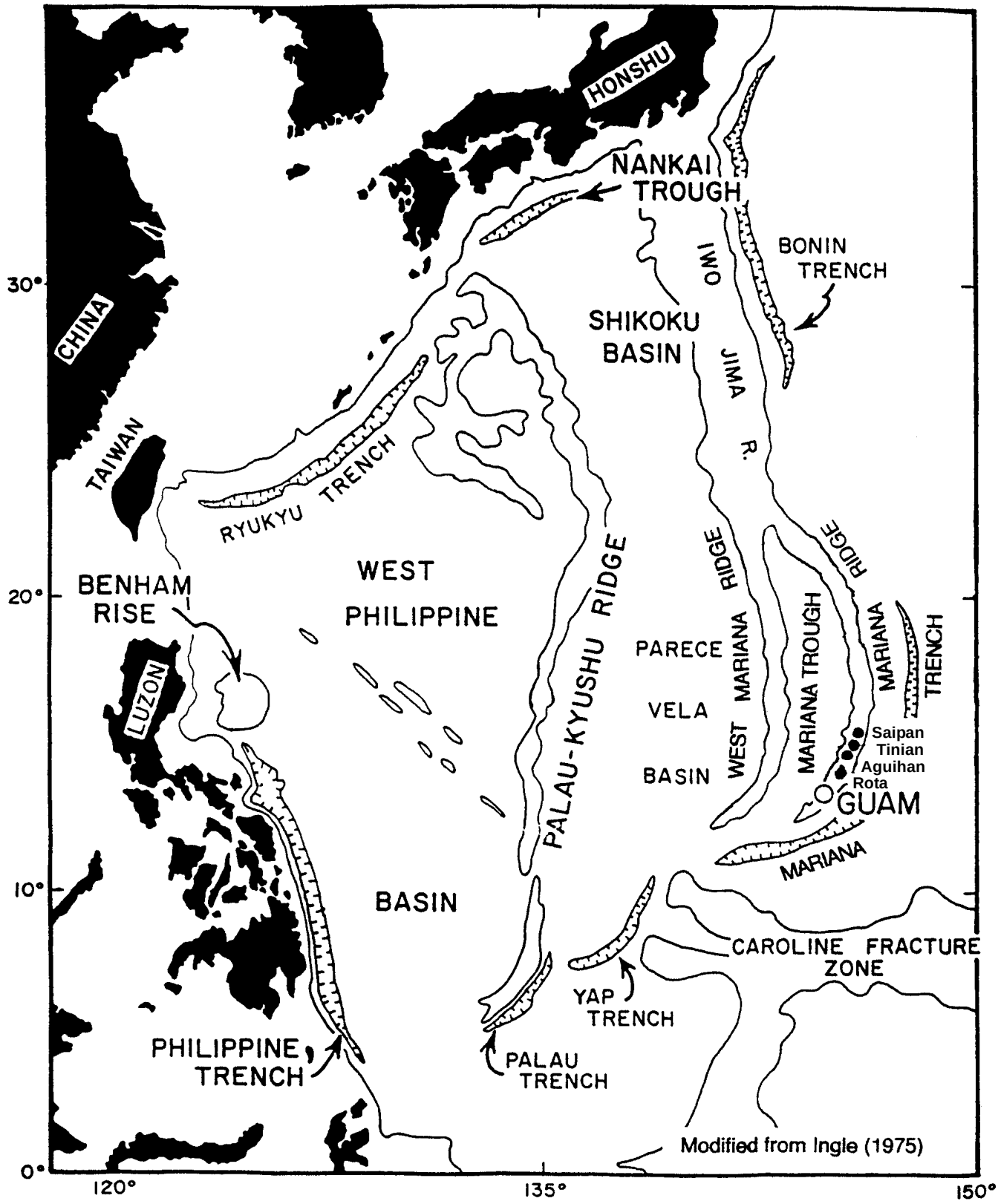

Figure 1. Location map for Guam and southern Mariana Islands.

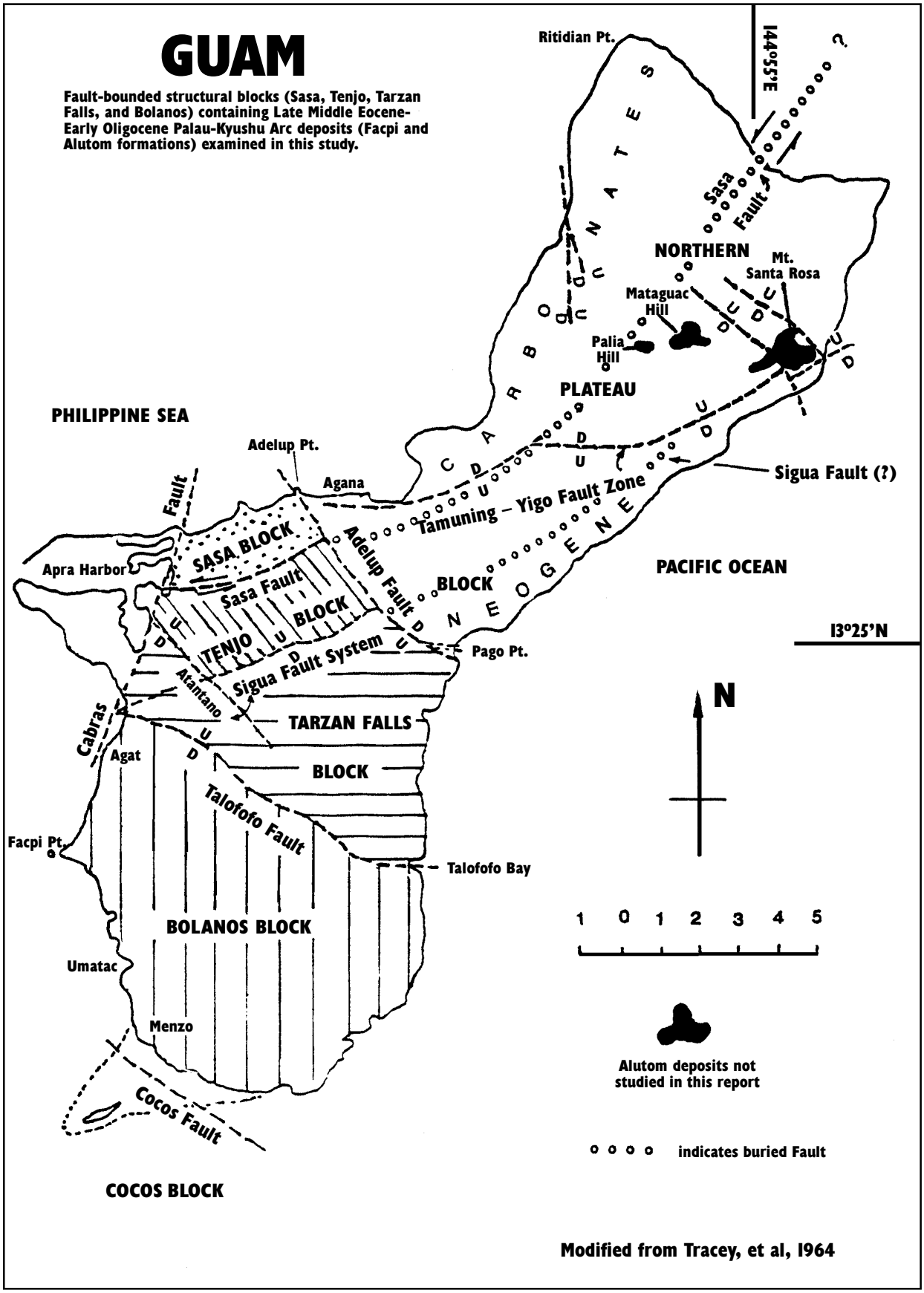

Figure 2. Fault Block Map.

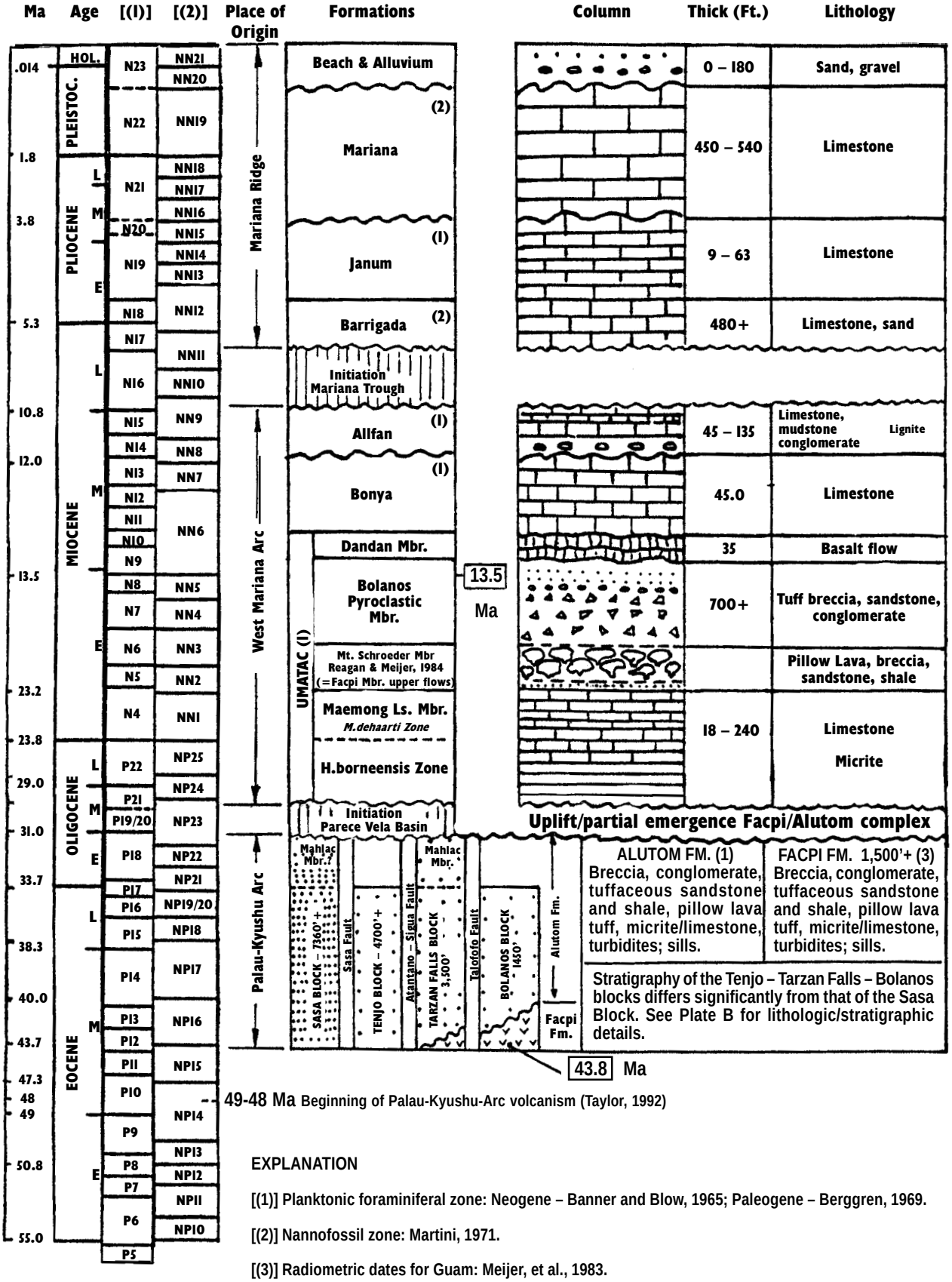

Figure 3. Generalised Stratigraphy in Guam. Stratigraphic sequence adapted from (1) Tracey, Jr. et al. (1964), (2) Tayama, R. (1952), and (3) Reagan and Meijer (1984). Cenozoic radiometric dates Berggren et al., 1995.

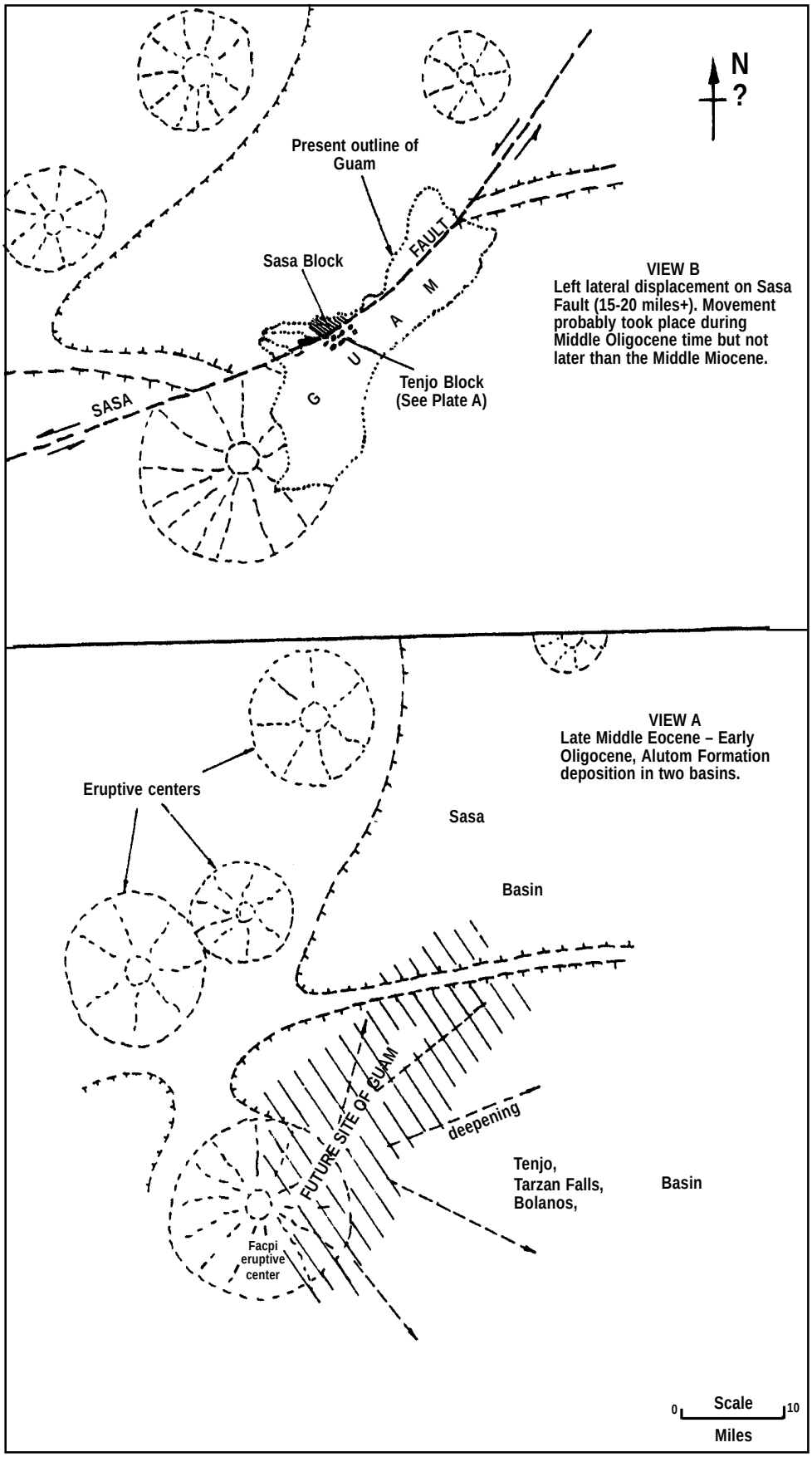

Figure 4. Cartoon of portion of Palau-Kyushu-Arc showing in principle, Sasa Fault history. Submarine topography strictly hypothetical. Orientation of Guam's site with respect to true north not known at time of View A.

differentiated the balance of the Alutom Formation beneath the Mahlac. The Alutom stratigraphic units mapped in this study constitute informally-derived stratigraphic units having the approximate status of members, following the American Stratigraphic Code (1944). They provide a basis for more refined future stratigraphic studies of the Alutom wherein formally named units may be established. This study followed the geochronologic classification based on calcareous nannoplankton of Martini (1971).

Because the Sasa Block section is sufficiently distinct from those of the Tenjo, Tarzan Falls and Bolanos Blocks, which are comparable, different map unit designations were used. For the Sasa Block, all the stratigraphic units have an "s" in their designation (e.g. Unit As-3, Unit As-7, etc.). For the other three blocks a simpler design, common to all, was followed (e.g. Unit Aa, Unit Af, etc.) Two exceptions to the above criteria are as follows: (1) the Mahlac Member designation of Tracey, et al. (1964), for the highest unit in the Alutom Formation, was retained, and, (2) one stratigraphic unit is interpreted as common to all four blocks and is denoted Unit Av. Fossil localities in the text and appendix are designated with an "F" (e.g. Loc. F-9), and rock sample localities with an "R" (e.g. Loc. R-16).

HISTORICAL PERSPECTIVE

Late Middle Eocene-Early Oligocene volcanogenic deposits form the oldest known, subaerially-exposed, rocks in the southern Mariana Islands, including Saipan, Tinian, Aguihan, Rota and Guam. The Facpi and Alutom formations of the present investigation, are essentially rifted-off portions of the Palau-Kyushu Arc (PKA) that developed in the western Pacific during the Early/Middle Eocene (49-48 Ma) adjacent to a complexly-formed subduction zone (Stern and Bloomer, 1992).

Following the views of Karig (1971a, 1971b, 1975) and Hussong and Uyeda (1982), the PKA appears to have been split by back-arc spreading in the Middle Oligocene (~30-32 Ma) creating the Palau Kyushu Ridge (remnant arc), a fore-arc segment named West Mariana Arc, and an intervening Parece Vela back-arc Basin. Again, during the Late Miocene (~10 Ma), the PKA fore-arc segment was split by back-arc spreading to produce the West Mariana Ridge, the Mariana Ridge, and the intervening Mariana Trough. In each of these back-arc spreading steps, Facpi and Alutom deposits were translated eastward, or oceanward, until reaching their present Mariana Ridge location. The Mariana Ridge, besides containing the PKA basement deposits, also includes Late Oligocene to Late Miocene deposits that accumulated on the West Mariana Ridge before it split, as well as Late Miocene-Recent deposits that formed on the Mariana Ridge after it was formed. The island thus represents a composite of rock units that were acquired in 3 different island arc environments, in differing geographic locations, over about a 49 million year interval. The currently active Mariana Arc volcanic chain, which has a minimum age of 1.3 million years (Meijer, et al., 1983), is located on the eastern margin of the Mariana Trough. Guam assumed its modern topographic outline following major uplifts, accompanied by erosion, in the Late Cenozoic.

Tracey, et al. (1964) recognized two distinct sequences of volcanic origin on Guam and named them Alutom Formation and Umatac Formation. Both sequences were presumed to have developed from sources nearby Guam. The Alutom Formation, then considered the older of the two, was believed to have developed during the Late Eocene-Early Oligocene interval from materials derived from an Eocene volcano northwest of Guam. The four-fold Umatac Formation was interpreted to have received its volcanic deposits from a Miocene volcano located southwest of Guam. Both volcanoes were presumed by Tracey, et al. (1964) to have eventually collapsed producing calderas.

The Alutom Formation of Tracey, et al. (1964) underlies the mountainous terrain of south central Guam and small areas of northeastern and southwestern Guam (Plate A). Tracey, et al. (1964) designated Mt. Alutom as the type locality but a type section was not established. The uppermost beds of the Alutom, consisting of calcareous tuffaceous shale, were named the Mahlac Member for exposures near the Mahlac River in east-central Guam. Cloud and Cole (1953) determined a Late Eocene [Tertiary b; East Indian Letter Classification (Van der Vlerk and Umbgrove, 1927)] age for the Alutom underlying the Mahlac Member. Todd (1966) dated the Mahlac Member as Early Oligocene (*Globigerina selli* Zone). Tracey, et al., (1964), recognized Alutom depos-

its at Mt. Palia, Mataguac Hill and Mt. Santa Rosa in northeast Guam, surrounded by Late Cenozoic carbonates, but these deposits were not included in this study because of their substantial distance from the main study area.

Unconformably overlying the Alutom, in southern Guam, is the Umatac Formation (Plate A), a complex of pillow lava, shale, breccia, limestone, flows, conglomerate and pyroclastic detritus. Tracey, et al., (1964) divided it into four members and assigned them to the Miocene. These in ascending order include: Facpi Volcanic Member, Maemong Limestone Member (mapped as an intercalation within the Facpi Volcanic Member), the Bolanos Pyroclastic Member, and the Dandan Flow Member. Type sections were not established for these units. An excellent cross section through the west slope of the Bolanos block shows the complete Umatac stratigraphic section (Stark, 1963). Subsequent studies in southwest Guam by Meijer, et al., (1983), and Reagan and Meijer (1984) indicate that those flows of the Facpi Volcanic Member (lower flows), which underlie the Maemong Limestone Member, are of Late Middle Eocene age, rather than Miocene as dated by Tracey, et al. (1964). With this new information, Reagan and Meijer (1984) revised the status of the pre-Maemong volcanic beds of the Facpi Volcanic Member and designated them Facpi Formation, now recognized as the oldest formational unit exposed on Guam.

THE ARC ROCKS

Facpi Formation

The Facpi formation is widely exposed on the west slope of the Bolanos Block in southwest Guam and crops out in several places north of the Talofofo Fault in the Tarzan Falls Block (Plate A). The Facpi is composed mainly of arc boninite pillow lava, pillow breccia, hyaloclastite, green and reddish-weathering breccia, conglomerate, and green, tuffaceous sandstone and shale; volcanic rocks of arc tholeiite composition occur locally. Boninite dikes are numerous; Stearns (1937) counted 108 dikes along the southwest Guam shore between Facpi Point and Merizo (Bolanos Block), a distance of 8 miles. Most of the dikes trend northwesterly, but a few strike to the northeast. Meijer, et al. (1983) obtained a radiometric age of 43.8 Ma (Late Middle Eocene) from pillow lava at Toguan Point (Lat. 13 17.25'N, Long. 144 39.68'E) and a Late Middle Eocene age for radiolarians from interpillow ooze near Foaha Point (Lat. 13 18.68'N, Long. 144 39.04'E) [Fig. 3). Calcareous nannoplankton from Facpi interpillow ooze (Loc. F-26) also confirm a Late Middle Eocene age for the formation. A basaltic dike collected near Merizo fire station, southwestern Guam (Lat 13 17.49'N, Long. 144 40.35'E) and dated at 35.8 Ma indicates intrusion during the Late Eocene, (Meijer, et al., 1983).

If the model by Hussong and Uyeda (1982) is accepted concerning the origins of the Palau-Kyushu-Ridge, the West Mariana Ridge, and the Mariana Ridge, then the Facpi Formation is expected to be present as arc basement in these ridges. Undated basaltic arc basement, stratigraphically below Middle Oligocene volcaniclastic sediments, was encountered in Leg 59, DSDP site 448 (Kroenke, L. and Scott, R., et al.,1980) on the Palau-Kyushu-Ridge and may be a Facpi Formation correlative.

The Alutom Formation

The Alutom Formation crops out in 4 major fault blocks (Sasa, Tenjo, Tarzan Falls, and Bolanos)[Fig. 2]. The sections in each block, though of substantially differing thicknesses, span essentially identical time intervals (Late Middle Eocene - Late Eocene); the Sasa and Tarzan Falls sections also include Early Oligocene strata [Plate D]. Alutom deposition, thus, took place in the Palau-Kyushu Arc between about 44 and 32 Ma, a span of some 12,000,000 years. Stratigraphic thicknesses for Alutom Formation sections differ among the four blocks. The Sasa block (6, 070-7,360 ft.) has the greatest thickness and this is a minimum value as its base is concealed. The Tenjo block (2,950-4750 ft.) is a minimum figure also; the lowest beds of the section are fault bounded by the Atantano-Sigua fault. Thicknesses of the Tarzan Falls (2,750-3,500 ft.) and the Bolanos block (1,100-1,450 ft.) appear to be true values as both sections lie depositionally on Facpi Fm. pillow lava. Tracey, et al. (1964) estimated the thickness of the Alutom Formation, as a whole, at 2,000-3,000 ft. Although their investigation clearly delineated a number of fault blocks composed of Alutom strata, thickness values for the Alutom strata in these blocks were not reported. The relatively greater thickness of the Sasa block

section appears out-of-place compared to the other blocks, but stratigraphic sections up to ~9,000 ft. (3km) in thickness are known from the Mariana Ridge and elsewhere in the Philippine Sea area (Mrozowski and Hayes, 1980). New age data from the present investigation indicates that the lower part of the Alutom Formation is age-equivalent to the Facpi, each containing Late Middle Eocene (NP16) microfossils. The mapping of Reagan and Meijer (1984) recognized Alutom Formation strata unconformably overlying Facpi Formation beds east of Umatac (Fig. 3) in the Bolanos Block. These relations suggest that deposition of the Alutom began as Facpi accumulation terminated.

SUMMARY DESCRIPTION OF ALUTOM FAULT BLOCK SECTIONS

(See Plate D: Detailed Stratigraphy of the Alutom Formation)

Sasa Block Section

Units As-1, As-2 and As-3 Late Middle Eocene (NP16)

Three mappable units of Late Middle Eocene (NP16) age form the lower part of the section. These are in order of decreasing age: Unit As-1, Unit As-2 and Unit As-3.

Unit As-1 (850-1000 ft. thick) includes mainly thin, graded, tuffaceous sandstone and silty shale, massive tuffs (Loc. R-1) and a medially-located dark grey volcanic breccia which rests unconformably on the lower part of the section. The graded beds are inferred to be turbidites.

Unit As-2 (40-80 ft. thick) consists of hard, cliff-forming, green, andesitic tuff (Loc. R-2). It is probably made up of a number of individual tuff layers produced during a short-lived, eruptive event. Unit As-2 forms a distinctive "marker bed," useful in mapping the Sasa section along the lower west slope of Nimitz Hill.

Unit As-3 (650-800 ft. thick) is mainly thin, graded tuffaceous sandstone (Loc. R-3) and silty shale beds indicating probable turbidity current deposits. Convolute bedding, suggesting periodic downslope movement of layers, is revealed in two orientations, (1) in cross sections of beds, and (2) exposure of the upper, "wrinkled" surface of convoluted beds. The pattern of convolutions suggests a northward-inclined paleoslope. A tan, thick bedded tuff, with low-angle crossbeds, is interbedded with the turbidites indicating gentle currents swept the bottom. Near the top of the section, is a massive, coarse, crossbedded, sandstone containing shale rip-up clasts at its base, apparently incorporated into the sandstone after bottom currents eroded underlying beds.

Calcareous nannoplankton (Loc. F-1, Loc. F-2) are abundant in at least 6 horizons in the turbidite sequence; some radiolarians were also noted. Trace fossils, associated with the turbidites, include the coiled/meandering fecal trail of *Spirophycos* (?), and *Taphrihelminthopsis* (echinoid?) and *Nereites* (worm?), the latter two suggesting burrowing and/or grazing trails (Kilmer, 1991). Small radial structures, possibly representing jellyfish (?) or a scleractinian coral (?) also are associated with the turbidites. Seilacher (1967) grouped the above trace fossils under the *Nereites* facies which he regarded as of deep water origin (bathyal); they are found throughout the world in Late Cretaceous and Early Tertiary flysch deposits. Bourne and Heezen (1965), photographed a living enteropneustan worm producing fecal trails, similar to those found in Unit As-3, at a depth of 4,735m in the south Pacific. Similar trails are known from the Atlantic and Indian oceans at depths greater than 4,000m; some records indicate shallower depths. The close association of calcareous nannoplankton-bearing turbidites and the *Nereites* facies suggest that Unit As-3 was deposited in deep water (lower bathyal) less than 9,600 ft. (3,200m) in depth.

Unit As-4, Latest Middle Eocene to Early Late Eocene (NP17-Earliest NP18)

Unit As-4 (1,450-1,950 ft. thick) consists of a variety of rock units including an andesite flow (Loc. R-5), green and reddish-weathering breccia, green andesitic tuff (Loc. R-4), and tuffaceous sandstone and shale. The apparent geometric truncation of Unit As-3 suggests that a major angular unconformity separates Unit As-3 and Unit As-4. Foraminifers and spumellarian radiolarians occur in a grey, burrowed, calcareous, tuffaceous shale close to the base of the section (Loc. F-3)

and just above the inferred unconformity. The best preserved foraminifers extracted from the matrix resemble *Planorotalites pusilla pusilla*, a species of Paleocene age, suggesting that the Alutom unit here contains reworked fossils. Two other poorly preserved specimens of foraminifera may be *Subbotina triloculinoides* and *Acarinina primitiva* also Paleocene forms, but their identification is uncertain. If later studies show that these tentative identifications are valid, then the Palau-Kyushu-Arc may have originated in the Paleocene. The lower part of Unit As-4 appears to reflect andesitic composition (breccia, tuff and flow). The upper two thirds of the unit appear to be mainly reddish-weathering breccias.

Unit As-5 Latest Middle Eocene-Early Late Eocene (NP17-earliest NP18)

Unit As-5 (350-400 ft. thick) is a massive cliff forming unit composed of white, cross-bedded, medium to coarse-grained, tuffaceous sandstone (Loc. R-6) and massive pebble to boulder conglomerate composed of basaltic andesite clasts. The section rests disconformably on Unit As-4 and is well exposed below Spruance Drive, just east of "Top of the Mar" Naval Restaurant. The sandstones are generally well sorted and contain angular grains. Conglomerate and sandstone units are interbedded throughout the section. Some sandstone units are truncated by erosional surfaces and overlain by conglomerate. An extension of Unit As-5 crops out along lower Spruance Drive close to Piti Middle School. Here occurs a small body (sill or flow ?) of basalt (Loc. R-7) apparently interbedded in the sandstone/conglomerate unit. The associated conglomerate is very poorly sorted and stratified and consists of basaltic clasts (up to 5 ft. in length) embedded in a coarse, white, tuffaceous sandstone. The subrounded to well rounded clasts suggest extensive abrasion in a shallow water environment with deposition being fairly rapid though permitting some subparallel alignment of the long axes of clasts. The sandstones are not calcareous and fossils were not recovered. The white tuffaceous sandstones of Unit As-5 (Sasa Block) and those found in Unit Ac (Tenjo Block) are somewhat similar lithologically and may represent close temporal relationship and source beds although apparently deposited in separate basins.

Unit As-6 Latest Middle Eocene-Early Late Eocene (NP17-earliest NP18)

Unit As-6 (128+ ft. thick), is a sequence of tuffaceous sandstone and shale, green breccia, and conglomerate exposed in Sasa Valley. These beds could not be completely examined owing to dense vegetative cover. As originally described by Tracey, et al. (1964), this section includes a basaltic flow (considered andesitic in this study) at the top of the section which in turn is overlain by a thick unit of variegated conglomerate. In this study, the basalt of Tracey et al., (1964) and associated reddish-weathering breccia are assigned to Unit Av, while the variegated conglomerate is mapped as the basal bed of Unit As-7. The outcrop pattern of Unit As-6 suggests that it is thickest in the lower Sasa Valley area, where it appears to overly Unit As-5 conglomerate along lower Spruance Drive; the unit narrows (in both areal extent and thickness) to the northeast along upper Spruance Dr. where it underlies Unit As-7. No fossils were reported by Tracey, et al., (1964) from the section herein assigned to Unit As-6.

Unit Av Late Eocene (NP18)

Unit Av (450+ ft. thick) is the only Alutom unit mapped in all four blocks. It consists of mainly massive, reddish-weathering, variegated breccia, thinly bedded, reddish-weathering, gritty, tuffaceous sandstone and shale, and minor bodies of reddish-weathering pillow andesite (Loc. R-8). The section rests unconformably on Unit As-6 and overlaps onto Unit As-5. Unit Av is exposed in Sasa Valley and can be traced northeasterly to Nimitz Hill and into the Fonte River canyon area forming a synclinal structure. Unit Av is further described under the other three blocks, especially the Tarzan Falls block where it appears best exposed.

Unit As-7 Late Eocene (NP18-NP20)

Unit As-7 (1,000+ ft. thick) includes limestone-bearing conglomerate, grey breccia, tuffaceous sandstone and shale, brown, variegated conglomerate, white and green tuffaceous siltstone, pumiceous tuff (Loc R-9), andesitic tuff and biomicrite. The section is folded into a syncline

which also includes underlying Unit Av and Unit As-6. Tracey, et al. (1964) reported an abundance of the large foraminifer, *Camerina djokdjokarta* (Martin), from the matrix of a green breccia (Loc. R-3A), apparently cropping out immediately west of the Sasa Fault at the head of Sasa Valley. These foraminifers suggest a shallow water environment but in the presence of a breccia it seems probable the fossils were carried to a deeper site before being deposited. Higher in the section, near the Nimitz Hill Reservoir, planktonic foraminifera and sponge spicules were recovered from a brown, shale clast in breccia (Loc. F-4), and at another nearby locality (Loc. F-5), nannofossils were recovered from a limestone clast in conglomerate. Contiguous exposures linking the last three localities with a southwest extension of Unit As-7 to the south west side of the Sasa River could not be demonstrated because of vegetative cover. In the latter area, a pink micrite (Loc. F-6) weathering out of a gutter on a newly formed Apra Harbor Naval Reservation road contains calcareous nannoplankton. The precise ages of these four fossil assemblages are not clear; two of them (Loc. F-4 and Loc. F-5) are reworked materials (clasts): Loc. F-3A, because it includes large foraminifers, cannot be accurately related to the nannofossil geochronology of Martini (1971) at this time; Loc. F-6 fossils range from Late Eocene (NP-20) to base of Middle Oligocene (NP22). Localities F-3A, F-4, and F-5 are here considered to fall within the Late Middle to Late Eocene part of the Alutom Formation based on lithologic criteria. Locality F-6 may be either Late Eocene or Oligocene in age, possibly correlative with the Early Oligocene Mahlac Member of the Alutom Formation in the Tarzan Falls block.

Sasa Block Petrographic Summary (See Appendix)

Tuffs and tuffaceous sandstones within the Sasa block typically contain andesite and basalt clasts in a matrix of chlorite. Clasts commonly have a matrix of altered glass and may be aphyric or contain phenocrysts of clinopyroxene, zoned plagioclase, and infrequent orthopyroxene. Chlorite alteration of clasts is extensive in most samples. Average grain size in tuffs and tuffaceous sandstones is generally less than 1 mm. Andesitic and basaltic flows contain clinopyroxene and strongly zoned plagioclase phenocrysts, in an intersertal matrix. Chlorite alteration in flows is moderate to extensive. Micritic limestones may contain fine-grained glassy volcanic clasts, scattered plagioclase grains, and some microfossils.

Tenjo Block Section

Unit Aa, Late Middle Eocene (NP16)

Unit Aa (1,500 ft.-thick) includes mainly white to green, thin bedded tuffaceous shale, claystone and sandstone. A white, cross-bedded, sandy micrite appears to form the base of the section; it contains calcareous nannoplankton and benthic foraminifers (Loc. F-7; Loc. F-7A). A basaltic conglomerate and closely associated basaltic body (Loc. R-11), possibly a sill, occurs near the top of the section below the south slope of Mt. Tenjo. This basalt may be the oldest igneous body in the Alutom Formation. A rhythymically-bedded red and green shale facies occurs locally, near the base of the section and reappears higher in the Tenjo Block section, where it is designated Unit Ab(u). Benthic foraminifera (Loc. F-7A), from the "basal" micrite, point to middle neritic-upper bathyal environments. Slump folds, having amplitudes exceeding 6 feet, occur in a number of places indicating local abrupt downward movements on a slope.

Unit Ab(l), Late Middle Eocene (NP 16)

Unit Ab(l) (250-350 ft.-thick) is composed of green, cliff-forming, thick and thin-bedded green, tuffaceous sandstone and shale that form a 200 ft.-high cliff rimming the southern slopes of the Mt. Tenjo/Mt. Alutom mountain mass. Although somewhat different in lithologic character, these green cliff-forming deposits are considered age-equivalent to thin-bedded green, deposits that form Tarzan Falls in the Tarzan Falls block; they are considered facies of the same lithogenetic unit. Units Ab(l) in both blocks are overlain by the same sequences of red and green, thin beds assigned to to Unit-Ab(u). Fossils were not found in Unit Ab(l) in the Tenjo block.

Unit Ab(u) Latest Middle Eocene-Early Late Eocene[NP-17]

Unit Ab(u) [150-250 ft.-thick] is a strikingly colorful sequence of rhythmically-alternating red

and green tuffaceous shale. The units range from 2-6 inches in thickness and tend to be evenly bedded. They contain radiolaria (Loc. F-8) and siliceous sponge spicules. The basal contacts of some green beds are sharp and these beds appear to grade upward into red zones. Convoluted bedding occurs at several horizons, and ripple marks of unknown origin occur near the top of the section. The origins of the colors and their alternations are not presently understood. Because organic content may control the oxidation state of iron in the sediments (Boggs, 1992), some process regulating organic content on the ocean floor may have been operative which could lead, diagenetically, to the production of Fe^{+++} iron (for red beds) and Fe^{++} iron (for green beds). If the beds are turbidites, then the separation process that customarily forms grading may be responsible for controlling the amount of organic detritus. The lithology and fossil content suggests a deep sea ooze in a bathyal or abyssal environment.

Unit Ac Latest Middle Eocene to Early Late Eocene (NP17-Earliest NP18)

Unit Ac (300-500 ft.-thick) is composed mainly of black, dacitic breccia, massive-thick bedded, white tuffaceous sandstone and massive conglomerate. The unit is known only from the Tenjo Block. It rests conformably on Unit Ab(u) and apparently is unconformably overlain by Unit Af. The breccia clasts (Loc. R-12) and sandstone (Loc. R-13; Loc. R-14) are chaotically intermixed in a small knoll along the Mt. Tenjo road, about 1/2 mile from where the road leaves the main road to Mt. Alutom. The breccia/sandstone association when traced to the south, toward Mt. Tenjo, changes to predominantly breccia clasts, to the point where the breccia assumes the appearance of a broken or dismembered flow and/or hyaloclastite. This relationship suggests that a flow, originating south of the Mt. Tenjo area, moved northward intermixing with sea floor sediment in this area. A conglomerate bed, apparently underlying the breccia/sandstone unit, consists of massive, poorly sorted, cobble/boulder (Loc. R-15) clasts of basaltic and andesitic origin; it probably represents a debris flow. Thin, blue, chalcedony veins cut the breccia/sandstone unit. Fossils were not found in Unit Ac so its equivalent stratal position in other blocks has not been recognized. Unit Ac is tentatively regarded as being slightly older than Unit Ad. This is because a massive conglomerate bed, resembling that encountered along the Tenjo Road in Unit Ac, occurs at the north end of the Tenjo Block adjacent to the Adelup Fault, where it appears to directly underly Unit Ad. It is possible that units Ac and Ad may interfinger.

Unit Ad Latest Middle Eocene - Early Late Eocene (NP17-Earliest NP18)

Unit Ad occurs in two main areas: (1) Unit Ad (South) exposures south of an east-west line through Nimitz Hill Reservoir and (2) Unit Ad (North) at the extreme north end of the Tenjo Block adjacent to the Adelup Fault. They are separated by an area of Unit Av (Plate A).

Unit Ad (South) occupies an anticlinal structure, adjacent to the Sasa Block, about 3/8 mile northwest of Mt. Chachao. The section in this block includes thin bedded tuffaceous micrite containing calcareous nannofossils (Loc. F-9; Loc. F-9A), massive spheroidally weathering tuffaceous shale, fossiliferous limestone-bearing conglomerate (Loc. F-10) and tuffaceous sandstone and shale with convoluted bedding.

Unit Ad (North) includes white and black-weathering thin bedded tuffaceous sandstone and shale giving an impression of "ribbons." In addition, there are massive thick bedded white tuffaceous sandstones (Loc. R-16; Loc. R-18), radiolarian-bearing shale, grey gritty sandstones, grey pebble/cobble breccia (Loc. F-10; Loc. F-11) and red and green tuffaceous shale. Some thick bedded, cross bedded sandstone (Loc. R-18) beds grade upward into coarse, laminated shale which in turn grades upward into white tuffaceous shale. Isolated blocks (0.5 ft. dia. 15 cm) of sub-rounded, porphyritic black basalt occur within sandstone and shale beds. Many of the beds exhibit slump folding; some beds are completely truncated or sheared off by overlying adjacent slumped masses. Flame structures (directed southward) were noted at one locality; rip-up shale clasts are present near the base of some thin bedded shale beds. A series of large blocks (3 ft. dia.; 1m) of basalt (Loc. R-17) form a line over several hundreds of feet of grassy surface; they may represent either an extrusion or intrusion, or possibly a basaltic conglomerate. Micrite was not recognized in Unit Ad-North. Significant angular discordance (60°) occurs near the top of the section

where steeply-dipping grey, coarse tuffaceous sandstone is overlain by grey, gritty sandstone and grey, pebble/cobble breccia.

Unit Ad (North) and Unit Ad (South) are, to a substantial degree, dissimilar in lithologic character and both directly underlie Unit Av. Although calcareous nannoplankton were found only in Unit Ad (South) and radiolarians only in Unit Ad (North), the two units appear to be of approximately the same age (e.g. ~NP17); they are interpreted as facies of the same lithogenetic unit. Several major faults separate Unit Ad (South) and Unit Ad (North) and movements along these may have contributed to the lithologic dissimilarity between the two by providing depositional sites of differing properties (e.g. paleo depth, current regime, paleo slope, source areas, etc.). Unit Ad (North) appears to be composed of coarser detritus than Unit Ad (South). Sedimentary structures in Unit Ad (North) suggest substantial downslope movements and bedding disruption during deposition. The marked angular discordance noted near the top of Unit Ad (North) may have been caused by slumping on a scale not visible in outcrop, or it may represent a tectonic disturbance that tilted a small fault block. Erosion of the steeply-inclined beds was probably accomplished by submarine processes. The radiolarian-bearing Unit Ad (North) may reflect somewhat deeper marine conditions than do the calcareous nannoplankton-bearing micritic rocks and limestone-bearing conglomerates of Unit Ad (South).

Unit Av Late Eocene (NP18)

Unit Av (200-750 ft. thick) occupies much of the northern part of the Tenjo Block. It consists almost entirely of reddish-weathering, massive, thick-bedded, variegated, cobble-boulder, breccia composed of subrounded andesitic and basaltic clasts. The deposits are frequently poorly sorted and stratified. Interbedded are thick sequences of thin-bedded red, gritty sandstones and pebble conglomerate. Pillow lava was recognized at one place but overall did not appear abundant. Fossils were not found in the present study, but Cole (1963) reported a rare specimen of the benthic foraminifer *Halkyardia bikiniensis* (Cole) next to Pipeline Road leading from the Mt. Alutom road to Mt. Macajna. No details were given on lithology and/or local stratigraphic occurrence of this specimen. Cole (1963) interpreted the age of the rock to be "Eocene, or maybe Oligocene with reworked Eocene." Based on stratigraphic controls in the Alutom terrain, Unit Av appears to be Late Eocene in age.

Unit Af Late Eocene (NP18-NP20)

Unit Af (250-1,000 ft. thick) is composed of mainly thin-bedded, graded tuffaceous micrite, reddish-weathering breccia, and white thin bedded tuffaceous sandstone and shale. It is exposed along the Mt. Tenjo Rd., and along the north slope of Mt. Alutom between Mt. Chachao and a point northeast of Mt. Tenjo where it becomes part of the western flank of a large anticlinal structure. The section is well exposed slightly east of Mt. Chachao where thin graded sandstone/shale beds are common (Loc. R-19, Loc. R-20). Higher in the section are white thick bedded, micritic, tuffaceous shale. One hard, white, thin-bedded, micritic shale near the base of the section shows evidence of borings. An exposure of Unit Af occurs in a small down-faulted block located on the Menengon Rd. which extends southeasterly from the Mt. Tenjo Road. Here the section consists of (1) a thick green sandstone bed which grades upward into thick bedded grey cherty micrite and (2) thin and thick, white micrite. This section of Unit Af, which contains both calcareous nannoplankton (Loc. F-12) and radiolarians (Loc. F-13), rests unconformably on Unit Aa.

Tenjo Block Petrographic Summary (See Appendix)

Flows are basaltic. Flow textures and mineralogy range from vesicular, with fresh clinopyroxene and plagioclase phenocrysts in a groundmass of altered glass, to unaltered rocks containing two pyroxenes and plagioclase, in an intergranular matrix. Pyroclastic flows, tuffs, and volcaniclastic rocks have a wide assortment of textures and compositions. Some clastic rocks consist almost entirely of basalt and/or andesite clasts. A dacite tuff contains angular pumice fragments and broken crystals of quartz, plagioclase, hornblende, and clinopyroxene. Mudflow or pyroclastic flow deposits commonly contain a variety of clast compositions, including ash flow fragments. Altera-

tion to chlorite ranges from extensive to minor. Micritic carbonates in the section contain microfossils as well as basalt and mineral fragments.

Tarzan Falls Block Section

The Facpi Fm. crops out in the Tarzan Falls block but is not seen in depositional contact with the block's oldest units, Aa , Ab(l), or Ab(u). Where the Facpi is exposed, it is in depositional contact with Unit Ad (NP17), suggesting that Units Aa, Ab(l), and Ab(u) were down-faulted prior to Latest Middle Eocene time allowing Unit Ad to be deposited unconformably over these units directly onto Facpi pillow lava. At one place (Loc. F-14), close to Divide: 526 ft., a calcareous matrix between fragments of Facpi pillow lava, or hyaloclastite, yielded calcareous nannoplankton of Late Middle Eocene (NP16) age.

Two mapped Alutom units within the Tarzan Falls block section are considered of Late Middle Eocene (NP16) age. These are, in order of decreasing age: (1) Unit Aa and (2) Unit Ab(l). The units are not found in a continuous outcrop sequence but rather are apparently covered by younger units in a zone of down-dropped fault blocks in the Tarzan Falls valley. Unit Aa has very limited areal exposure in the Tarzan Falls block; it is well developed in the Tenjo block and is discussed under that block.

Unit Ab(l) [100 ft. thick] Is a sequence of thin-bedded, hard, green calcareous nannoplankton-bearing tuffaceous shale. It crops out at only one place (Loc. F-15), forming Tarzan Falls itself, in the bottom of the Tarzan River canyon. Also included within Ab(l) is a massive to thick bedded body (10-15 ft. thick) of pumiceous tuff overlying the shale. The shale has no discernable sedimentary structures, and is inferred to have been deposited in a quiet water environment. The pumiceous tuff may have accumulated as pyroclastic detritus from a major eruption.

Unit Ab(u) Latest Middle Eocene - Early Late Eocene (NP17-earliest NP18)

Unit Ab(u) (250 ft. thick) is mainly thin bedded alternating red and green tuffaceous shale with some thick bedded tuffaceous sandstone and pumiceous tuff. A few radiolarians and sponge spicules and ? fecal pellets were found (K A. Aalto, pers. commun.; 1994) in the shale. Black carbonaceous, plant-like rods or seaweeds were found in the bedding plane of a green bed. The cause of the alternating red and green colors is not clear; but may be due to variations in the original organic content of the sediments which in turn affects the oxidation state of iron contained in the beds.

Unit Ad Latest Middle Eocene - Early Late Eocene (NP17-Earliest Np18)

Unit Ad (450-600 ft-thick) consists mainly of white-grey, thin-bedded micrite, bioclastic limestone (Loc. R-22), limestone-bearing conglomerate, pumiceous tuff (Loc. R-21), breccia and tuffaceous sandstone and shale. It rests unconformably on Facpi Formation in the area between Cross Island Highway and the Talofofo Fault Zone to the south. It also overlaps depositionally on Unit Aa, adjacent to the Atatano/Sigua Fault System. The overall aspect of the unit is light-colored compared to adjacent units (Unit Av and Facpi Fm.). Thick, pebble-cobble conglomerate beds composed of angular to subrounded clasts of basalt and limestone occur at two horizons. Limestone clasts contain fragments of macrofossils, possibly shallow-water coral and/or mollusks. The conglomerate beds cut into underlying sandstones, producing channel-like features. Other fossil assemblages from micritic deposits include calcareous nannoplankton, benthic foraminifers and a few radiolarians (Loc. F-16, Loc. F-17, Loc. F-18, Loc. F-18A, Loc. F-18B). One bedded limestone locality (Schlanger, 1964; Loc. Ek-7) yielded (1) well preserved planktonic foraminifera (globigerinids) associated with (2) broken tests of larger foraminifers and calcareous algae debris. Schlanger also reported (Loc. Fk-4-2) the remains of coral, mollusks and algae in another Late Eocene limestone. The globigerinids suggest deep-water basinal conditions into which the larger foraminifers were carried from shallow environments. Macrofossil evidence in limestone conglomerate clasts also suggest down-slope transport from shallow water environments around arc volcanoes.

Unit Av Late Eocene, (NP18)

Unit Av (350 ft.. thick) is widely exposed in the Tarzan Falls block; it is best revealed in a west facing slope (elev. 500-700') of a major northeast-trending ridge located approx. 2,500 ft. east of Magazine Road leading to the U.S. Naval Magazine (Coordinates: Latitude 13° 23.7' N; Longitude 144° 41.6' E). Unit Av is the only Alutom unit that is recognized in all four fault blocks; it rests unconformably (?) on Unit Ad, and overlaps onto Unit Aa. The west-facing section is an estimated at 250 feet thick; it consists of two pillow basalt beds (~20 ft. thick) interbedded with massive, reddish-weathering volcanic breccia and minor thin-bedded tuffaceous shale. The lowermost part shows a highly disturbed "mixed" sequence of pillow lava, and reddish weathering breccia. Intermixing of pillow lava and breccia also occurs higher in the section. Breccia consists of extremely unsorted and poorly stratified blocks of red, white, grey, orange and green angular-subrounded clasts ranging from pebbles to large blocks (to 8 ft. in long dimension) set in a tuffaceous sandstone matrix. Some of the green clasts in the breccia are fragments of amygdaloidal pillow lava. Unit Av, in overall aspect is strongly reddish to crimson and forms prominent exposures. An interesting aspect of some of the thin-bedded tuffaceous shale, normally of reddish color, is that certain small areas (~3 ft. dia.) are white and calcareous; these grade subtly into surrounding reddish-weathered shale lacking calcium carbonate. Evidently, the original color of the shale was white and its original composition was calcareous, with subsequent weathering causing a color change and a loss of lime. No fossils were recovered from these remnants. The poorly sorted and non-stratified breccias clearly suggest deposition through a debris flow mechanism.

Unit Ae Late Eocene (NP18-NP20)

Unit Ae (450-600 ft. thick) consists of a mixture of brown massive-thickbedded sandstones and thin-bedded shale, green tuffaceous shale, basaltic breccia, and minor micrite. The section is limited to the eastern margin of the Tarzan Falls block where it is overlain by Unit Af. The unit underlying Unit Ae is not visible but it is inferred, on the basis of relative ages, to be Unit Ad. The bulk of the section is exposed on an old dirt road leading downward to the Ylig River beginning from Divide: 526 ft. [a marked topographic feature on the USGS Talofofo Quadrangle] on the Cross Island Highway. Calcareous nannoplankton assemblages were found at two, fine-grained micrite localities (Loc. F-19; Loc. F-20) in this unit.

Unit Af Late Eocene (NP18-20)

Unit Af (550-1,000 ft. thick) includes mainly white-grey, calcareous nannoplankton-bearing micrite Loc. (F-22, Loc. F-23), reddish-weathering variegated breccia, limestone-bearing conglomerate (Loc. F-21), pumiceous tuff and tuffaceous sandstone and shale. It locally overlies Unit Ae, unconformably in the Tarzan River area but further north it lies on Unit Av; Unit Av underlies the Mahlac member of the Alutom Formation, but the contact was not seen in the area of this study. Unit Af is exposed over wide areas to the east of Mt. Tenjo and further to the east is overlain by the late Cenozoic Mariana Limestone. Its northern boundary is the Adelup Fault. One mile northeast of the Leo Palace Resort, along the Resort entry road, a massive megabreccia is exposed in a road cut; it is composed of poorly sorted clasts of white limestone, pink tuffaceous shale, grey sandstone, black basalt in a coarse sandy matrix. Clast sizes range from pebble-size to very large angular-subrounded blocks and slabs, some exceeding four feet in long dimension. One relatively thin, elongate slab of white limestone appears to have been pulled or broken apart and contorted into a tight, recumbant anticline. The entire megabreccia appears to be the product of extensive downslope movement in which a wide variety of clast lithologies were involved. The roadcut also reveals steeply-dipping, but otherwise undisturbed, a thin bedded tuffaceous shale unit, which lies between the megabreccia and another higher breccia unit. The entire sequence appears capped, unconformably, by a massive brown sandstone. Benthic foraminifers, suggesting "relatively deep water deposits, such as currently being deposited on the outers slope of Guam," (Todd, 1966), occur in Unit Af in the Pulantat area, a short distance east of the megabreccia locality and west of Yona.

Several massive to thick-bedded conglomerate beds form knobby outcrops in Windward Hills and south of the Cross Island Highway. The con-

glomerate units occur stratigraphically above and east of the micrite/pumiceous tuff sequence which forms extensive white exposures 1/2 mile east of (Divide 526 ft.) on both sides of the Cross Island Highway. The conglomerates are composed of poorly sorted and stratified angular-subrounded basalt pebbles and cobbles set in a sandy calcareous matrix. Interbedded are coarse, crossbedded sandstones and breccias.

Mahlac Member (Alutom Formation) [NP21-23]

The Mahlac Member (200 ft. thick) is exposed in the eastern part of the Tarzan Falls block where it overlies Unit Af and is overlain unconformably by the Bolanos Pyroclastic Member (Umatac Fm.). It is composed of buff, well bedded, calcareous shale containing abundant benthic and planktonic foraminifers. (Age is based on reevaluation of Mahlac foraminiferal faunas of Todd (1966) by Resig, per. commun., 1997).

Tarzan Falls Block Petrographic Summary (See Appendix)

Tuffs within the Tarzan Falls Block are very fine-grained (average clast size less than 0.2 mm). Clasts are glassy, and some are pumiceous. Broken crystals within tuffs consist of plagioclase, quartz, clinopyroxene, and orthopyroxene. Basalts range from an aphyric, highly vesicular flows to hyaloclastites. The only carbonate rock examined in thin section is tuffaceous (approximately 40% basalt clasts and 60% rounded carbonate clasts). The limestone is grain-supported and well sorted.

Bolanos Block Section

Unit-Facpi Fm, Late Middle Eocene (NP-16)

A white calcareous matrix from an interpillow area of massive, cliff-forming, pillow basalt (Loc. R-26) was collected on the Agat-Umatac Highway. It was found to contain calcareous nannoplankton.

Unit Ah Late Middle Eocene (NP16)

Unit Ah (60-100 ft. thick) is located 4 miles south of Agat on the east side of Highway 4 where it rests unconformably on pillow basalt of the Facpi Fm. (Loc. R-25). It is unconformably overlain by the Maemong Limestone Member (Late Oligocene) [Loc. F-30, Loc. R-27] and the Facpi Volcanic Member (upper flows member) [Loc. F-31], both of the Umatac Formation. The lower half of the Unit Ah is predominantly thin bedded, white to grey, micrite (Loc. R-26) and tuffaceous sandstone. Microfossils (Loc. F-27, Loc. F-27A, and Loc. F-27B) are abundant, including planktonic foraminifers, calcareous nannoplankton and radiolarians; the rarity of benthonic foraminifera (1%) indicates the deposit is a pelagic foraminiferal limestone, or "ooze," deposited at depths greater than 4,500 ft. (1,500 m). A small amount of bedding deformation suggests sporadic downslope movements. The upper half of the section includes white, thin-bedded micrite, brown tuffaceous sandstone, green tuffaceous shale and conglomerate; some beds include small angular basaltic clasts in fine-grained matrices. Trace fossils are present in the green shale, including branching forms and a petaloid form, possibly a feeding structure with attaching "stem," suggest burrowing organisms were present.

Unit Ad Latest Middle Eocene (NP17-Earliest NP18)

Unit Ad (250-350 ft. thick), lies unconformably on the Facpi Formation in the Finile Road area, near Agat. It consists mainly of white "cherty" micrite and tuffaceous sandstone and shale. The basal unit appears to be a greyish-brown, laminated sandstone. Calcareous nannoplankton are common at several horizons within the micrite (Loc. F-28).

Unit Av Late Eocene (NP18)

Unit Av (50-450 ft. thick) consists of massive, reddish-weathering coarse, locally folded, volcanic breccia, and reddish-weathering tuffaceous sandstone and shale. Some breccia clasts exceed 10 ft. in diameter, are rounded, and consist of layers of tuffaceous shale and sandstone. No fossils were

found. Pillow andesite flows, seen in Unit Av in the adjacent Tarzan Falls and Tenjo blocks, were not recognized in the Bolanos block section but may be present and concealed. Massive breccia with chaotically organized clasts up to 10 ft. in diameter, suggests a debris flow deposit.

Unit Af Late Eocene (NP18-NP20)

Unit Af (100-300 ft. thick) consists of limestone-bearing conglomerate, calcareous tuffaceous shale, reddish-weathering breccia, and tuffaceous sandstone and shale. Limestone clasts in the conglomerate are similar to those seen in the Tarzan Falls and Tenjo blocks that include fragments of macrofossils (coral and mollusks). Calcareous nannoplankton and both planktonic and benthic foraminifers are present in the calcareous, tuffaceous shale, (Loc. F-29, Loc. F-29A). The benthic foraminifers suggest deposition at middle bathyal depths (1,500-4,500 ft. depth; 500-1,500 m). Two species, *Amphistegina sp.* and *Pararotalia sp.*, represent displaced forms, derived from shallow-water environments.

Bolanos Block Petrographic Summary (See Appendix)

Basalt within the Bolanos Block contains phenocrysts of clinopyroxene and orthopyroxene and hazy outlines of plagioclase phenocrysts completely replaced by chlorite. Limestones in this block are micritic and contain abundant microfossils, small amounts of broken mineral grains and volcanic clasts.

SUMMARY OF CRYSTALLINE IGNEOUS ROCK OCCURRENCES IN THE ALUTOM FORMATION

There are three types of occurrences of crystalline igneous rocks mapped in the Alutom terrain including, 1- Black basalt of unknown origin, 2- Green dikes/sills, and 3- flow rocks. Also included in this section are reports of crystalline igneous rocks in the Alutom Formation by other geologists.

1) The basaltic bodies are hard, dense, locally olivine-bearing, dark grey to black rocks which are shown on the geologic map (Plate A) as small, ovoid, black areas marked "Ig". Soil and vegetative cover obscure virtually all contacts with adjacent rocks making it problematic whether these bodies are intrusions or flows. The basaltic bodies occur in a number of situations:

(a) Sub-circular bodies ranging from 50 to 200 ft. in diameter/or longest dimension. Four of these were mapped in the Tarzan Falls block, two in the Tarzan River area, and two in a ridge bordering and on the south side of the Cross-Island Highway (C.I.H.).

The localities are:

(1)	Tarzan Falls River Area Lat. 13° 23.63' N; Long. 144° 43.90' E	Tarzan Falls Block Talofofo Quad., 1968
(2)	Tarzan Falls River Area Lat. 13° 23.77' N; Long. 144° 42.78' E	Tarzan Falls Block Talofofo Quad., 1968
(3)	Ridge above C. I. H. Lat. 13° 23.82' N; Long. 144° 42.16' E	Tarzan Falls Block Talofofo Quad., 1968
(4)	Ridge above C. I. H. Lat. 13° 23.87' N; Long. 144° 41.99' E	Tarzan Falls Block Agat Quad., 1968

(b) Thin elongate bodies cropping out in road cuts and steep slopes. The exposed areas of these bodies appear to range from 3-5 ft. in shortest dimension and in excess of 8-10 ft. in longest dimension. Two such bodies were mapped, one exposed along the south slope of Mt. Tenjo (Loc. R-11), the other in a road cut of Spruance Dr. (Loc. R-7).

The localities are:

(1)	South Slope of Mt. Tenjo Lat. 13° 24.98; Long. 144° 42.02' E	Tenjo Block Talofofo Quad., 1968
(2)	Roadcut in Spruance Dr. Lat. 13° 27.95' N; Long. 144° 41.89' E	Sasa Block Apra Harbor Quad., 1968

(c) A series of basaltic blocks which occur, more or less, in a line from 200-300 ft. in length. The trends of these lines of blocks closely follow the regional strike of adjacent strata and faults. One series of basalts (Loc. R-24), 3/4 mile north of C.I.H., possesses a glassy matrix, which suggests a possible hyaloclastite. A second alignment of scattered basaltic boulders (Loc. R-17) occurs near the Corn Memorial at the north end of the Tenjo Block where it lies within and parallels tuffaceous sandstone and shale of Unit Ad (North). A third alignment of

basalt blocks occurs 2/3 mile north of C.I.H. (Loc. R-23) parallel, and adjacent, to the southeast prolongation of the Atantano fault .

The localities are:

(1)	Locality R-24 (near C.I.H.) Lat. 13º 24.69' N; Long. 144º 42.30' E	Tarzan Falls Block Talofofo Quad., 1968
(2)	Locality R-17 (Corn Memorial) Lat. 13º 27.08' N; Long. 144º 44.13' E	Tenjo Block Agana Quad., 1968
(3)	Locality R-23 (Near C.I.H.) Lat. 13º 24.52' N; Long. 144º 42.15' E	Tarzan Falls Block Talofofo Quad., 1968

2) Not shown on Geologic Map (Plate A) are coarse-grained, green dikes or sills (1-6 ft. thick) apparently cross-cutting local strata, occur in a few localities. These rocks form small, rounded outcrops, are crumbly and appear far more weathered than any of the black basalt bodies. At one locality, and adjacent to R-23, they are truncated by a northwest-trending fault that intersects them at right angles. Along one segment of the fault, the intrusives dip systematically in opposite directions around an axis, suggesting that they may actually represent a family of sills, which were folded before or during faulting. Two other small, green, coarse-grained bodies were mapped; one 3,000 ft. southeast of Divide: 526 ft. on C. I. H. in a small exposure of Unit-Av, the other in Unit-Af in the Mt. Tenjo area near a small complex of thin, blue, chalcedony veins.

The localities are:

(1)	Two-thirds mile north of C.I.H. Lat. 13º 24.52' N; Long. 144º 42.15' E	Tarzan Falls Block Talofofo Quad., 1968
(2)	Southeast of Divide: 526 ft. (C.I.H.) Lat. 13º 22.72' N; Long. 144º 43.33' E	Tarzan Falls Block Talofofo Quad., 1968
(3)	Mt. Tenjo area Lat. 13º 25.83' N; Long. 144º 42.17' E	Tenjo Block Agana Quad., 1968

3) Flow rocks. With the exception of one andesite flow noted near the base of Unit As-4 in the Sasa Block, all flow-rock occurrences are green, reddish-weathering amygdaloidal pillow andesites which are confined to Unit Av, the only stratigraphic unit found in all blocks. The pillow andesite exposures are usually of small size and areal extent. They appear most commonly in Unit Av exposures in the Tarzan Falls Block and to a lesser extent in the Sasa Block. They were not encountered during reconnaissance traverses of Unit Av in the Tenjo and Bolanos blocks but are considered likely to be present in each.

Meijer et. al., (1983) dated a number of crystalline igneous rocks from the Alutom including (1) Andesitic pillow lava at Mt. Santa Rosa (35.6 +- 0.6 Ma) [Late Eocene], (2) two basaltic andesite clasts at Mt. Santa Rosa (34.7 +- 0.7 Ma; 34.3 +- 0.6 MA) [Late Eocene], (3) A basaltic sill in Sasa Valley, Sasa Block (32.2 +- 1.0 Ma) [Early Oligocene] and (4) A dacitic clast from Mt. Alutom, Tenjo Block (35.3 +- 0.8 Ma) [Late Eocene].

The radiometric ages of pillow andesite and the basaltic andesite clasts on Mt. Santa Rosa appear very close to the age determined paleontologically for Unit Av. Thus, there is a possibility that the pillow-andesite section forming the core area of Mt. Santa Rosa in northeast Guam is a northern extension of pillow-andesite-bearing Unit Av delineated in southern Guam. Meijer, et. al. (1983) suggested that the basaltic sill found in the Sasa Block and dated at 32.2+-1.0 Ma (Middle Oligocene), was emplaced in Alutom strata during rifting of the Palau-Kyushu-Arc that produced the Parece Vela Basin and the West Mariana Ridge. The age of the dacite clast found at Mt. Alutom (35.3 +- 0.8 Ma) is somewhat younger than anticipated for Unit Ac, the only stratigraphic unit recognized in the Tenjo Block that contains dacitic detritus. Additional stratigraphic study and radiometric dating will be required to clarify this apparent ambiguity.

UMATAC FORMATION

Maemong Limestone Member

The Maemong Limestone Member, originally believed to be of Miocene age (Tracey, et al., 1964), is discussed here because it is the oldest Tertiary deposit resting depositionally on the Facpi/Alutom arc complex and thus forms an upper time limit for Alutom deposition. Maemong limestones occur along the western slope of the Bolanos Block where they rest unconformably on the Facpi/Alutom arc complex of Late Middle Eocene - Late Eocene age. They also occur in a cluster of deposits in the eastern part of the Tarzan Falls Block where they rest unconformably on the Alutom [Unit Af (Late Eocene) and Alutom Mahlac Mem-

ber (Early Oligocene)]. One locality (Loc. F-24), near the intersection of the Cross Island Highway and Magazine Road, near Santa Rita, consists of thin graded, green sandstone and siltstone; it is included in the Maemong Member on the basis of calcareous nannoplankton age (NP24-NN1); otherwise, it is lithologically unlike typical Maemong carbonate rocks

Forman and Schlanger (1957) described the cluster of Maemong deposits in east-central Guam as reefwall/lagoonal facies composed of reef limestone remnants, and those exposed on the west slope of the Bolanos block as fore-reef/basinal facies consisting of calcarenites, conglomerates, breccias and calcareous shales with reef structures completely lacking. They considered these assemblages to be essentially age-equivalent and of Early Miocene age; the fore-reef/basinal facies was interpreted to represent a paleodepth of possibly 4,000 ft. on an outer slope. Schlanger (1964) revised his view of the age relations of the two Maemong facies and considered the basinal facies the oldest of the two, but, apparently still of Early Miocene age. Garrison, et al., (1975) appear to have extended the age of the Maemong downward into the Late Oligocene (Table 1, Stratigraphic chart), but without corroboration in the following text.

Maemong limestone deposits, exposed along the southwest slope of the Bolanos Block, contain two larger foraminiferal faunas that are distinctive and do not occur together in the same deposit. One of these faunas contains the species *Heterostegina borneensis*, the other *Miogypsinoides (Miogypsina) dehaarti* (Cole, 1963). Both species are generally regarded by paleontologists working in the Indo-Pacific Region to have age diagnostic value with *H. borneensis* being slightly older, and commonly found in strata directly underlying beds containing *M. dehaarti*. In both areas of Maemong outcrops, the two species and their associated faunas are present. Unfortunately, stratigraphic relations between individual limestone deposits are not accurately known at this time. During the work of Tracey, et al., (1964), the East Indian Letter Classification (Van der Vlerk and Umbgrove, 1927), based on stratigraphic ranges of larger foraminifers, was used to date rocks. Following this scheme, *H. borneensis* was considered of Early Tertiary e age(=Early Miocene) and *M. dehaarti* of Late Tertiary e age (= ~Middle Miocene). The present study sampled a number of limestone deposits on the west slope of the Bolanos Block, one a thin-bedded micrite (Loc. F-30, Loc. F-31, Loc. R-27) that was found to contain abundant calcareous nannoplankton showing a consistent Late Oligocene (NP24-NP25) age. The life-long unpublished work of Dr. Geoff Adams ("The Zonation and Correlation of Cenozoic Shallow-water Carbonates in the Indo-Pacific Region") has revised the ages of *H. borneensis* and *M. dehaarti* (Fig. 3) and placed them into context with the calcareous nannoplankton geochronology. *H. borneensis* should now be considered Late Oligocene (base NP24- top NP25) in age, and *M. dehaarti* as Early Miocene (base NN1- to within NN5)[Whittaker, pers. commun., 1998].

The data thus assembled indicates that the Maemong Limestone Member spans the Late Oligocene/Early Miocene interval, and that the hiatus separating the oldest Maemong and the youngest Alutom lies within the Middle Oligocene interval (~30-32Ma; NP23) following the geochronology of Berggren, et al., (1995). It is during this hiatus that rifting of the Palau-Kyushu-Arc is believed to have been initiated.

Unconformably overlying the Maemong, on the west slope of Mt. Lamlam (Bolanos Block), is the Facpi Volcanic Member (upper flows unit); a sequence of thin-bedded, grey sandstone and claystone was sampled (Loc. F-32) and found to contain abundant, but poorly preserved, planktonic foraminifers. The age is Oligocene or younger.

STRUCTURAL GEOLOGY

Fault Blocks

The area underlain by the Arc rocks (Alutom and Facpi formations) in southern Guam is laced by an extensive system of intersecting northeast (N60 E) and northwest (N60-70 W) trending faults (Plate A). The fault pattern density, which is not reflected in surrounding, younger formations (Miocene - Pleistocene), suggests that the Arc rocks were subject to complex, tectonic dislocations during their time of origin and at least up to the Late Oligocene. Field study suggested that the

intersecting fault block system (Fig. 2) actually represented a collage of four fault-bounded blocks, which formed during the early stages of arc development. Fault block criteria depended on (1) relative internal consistency of stratigraphic record, (2) general unity of topographic expression and (3) fault patterns. Four blocks were delineated, including Sasa Block, Tenjo Block, Tarzan Falls Block, and Bolanos Block. The Sasa, Tenjo and Tarzan Falls blocks are defined by two northeast-trending faults, the Sasa and Sigua faults. These blocks and their intervening faults project northeasterly where they are truncated by the north-west trending Adelup Fault. Because of the presence of Alutom exposures in northern Guam (Mount Santa Rosa, Mataguac Hill, and Mt. Palia), it is probable that Alutom fault block sections, and their defining faults, are concealed beneath the Miocene - Pleistocene carbonates that form the 15 mile-long northern plateau. Several northeast-trending fault zones that shear the carbonate plateau rocks may reflect recurrent movement along faults that originally were established in the Arc basement. The Sigua Fault, and the northwest trending Atantano Fault intersect forming the Atantano-Sigua fault system, their intersection pattern forms the southern and eastern boundary of the Tenjo Block, as well as the northern boundary of the Tarzan Falls Block. The latter block extends southward to its contact with the Bolanos Block along the Talofofo Fault. The Talofofo Fault is the southernmost of a number of northwest-trending faults that cross the Tarzan Falls block; these faults appear to have controlled depositional patterns to the north and south of the block during Alutom time.

The general pattern of exposures in each block and the prevailing direction of dip of stratigraphic units in each, suggests that the blocks have been tectonically tilted, although in different directions. The Sasa Block is tilted 15°-20° to the south. The Tenjo Block is divided into two sub-blocks by transverse faulting; the southern sub block, containing Mt. Alutom (elev. 1074 ft.) and Mt. Chachao, dips 10°-15° northeast; the northern sub-block dips opposite, southwest, at 10°-15°. The Tarzan Falls block dips to the southeast at 15°-25°. The Bolanos Block, containing Mt. Lamlam (1332 ft.), the highest point on Guam dips northeast at 5°-10°. The present block tilt angles may be a net result of block movements that developed at three different times; (1) uplift of the Arc rocks during the Middle Oligocene, (2) uplift prior to Late Miocene, and (3) Plio/Pleistocene uplift.

Correlations of lithostratigraphic units among the Alutom sections (Plate D) show the following results: (1) Within the Tenjo, Tarzan Falls and Bolanos sections, units Ad, Av and Af are present, (2) Units Aa and Ab are found only in the Tenjo and Tarzan Falls sections, (3) Unit Ac is restricted to the Tenjo block, and (4) Unit Ae is restricted to the Tarzan Falls block. Unit Av appears to be the only stratigraphic unit mapped that is present in all four blocks. The Sasa Block section shows marked lithostratigraphic contrast with fault juxtaposed Tenjo section as well as the Tarzan Falls and Bolanos sections.

Unconformities are evident within the Alutom successions of all blocks indicating that the Alutom basin was subject to repeated tectonic events, including uplift and tilting, accompanied by erosion (Plate D). Some unconformities are disconformities; others show marked angular discordance, one up to 60°. The unconformities number: Sasa Block (5), Tenjo Block (3), Tarzan Falls Block (2) and Bolanos Block (1). There is no evidence that the unconformities in one block are synchronous with those in adjacent blocks. A major unconformity of Late Middle Eocene age (~44-41 Ma), separates the Facpi and Alutom Formations in the Bolanos and Tarzan Falls Blocks. A second major unconformity separates the Alutom Formation from the overlying Late Oligocene Maemong Limestone Member (Umatac Formation) in the Bolanos Block; the hiatus coincides with the initial splitting (31-29 Ma) of the Palau-Kyushu-Arc and development of the Parece Vela spreading basin and West Mariana arc. No evidence was found to indicate that erosion producing the unconformities took place under subaerial conditions; rather, the consistent deep water environment in which the Alutom was deposited suggests that erosion was accomplished by bottom currents and debris flows.

Faults

The following field criteria were used to identify and map faults: (1) exposed fault planes, (2) zones of shearing, (3) abrupt changes in rock type and/

or bedding attitudes, (4) scarps, and (5) truncated ridges.

Virtually all faults, whether they be major ones that bound the structural blocks, or intra-block faults, appear to be very steep (75°-85°). The offset patterns of stratigraphic units and the close association of faults with relatively straight scarps and ridges suggest that most faults have acted as normal faults, consistent with an arc terrain generally regarded as of strongly extensional origin (Stern and Bloomer, 1992; Fryer, 1996). Vertical displacements along major faults are estimated roughly as follows: Atantano Fault (~1,000 ft.), Sigua Fault (~1,000 ft.), Talofofo Fault (~500 ft.), Alutom/Ylig Fault (~500-1,800 ft.), Chachao Fault (~400 ft.) and the Transverse Fault (~1,000 ft.) which divides the Tenjo Block into two sub-blocks. The balance of faults mapped in this study seem to have vertical displacements ranging from 100 to 300 ft. with an estimated 200 ft. average. Tracey, et al (1964) estimated a vertical displacement of 300 ft. along the Adelup Fault since Late Miocene time.

Evidence in Alutom terrain, suggest that strike-slip and/or oblique movement has probably occurred along at least one major fault and may be generally more extensive than previously thought. The Sasa Block possesses an Alutom lithostratigraphic succession that, with the exception of Unit Av, differs very significantly from that of the Tenjo Block against which it is juxtaposed along the Sasa Fault. In addition, a narrow ridge that lies along the south side of the Sasa Fault projection appears to be bent left near the contact suggesting left-lateral dislocation. Stream patterns of the Aguada and Sasa rivers along the Sasa Fault trace, in a left-lateral configuration, also support left-lateral, strike-slip movement along the fault. These findings suggest that the Sasa Block is an allochthonous block (Fig. 4), having been moved to its present position by left-lateral strike-slip motion. If it is assumed that the dissimilar Sasa and Tenjo sections continue northeastward beneath the northern carbonate plate in fault contact along the Sasa fault, then left lateral displacement would be expected to exceed 15-20 miles. Strike-slip faulting along the Sasa Fault occurred following deposition of the Mahlac Member (Early Oligocene), probably during regional uplift of the Alutom Formation during the Middle Oligocene interval. Left lateral movement is consistent with clockwise rotation of the Philippine Plate margin postulated by Keating and Helsley (1985) during the Eocene.

Several exposed faults lying on the southwest prolongation of the Atantano fault in the Tarzan Falls Block reveal fault plane striations dipping between 12° and 40° to the horizontal. These data suggest that these faults have undergone oblique-slip, with the strike-slip component exceeding the dip-slip component. Another fault in the same area offsets a number of dikes (or sills) in a pattern which indicates that major movement was probably vertical; however, some minor fault offsets affecting the same intrusions a short distance away from the main fault, appear to indicate right-lateral motion. Mrozowski and Hayes (1980), in a study of Mariana fore/arc faulting, noted that strike-slip faulting is occurring in some modern fore arcs (e.g. northwest Sumatra), and allowed for the possibility of strike-slip motion on some Mariana fore arc faults.

There is indirect evidence that faulting was underway during deposition of Alutom deposits in the Tarzan Falls Block. In a northwest-trending fault zone, lying between the Atantano and Talofofo faults (Plate A), the oldest stratigraphic units recognized in the Tarzan Falls block, (Units Aa and Ab), totalling some 750+ ft. in thickness, appear to be overlapped and covered by the much younger Unit Ad which rests depositionally on the Facpi Formation basement. Units Aa and Ab are not found south of this fault, either in the southern part of the Tarzan Falls Block or the Bolanos Block; they do form major exposures to the north in the Tenjo block. Thus, Units Aa and Ab were either not present south of the fault zone, or were there and later removed as the rocks south of the fault zone were uplifted and eroded.

Other evidence of faulting during deposition of the Alutom occurs north of the Cross Island Highway, ½-1 mile northeast of Divide: 526 ft. Here a northeast-trending fault truncates Facpi Formation and Units Ad and Ae; the southeast projection of the fault appears to be buried by Unit Af indicating cessation of fault movement followed by unconformable overlap by younger strata.

The Alutom Formation was deposited on the surfaces of the four active fault blocks and geographically beyond them during a ~12 million year interval (Late Middle Eocene-Early Oligocene); the individual blocks were independently subject to uplift, tilting and erosion between, and possibly

contemporaneous with, depositional periods. A fault system, whether the result of regional tectonism or volcanic activity, is likely to have been established during the earliest stages of Palau-Kyushu-Arc origin, and was active throughout the duration of Alutom deposition. This conclusion is based on the following: (1) each block section reveals a number of non-synchronous unconformities, some showing marked angular discordance; (2) significant unit miss-ties between the Tenjo, Tarzan Falls and Bolanos Blocks; and (3) evidence of localized faulting in the Tarzan Falls Block. This interpretation allows for similar but not identical deposits to be laid down on each block surface, during the same interval of geologic time. In a similar case, Hussong and Uyeda (1981) have interpreted tectonically controlled deposition in two adjacent fault blocks drilled by Leg 60, DSDP sites (460 and 460A) in the Mariana forearc area. Here reworked sediments from adjacent areas were transported into active, down-dropped fault blocks and deposited at the foot of fault scarps.

Folds

A major structural aspect of Alutom geology is widespread folding (Plates B and C). Three types of folding were observed; (1) pene-contemporaneous deformation producing abundant slump folding, especially within the Tenjo Block section (Units Aa, Ab(u) and Ad), and Tarzan Falls Block section (Unit Av), (2) small-scale folds, traceable for a few hundred feet or less, which closely adjoin fault boundaries, and are considered "drag folds," (3) major, large-scale folds showing substantial axial length (to 1 1/2 miles). The latter are generally open, symmetrical folds with limbs dipping from 15°-55°. Many large-scale folds show low-angle plunge, a few are double-plunging. Unusual isoclinal-appearing folds were observed on aerial photographs; one of these occurs in the south face of the Mt. Alutom anticlinal structure but could not be confirmed in the field owing to difficulty of access. Two other tightly-folded anticlines occur in the Tarzan Falls Block just north of the Cross Island Highway. Most of the folds mapped in the Sasa, Tenjo and Tarzan Falls blocks trend northeasterly closely parallel to fault trends. However, in one case, an L-shaped ridge, located in the Tarzan Falls Block, bends from northeast to southeast and fold structures within the ridge show corresponding trend changes. In the Bolanos block, fold axes seen in the Facpi Formation terrain strike generally northwesterly in contrast to northeasterly trends in the other blocks composed of Alutom Formation. Cloud, et. al. (1956) recognized a few folds on Saipan in Miocene strata; they regarded only one as being of tectonic origin; other folds he considered might have formed by draping over an irregular surface. Tracey, et. al. (1964) drew from the geology of Indonesia to explain the large-scale folding on Guam. There, van Bemmelen (1949) believed that low angle faults beneath the Merapi volcano on Java allowed the broad volcano flank to glide downward against a buttressing group of hills, developing a set of arcuate-patterned anticlines and synclines in this "compressional" and gravitational event

In the present study, (1) the large-scale folds exhibit no tendency to be asymmetrical as might be expected from a down-slope movement, (2) there appears to be no structural topographic features either on Guam or in the offshore that might serve as a buttress against which Alutom strata could be folded, (3) fold axes differ between northwest (Facpi) and northeast (Alutom), and (4) at least one set of folds in the Alutom changes from a northeast to a southeast trend. These data do not support the Van Bemmelen explanation. The large-scale folds in the Alutom are interpreted as being of tectonic origin. They apparently developed about Middle Oligocene time, following deposition of the Mahlac Member, when there was major uplift of the Alutom and Facpi rocks, probably in the order of thousands of feet. If interpretation of the northeast-trending Sasa Fault as a strike-slip fault is correct, then the major northeast-trending folds in the Sasa and Tenjo blocks, in particular, may have formed through transpressive stresses as was suggested to me by Dr. Benjamin M. Page (pers. commun., 1984) to explain folding in the California Coast Ranges through San Andreas fault dynamics. Other folds in the Alutom terrain may be "drag folds" produced along faults of predominantly vertical movements.

Folding has been reported in both the West Mariana Ridge and Tonga Arcs. Karig (1971) has reported that the acoustic basement, at the West Mariana Ridge, is composed of tilted, fault-bounded blocks overlain by marine sediments which are either folded or faulted. A similar pat-

tern appears to occur in the North Tonga Arc where tilted fault blocks are overlain by marine sediments which apparently have been gently "folded" either by fault movements from below, or by draping over structural highs (Clift, et al. 1998). Evidence was not recognized on Guam in support of these fold origins.

Tracey, et al. (1964) mapped a thrust fault dislocating Alutom exposures at Mt. Santa Rosa. This structure was explained, as were the Alutom folds, by the free-gliding, gravitational theory of van Bemmelen (1949). Because van Bemmelen's theory does not now appear tenable on Guam to explain folding, the thrust fault likewise now appears to be more probably of tectonic origin and a "compressional" event.

PALEOENVIRONMENTAL INTERPRETATION

The large volume of pillow lava in the Facpi Formation, coupled with abundant dikes intruding into it, suggests that the formation represents a part, possibly the outer flank of a large, Late Middle Eocene volcano. The geographic location of the postulated volcano is uncertain. Guam's present location in a fore arc area, bounded by a subduction zone on the east, suggests that the volcanic source lay west or southwest of the present island, as Tracey, et al., (1964) had proposed, possibly beyond the eastern faulted margin of the Mariana Trough on the West Mariana Ridge. A cartoon suggesting a possible site of the postulated volcano with respect to the future location of Guam is shown in Fig. 4. Reagan and Meijer (1984) recognized abundant calcite in interpillow regions high in the Facpi Formation but it was nearly absent in Facpi volcanics further below. This relationship suggests that Facpi volcanics were initially deposited below the Eocene Calcite Compensation Depth (9,600 ft.; 3,200m)[Kennett, 1982] and later above it. These findings suggest that following deposition of the older part of the volcano, uplift took place, or there was a "filling-up" of the depositional site, or both, in either case, sufficient to raise the sea floor above the Eocene CCD.

The present Alutom outcrops of Tenjo, Tarzan Falls and Bolanos Formations indicate that they were laid down along a northeasterly axis. The Alutom units were deposited against the Facpi volcano flank with the sea floor probably deepening radially away from the volcano. The complete area of Alutom deposition undoubtedly extended far beyond the present island outline. The geometry of geologic cross sections, drawn along the southeast side of the island, indicates that the Alutom extends southeasterly beneath Oligocene and younger units within the Mariana fore arc. To the northeast, rocks of comparable lithologic character and possibly similar in age to the Alutom have been examined by the writer on Rota and Tinian. Further northeast on Saipan, Cloud, et. al. (1956) have mapped a series of Late Eocene-Oligocene volcanogenic and carbonate units (Hagman, Desinyama, and Matansa Formations) which may be broadly time correlative with the Alutom but may represent depositional basins unrelated to those of the Alutom formations. Three submarine "highs," Galvez Bank, Santa Rosa Reef and Southwest Cone, appear to be southern topographic extensions of the Guam island mass but their lithologic/formational makeup (Facpi Fm. (?), Alutom Fm. (?), or other) has not yet been revealed. To the immediate west, Alutom and Facpi rocks are apparently truncated by, and, perhaps, displaced downward, along major, high angle normal faults (Fryer, 1996; Karig and Ranken, 1982) that mark the eastern tectonic boundary of the Mariana Trough. The site of deposition of the allochthonous Sasa section lay several or more miles north of the north coast of Guam.

Reworked Paleocene species of calcareous nannoplankton were recovered from the Bolanos Block in the Facpi Fm. (Loc. F-26) and Alutom Fm. (Loc. F-27B), both formations of Late Middle Eocene age. Similarly, species of planktonic foraminifers and calcareous nannoplankton, resembling Paleocene and Early Eocene forms, were collected from Late Middle Eocene Alutom beds in the Sasa Block (Loc. F-3) and Tenjo Block (Loc. F-9A). These findings suggest redeposition from Paleocene/Early Eocene terrains that were closely associated with, or part of, the early growth of the Palau-Kyushu-Arc.

The Alutom intra-arc basin of Late Middle Eocene-Early Oligocene duration was a tectonically active depositional site formed of a collage of actively-moving fault blocks on whose upper surfaces deposition and erosion took place. With each new pulse of sedimentation added to the basin, each fault block became thicker while

still retaining its identity as a discrete structural entity. Over the duration of the Alutom intra-arc basin, a fairly consistent sequence of volcaniclastic flow-rock and carbonate rocks were deposited over the Tenjo, Tarzan Falls and Bolanos Blocks. This sequence, as exemplified in the Tarzan Falls Block, extended with fair continuity over most of the three blocks (Plate C) but it was modified, possibly as a consequence of local fault block subsidence or a rapid change in sediment source area, by adding Unit Aa to the Tarzan Falls Block, and Unit Ac to the Tenjo Block. The southern part of the Tenjo Block was further modified, by removal of most of Unit Av and all of Unit Ad, prior to Af deposition.

Two estimates of the depth at which the Alutom Formation was deposited include (1), Tracey, et al., (1964) [6,000 ft.; 2,000m] and, (2) Ingle (1975) [4,500 ft.; 1,500m]. Todd (1966) suggested that the benthic and planktonic foraminiferal fauna of the Mahlac Member (Early Oligocene) represented a paleodepth of about 600 ft. (200m). A recent review of Todd's foraminiferal species by Resig (pers. commun., 2,000) suggests that two distinct and unmixed faunas are represented, one upper bathyal (450-1,500 ft.; 150-500m), the other middle to lower bathyal (1,500-12,000 ft.; 500-4,000m). The Mahlac may represent a slight shallowing of the Alutom basin, perhaps as an early pulse of Alutom uplift that continued, terminating at the end of the Middle Oligocene. The data assembled suggest that most Alutom depositional sites ranged from upper bathyal through lower bathyal environments (~600-9,600 ft.; 200-3,200m) during the Late Middle Eocene/ Early Oligocene interval. Some sites were probably outer neritic (50m-150m) and some were below the Eocene CCD.

The Tenjo, Tarzan Falls and Bolanos Blocks may be viewed as a sequence of carbonate-rich (micritic) units, probably representing pelagic oozes, and intervening non-carbonate units composed of combinations of tuffaceous sandstone, shale, conglomerate, breccia, tuff and flows. Micrites are typically composed of calcareous nannoplankton and planktonic foraminifers. Radiolarians occur in some of the non-carbonate units but overall are less abundant in the Alutom than calcareous microfossils. The lower parts of the Tarzan Falls and Tenjo sequences, show two calcareous nannoplankton-bearing units (Unit Ab(l) and Unit Ad) and a stratigraphically intermediate radiolarian-bearing unit (Unit Ab(u). This sequence is suggestive of a fluctuating intra-arc basin floor with the radiolarian-bearing unit representing the deeper paleodepth, possibly approaching the Eocene CCD (9,600ft.; 3,200m).

Unit Af, which is also nannoplankton rich in the Tarzan Falls Block, contains both nannoplankton and radiolarians, though at different horizons in the Mt. Tenjo area to the north. This relationship also suggests depth fluctuations possibly close to the Eocene CCD. A third stratigraphic relationship between radiolarian and calcareous nannoplankton occurrences is shown in Unit Ad. This unit is richly nannoplankton-bearing in the southern part of the Tarzan Falls Block, [where it is referred to as Unit Ad(South)], but traced some 8-9 miles to the northern extremity of the Tenjo Block, Unit Ad [there referred to as Unit Ad(North)] contains two radiolarian assemblages and no calcareous nannoplankton.. This relationship suggests that the paleodepth of Unit Ad(North) was close to the Eocene CCD, or slightly below it, shallowing southward. Unit Ad(North) may represent one of the deepest parts of the Alutom intra-arc basin preserved on the island.

The Sasa Block section possesses nearly all of the lithologic facies that are found in the Tenjo, Tarzan Falls and Bolanos Blocks and thus its site of deposition experienced similar depositional processes. The Sasa Block section differs, however, in several important ways from the three blocks. It does not include the thrice-fold carbonate sequence that occurs in the other three blocks; only a small micritic deposit occurs near its uppermost limit. In addition, the Sasa Block includes a significant thickness of turbidites in its lower part composed of epiclastic sandstones and siltstones, and worm-like trace fossils, which are not recognized in the other three blocks. Nannoplankton do not appear abundant except near the bottom and top of the section. Shallow water, larger foraminifers occur in a breccia matrix near the middle of the formation and were probably carried to a deep-water site by debris flows. Other distinctive units not found in the Tenjo, Tarzan Falls and Bolanos Blocks include: (1) an andesitic flow (Loc. R-5) and a thick, green, crystalline andesitic tuff (Loc. R-4) in Unit As-4, and (2) a thick body of boulder - cobble conglomerate (Unit As-6), containing well-rounded clasts, possibly formed in a shallow environment. The

oldest one quarter of the Sasa Block section generally suggests deep-water deposition near an eroding volcano with detritus carried down to the basin floor by turbidity currents. The balance of the Sasa Block section was probably laid down in deep water but under variable depth conditions.

Fossils, apparently representing shallow lagoons and coral reef environments, occur in the Alutom as (1) individual tests of larger foraminifers, and (2) fragments of corals, molllusks and coralline algae, etc., in limestone blocks (Schlanger, (1964). These fossils occur in the Alutom Formation (Unit Ad, Unit Af, Unit As-5). The organisms probably lived in reef environments fringing emergent volcanoes, and were later freed by storms or volcanic explosions and carried downslope into deep water. Unit As-5 contains large, well-rounded, basaltic boulders that probably formed by abrasion at shallow depths and later were transported into a deep basin.

Sedimentological data is limited in this study, but major depositional processes postulated to have been active include: (1) Turbidity currents (graded sandstones and some micrites), (2) Debris flows (breccias and conglomerate), and (3) settling through the water column to produce oozes (micrite). Well-developed low-angle cross-bedding in some tuff beds indicates the presence of bottom currents. Some tuffaceous sandstone and shale beds that show no evidence of sedimentary features, other than fine-grained, homogeneous textures, suggest that they were deposited by gentle bottom currents, or by settling through the water column. Tuff beds may also have been deposited by bottom currents, including turbidity currents, or settling through the water column. Bottom currents were apparently of sufficient vigor to be able to erode bottom layers and produce irregular surfaces. Downslope movements were apparently fairly common producing bedding deformation ranging from convoluted bedding to massive, disruptive slump folds.

The origin of the intercalated breccia and pillow-andesite deposit (Unit Av), which appears to be the only stratigraphic unit present in all four blocks, is puzzling, especially because it is interpreted as having been deposited in two adjoining basins, simultaneously (Fig. 4). The unit may have originated during a moment, in the Late Eocene, when the arc was subject to great tectonic activity, including violent earthquakes, causing widespread downslope movement of debris flows, possibly incorporating previously erupted slabs of pillow-andesite from along the basin flanks. Alternatively, the pillow-andesite bodies may have erupted from a series of small vents along rift zones, in the deep part of the basin where debris flows and pillow-andesite flows could commingle to form Unit Av. A third postulate is that eruptions of pillow-andesite themselves, along basin margins, might trigger debris flows that could incorporate some flow rock, as they proceeded downslope.

TERMINATION OF ALUTOM FORMATION DEPOSITION

Alutom deposition apparently ceased on the Palau-Kyushu Arc at the end of the Early Oligocene. Arc basement rocks were uplifted in the order of several thousand feet and became emergent during the Middle Oligocene to produce a low-lying island mass. Differential movements along faults may have produced small-scale drag folds adjacent to the fault boundaries. Postulated left-lateral strike-slip faulting along the Sasa Fault juxtaposed the Sasa Block against the Tenjo Block at this time along with large-scale folding of the Alutom. The hiatus (~30-32 Ma) separating the Mahlac Member (Early Oligocene) and the Maemong Limestone Member (Umatac Fm.) [Late Oligocene/Early Miocene] coincides with the commencement of Middle Oligocene (31 Ma) [Fryer, 1996] rifting of the Palau-Kyushu-Arc to produce the Palau-Kyushu Ridge (remnant arc), the West Mariana Arc and the intervening Parece Vela Basin (Fig. 3). Subsequent splitting (~10 Ma) [Fryer] of the West Mariana Arc produced the West Mariana Ridge (remnant arc), Mariana Trough, and Mariana Ridge (Fig. 2), where the Palau-Kyushu-Arc basement rocks, the Facpi and Alutom formations, form the oldest exposures on Guam. Faults that were active during the lifespan of Alutom deposition probably continued to be active, all or in part, during latest Cenozoic time.

CONCLUSION

This study has shown that volcanic activity producing the Palau-Kyushu-Arc volcanic chain was near-simultaneously followed by intra-arc basin deposition of thick sequences of volcaniclastic, pyroclastic, carbonate and flow-rock (Alutom Formation) that represents a virtually continuous 12,000,000 year old record of much of the Arc's life-span. The linkage of lithostratigraphy and micropaleontology has made it possible to date accurately essentially all Alutom lithofacies, and allow for interpretation of ancient depositional environments and processes. The Alutom fault block sequences record the signatures of important tectonic, volcanic, depositional, and biological events that occurred during the Late Middle Eocene/Early Oligocene interval and thus offer promise as important, and reliably dated reference columns from which to elucidate and further expand the details of PKA history, and to relate with other island sequences of PKA origin. Evidence for strike-slip faulting at the close of Alutom deposition, apparently associated with widespread folding of Alutom terrain pose important future research problems on Guam and perhaps elsewhere in the southern Mariana Islands.

In the case of the principal southern Mariana Islands (Guam, Rota, Tinian and Saipan) some of the oldest arc basement rocks known in the western Pacific are accessible, well exposed, and available for study over substantial land areas, a situation that has no counterpart in oceanic areas where geological data is obtained from scattered deep-sea drilling sites, and geophysical interpretations. Late Middle Eocene to Middle Miocene arc deposits preserved on these islands provide a unique opportunity to examine the closely-related histories of the older Palau-Kyushu-Arc and the younger West Mariana Arc.

The present remarkable, large-scale understanding of arcs, back-arcs, subduction events and plate movements in the western Pacific, that has developed since the advent of plate-tectonic theory, provides a solid, reliable context within which detailed studies of arc histories, as revealed in the southern Mariana Islands, can now be merged and integrated. The foregoing discussion calls for renewed interest and focus on a sustained program of island geological studies in the southern Mariana Islands as a means of more comprehensively understanding arc origins and development in the western Pacific. The Guam study is proposed as an initial contribution toward this promising goal.

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Hafa Adai!

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APPENDIX

This section provides data and findings on samples collected from the Alutom Formation in two categories: 1) Micropaleontology and 2) Petrography.

A. Micropaleontologists who were directly concerned with study of Alutom samples include:

1. Mr. Richard S. Boettcher (foraminifera) Micropaleo; Consultants, Inc., Encinitas, Calif. 92024
2. Mr. T.C. Huang (calcareous nannoplankton); Houston, Texas
3. Mr. Stan A. Kling (calcareous nannoplankton); Micropaleo Consultants, Inc., Encinitas, Calif. 92024
4. Dr. Johanna M. Resig (foraminifera, radiolaria); Dept. of Geology and Geophysics, Univ. of Hawaii, Honolulu, Hawaii 96822
5. Dr. Annika Sanfilippo (radiolaria); Univ. of California, San Diego, Scripps Institution of Oceanography, La Jolla, Calif. 92093
6. Dr. James A. Wilcoxon (calcareous nannoplankton); Wilcoxon Group Geological Consultants, Singapore

Localities from which fossils were recovered are identified in the text and Stratigraphic Chart (Plate D) by the letter "F," in the form of "Locality F-6."

Relative abundance schemes for species identified varied with each micropaleontologist so that it was necessary to prepare a master chart for possible reference:

(1) Boettcher (foraminifera)

A (abundant)	C (common)	F (frequent)	R (rare)	V (very rare)
100+	33 - 100	11 - 32	2 - 10	1

(2) Huang (calcareous nannoplankton)

X (abundant)	/ (common)	(few/normal)	(rare/present)
5 or more specimens per field	1 - 4 specimens per field	5 - 9 specimens per 10 fields	1 - 4 specimens per 10 fields

1 field means a microscopic field with magnification power of X1250

(3) Kling (calcareous nannoplankton)

A (abundant)	C (common)	FT (frequent)	FW (few)
101 - 1,000	26 - 100	16 - 25	6 - 15

(4) Resig (foraminifera, radiolaria)

A (abundant)	C (common)	R (rare)
= many specimens of a particular species	= several specimens of a particular species	one or two specimens of a particular species

(5) Sanfilippo (radiolaria)

A (abundant)	C (common)	F (Few)	R (rare)	VR (very rare)	B (barren)
710,001	5,001 - 10,000	1,001 - 5,000	11 - 1,000	1 - 9	none

(6) Wilcoxon (calcareous nannoplankton)

Relative abundance based on 500x magnification

Abundant	Common	Few	Rare
Many specimens observed in a single field of view	Implies several specimens in a field	One specimen is apt to be observed in a field	A specimen may require search of many fields

Relative abundance figures were not provided in all cases.

Biochronologic systems used by analysts are the following:

Boettcher and Resig (foraminifera)

(a) Berggren, W.A., and Miller, K.G., 1988, Paleogene tropical planktonic foraminiferal biostratigraphy and magnetobiochronology, Micropaleontology, 34(4), p. 362 - 380.
(b) Blow, W.H., 1979, The Cainozoic Globigerinidae, 3 vols., Leiden: E. J. Brill, 1413 pp.
(c) Toumarkine, M., and Luterbacher, H., 1985, Paleocene and Eocene planktonic foraminifera, In: Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K., Eds. Planktonic Stratigraphy. Cambridge University Press, p. 87 - 154.

Huang, T.C. (calcareous nannoplankton)

Martini, E., 1971, Standard Tertiary and Quaternary calcareous nannoplankton zonation. In Farinacci, A. (Ed.), Planktonic Conference., 1970, Proc.: Rome (Technoscienza), 2 : 738 - 785.

Kling and Wilcoxon (calcareous nannoplankton)

(a) Bukry, D., 1973. Low-latitude coccolith biostratigraphic zonation. In: N. T. Edgar, J. B. Saunders et al., Initial Reports of the Deep Sea Drilling Project, 15. U.S. Government Printing Office, Washington D. C., pp. 685 - 703.
(b) Bukry, D., 1975. Coccolith and silicoflagellate stratigraphy, Northwestern Pacific Ocean, Deep Sea Drilling Project Leg 32. In: R.L. Larson, R. Moberly, et al., Initial Reports of the Deep Sea Drilling Project 32. U. S. Government Printing Office, Washington, D. C., pp. 677 - 701.
(c) Okada, H. and Bukry, D., 1980. Supplementary modification and introduction of code numbers to the lower latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). Marine Micropaleontology, 5(3), 321 - 325.

Sanfilippo (radiolaria)

Sanfilippo, A., Westberg-Smith, M.J., and Riedel, W.R., 1985, In Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K. (eds.) Cambridge University Press, Cambridge, UK., pp. 631 - 712

B. Petrographic data and findings were provided by Dr. John D. Longshore, volcanologist, Dept. of Geology, Humboldt State University, Arcata, Calif. 95521. Localities for which thin sections were prepared for petrographic examination are identified in the text and on the Stratigraphic Chart (Plate D) by the letter "R," in the form of (e.g. "Locality R-9"). The results of these analyses are presented on the next and ensuing pages.

C. Geologic mapping: Dr. Frank H. Kilmer, Department of Geology, Humboldt State University, Arcata, California 95521.

PETROGRAPHIC RESULTS

SASA BLOCK
FOSSIL RECORD

Locality F-1 — **Latitude 13° 28.40' N**
Field No. 9-4-89-7 — **Longitude 144° 43.66' E**
Unit As-3 (Sasa Block) — **Agana Quad., 1968**

Description: In north-facing slope (100 ft. elev.) approx. 1,000 ft. due south of intersection of Marine Drive and Halsey Road (Adelup Point area). Thin, green shale at base of layered section exposed in cliff produced by man-made excavation. Bed lies about 18 stratigraphic feet below tan, two foot-thick, cross-bedded tuff.

Calcareous Nannoplankton: *Calcidiscus protoannulus* (R), *Coccolithus pelagicus* (F), *Cylicargolithus floridanus* (C), *Discoaster barbadiensis* (R), *Helicosphaera heezeni* (R), *Reticulofenestra umbilica* (R), *Sphenolithus furcatolithoides* (R), *S. spiniger* (F)

Age: Late Middle Eocene [NP16 (top)] {Huang}

Locality F-2 — **Latitude 13° 28.38' N**
Field No. 9-4-89-9 — **Longitude 144° 43.65'**
Unit As-3 (Sasa Block) — **Agana Quad., 1968**

Description: In north-facing slope (130 ft. elev.) approx 1,150 ft. north of Marine Drive/Halsey Road intersection. Thin grey-green fine sandstone bed about 8 ft. above tan, x-bedded tuff (of Loc. F-1).

CalcareousNannoplankton: *Coccolithus pelagicus* (f), *Cyclicargolithus floridanus* (c), *Discoaster barbadiensis* (r), *Helicosphaera heezeni* (r), *Reticulofenestra umbilica* (r), *Sphenolithus furcatoli thoides* (r), *S. radians* (R)

Age: Late Middle Eocene [NP16 (top)] {Huang}

Locality F-3 — **Latitude 13° 28.31' N**
Field No. 5-11-90-2 — **Longitude 144° 43.65' E**
Unit As-4 (Sasa Block) — **Agana Quad., 1968**

Description: In northwest-facing slope (200 ft. elev.) approx. 1,800 ft. north of Marine Drive and Halsey Road intersection. Grey, calcareous shale in thin bedded medium sandstone/shale section.

Foraminifera: ? *Acarinina primitiva*, ? *Planorotalites cf. P. pusilla pusilla*, ? *Subbotina triloculinoides*.

These foraminifers resemble Paleocene species and may be reworked.

Radiolaria: Poorly preserved, large spumellarians

Age: Uncertain: Assemblage could be Paleocene or Eocene [Resig]

Locality F-3A — **Latitude 13° 26.57' N**
Field Loc. Fn-2 (of Tracey et. al., 1964) — **Longitude 144° 42.34' E**
Unit As-7 (Sasa Block) — **Agana Quad., 1968**

Tracey, et. al., 1964, collected the large foraminifer, identified by Cole (1963), as *Camerina djokdjokarta*, from near the base of Hill 863 ft., which is adjacent to the Sasa Fault of the present study. The locality lies about 1 1/2 miles southwest of Apra Harbor Naval Reservation entrance on Marine Drive at approx. elev. 360 ft. The foraminifers were recovered from the tuffaceous matrix of a dark-green breccia adjacent to and slightly west of the Sasa Fault.

Foraminifera: *Camerina djokdjokarta* (Martin)

Age: Cole (1963) assigned the age of this occurrence as: "Eocene or Oligocene with reworked Eocene." A. Racey (1998, pers. commun.) regarded the age of this species as Late Middle-Early Upper Eocene?

Locality F-4 — **Latitude 13° 26.82 N**
Field Loc. 2-13-94-5 — **Longitude 144° 42.60 E**
Unit As-7 (Sasa Block) — **Agana Quad., 1968**

Description: Brown Shale clast from massive, grey-brown breccia in roadcut of old, poorly used road which connects to the Mt. Alutom Road about 600 ft. due east. A south-facing slope (elev. 640 ft.), about 800 ft. southwest of Nimitz Hill reservoir.

Foraminifera: *Acarinina bullbrooki?* (R), *A. spinuloinflata* (R), *Globigerina senni* (V), ? *Morozovella spinulosa* (R)

Porifera: Sponge spicules (FW)

Age: Probable Middle Eocene (P10-P14) (=NP14-NP17) [Boettcher]

Locality F-5 — **Latitude 13° 26.86' N**
Field No. 10-7-94-4 — **Longitude 144° 42.54' E**
Unit As-7 (Sasa Block) — **Agana Quad, 1968**

Description: Limestone clasts taken from, massive, grey-brown pebble-cobble conglomerate in roadcut of old road (of Loc. 2-13-94-5) about 300 ft. westerly from the latter locality.

Calcareous Nannoplankton: *Dictyococcites bisecta* (F), *Sphenolithus moriformis* (F-C), *S. pseudoradians* (R)

Age: Late Middle Eocene - Late Middle Oligocene (CP14a-CP19a) (=NP16-NP24) [Wilcoxon]

Locality F-6 — **Latitude 13° 26.62 N**
Field No. 10-7-94-BB — **Longitude 144° 41.72 E**
Unit As-7 (Sasa Block) — **Apra Harbor Quad, 1968**

Description: Fragments of pink micrite weathering out of a gutter of Naval road which leads 1.75 miles westward to U.S. Naval petroleum facility (Apra Harbor Naval Res.) on Marine Drive. This road is the southernmost one of a complex of roads at the head of Sasa Valley. Locality is directly above head of Laguas River Valley at approx. 280 ft. elev.

Calcareous Nannoplankton: *Cyclicargolithus floridanus* (R), *C. luminis* (R), *Dictyococcites bisecta* (fragment)

Age: Probably Late Eocene - base of middle Oligocene
(P15b-CP16c) (=NP18-NP21) [Wilcoxon]

SASA BLOCK
ROCK SAMPLE RECORD

Locality R-1 — Latitude 13° 28.53' N
Field No. 3-19-90-x — Longitude 144° 43.55' E
Unit As-1 (Sasa Block) — Agana Quad., 1968

Description: Massive dark grey, lithic, tuffaceous sandstone (or tuff?) in cliff behind buildings about 800 ft. southwest of Marine Dr./ Halsey Rd intersection (elev. 10 ft.)

The bulk of this rock is altered mafic (?) glass clasts that average less than 1mm diameter. Clasts have very irregular shapes. Clinopyroxene grains, mostly unaltered and less than 0.4mm across, are sparsely scattered in the rock. There are a few broken plagioclase crystals between and within glass clasts; most are severely altered to chlorite. Some vitric clasts are vesicular, the vesicles being clear and empty; other clasts are amygdular, with chlorite or calcite filling vesicles. All of the glass clasts are altered, mostly to chlorite, but there is some alteration to nearly opaque sideromelane (?), and there is minor alteration to calcite, and a few calcite veinlets are present. An isotropic zeolite, possibly analcime, is also present in one area. [Longshore]

Locality R-2 — Latitude 13° 28.45' N
Field Loc. 3-19-90 — Longitude 144° 43.47' E
Unit As-2 (Sasa Block) — Agana Quad., 1968

Description: Thick-bedded, green tuff. Sample taken from outcrop in steep cliff behind U.S. Navy Federal Credit Union, approx. 900 ft. southwest of Marine Drive/Halsey Road intersection (80 ft. elev.).

Chlorite alteration is very pervasive in this rock. The matrix is probably glass shards which have altered almost entirely to chlorite, with lesser amounts of possible epidote. Crystal clasts are weakly zoned plagioclase up to 3mm long; grains are euhedral to angular and fresh. Plagioclase composition is approximately An50, and plagioclase comprises about 15% of the rock. Some lithic clasts (less than 0.5 mm size) may be altered pumice fragments. [Longshore]

Locality R-3 — Latitude 13° 28.38' N
Field No. 6-1-90-2 — Longitude 144° 43.65' E
Unit As-3 (Sasa Block) — Agana Quad., 1968

Description: Thick-bedded, medium, green-brown weathering tuffaceous sandstone in exposed north-facing slope approx. 1,150 ft. north of Marine Drive/Halsey Road intersection (elev. 130 ft.). Bed lies about 25 stratigraphic feet above conspicuous cross-bedded, tuff.

The rock is matrix supported and well sorted. There is a highly diverse mixture of clasts; the clasts are angular and average approximately 0.25mm diameter. The matrix is chlorite, and the clast to matrix ratio is approximately 4:1. The clasts, in approximate descending order of abundance, are: several varieties of andesite (most with plagioclase phenocrysts in a fine-grained matrix); dark basalt (?) clasts with a very fine-grained (replaced glass?) matrix; zoned, intermediate plagioclase crystals; twinned and untwinned clinopyroxene crystals; orthopyroxene crystals; rounded microfossils.

There is no positive evidence (other than the fossils) to indicate that this is a re-worked sediment. However, the wide range of lithic clasts and mineral clasts implies that some mixing has occurred, and this rock was probably not formed by a single ash eruption. The matrix is chlorite and of replacement origin; the original matrix may also have been chlorite, but there is no way to determine that. [Longshore]

Locality R-4 — **Latitude 13° 28.04' N**
Field locality 4-18-90-1 — **Longitude 144° 42.75 E**
Unit As-4 (Sasa Block) — **Agana Quad., 1968**

Description: Massive, green, vitric tuff in exposures adjacent to house at end of Ramona St., Asan. Ramona St. intersects Marine Drive directly opposite Asan Memorial Beach.

The rock consists almost entirely of dark brown glass, partially altered to chlorite. A few scattered, angular plagioclase and clinopyroxene crystals (up to 0.3mm long) are present. Plagioclase is heavily altered; clinopyroxene grains are fresh. In plane polarized light, the rock has a fragmented appearance, indicating possible origin as a tuff; it may be a hyaloclastite. [Longshore]

Locality R-5 — **Latitude 13° 28.01' N**
Field No. 4-22-90-1 — **Longitude 144° 42.71' E**
Unit As-4 (Sasa Block) — **Agana Quad., 1968**

Description: Thick bedded andesite flow exposed on summit of knoll, (with U.S. Benchmark) above, and about 350 ft. south of house at end of Ramona St., Asan.

The phenocryst minerals are fresh, unaltered clinopyroxene and zoned plagioclase (about An40). Individual grains of both minerals reach 1.3mm in length, and glomerocrysts of both minerals may reach 3mm in diameter. Some pyroxene and plagioclase grains are totally replaced by chlorite; others are remarkably fresh. The groundmass is comprised of minute plagioclases, clinopyroxene, and opaque grains, with interstitial glass (partially altered to chlorite). The texture is intersertal. There is some flow alignment of plagioclase microlites around phenocrysts. [Longshore]

Locality R-6 — **Latitude 13° 27.26' N**
Field No. 10-14-91-2 — **Longitude 144° 43.03' E**
Unit As-5 (Sasa Block) — **Agana Quad., 1968**

Description: Thick-bedded, white, cross-bedded, medium tuffaceous sandstone exposed near summit area of Nimitz Hill; about 700 ft. west of "Top of The Mar" Naval Restaurant (elev. 480 ft.).

This is a very well sorted rock with an average grain size of approximately 0.5mm. Almost all clasts are highly angular. Clasts are andesite and basalt; most have glassy matrix, with plagioclase, clinopyroxene, and orthopyroxene grains occurring both within lithic fragments and as separate, broken crystals. Most clasts are fresh and unaltered; there is some alteration of glass to chlorite. [Longshore]

Locality R-7 — **Latitude 13° 27.95' N**
Field No. 10-5-94-3 — **Longitude 144° 41.89' E**
Unit As-6 (Sasa Block) — **Apra Harbor Quad., 1968**

Description: Basalt in road cut along north side of Spruance Dr. about 3/4 of a mile east of intersection of Spruance Drive and Marine Drive. Intrusive or extrusive origin is uncertain.

Plagioclase 45-55%; Clinopyroxene 20-30%; Chlorite alteration of glass 25-30%; Magnetite 5%.

Strongly zoned, subhedral plagioclase (approximately An50-70) laths average about 0.6mm length (maximum 1mm) and are randomly oriented. Subhedral clinopyroxene crystals are somewhat smaller (average 0.4mm). Strongly colored (Fe-rich?) chlorite fills spaces between the crystals. Subhedral to euhedral opaque grains (magnetite?) are less than 0.1mm diameter. Plagioclase, clinopyroxene, and opaques all appear fresh and unaltered.

Chlorite alteration is extensive, but it appears to be restricted to the originally glassy portions of the rock. The mineral grains present are quite fresh. Although this type of alteration could be caused by later heating, that type of metamorphism would generally affect some of the crystalline material as well as the glass. The alteration probably is either deuteric or possibly results from seawater percolating through the still warm flow. [Longshore]

Locality R-8 — Latitude 13° 26.62' N
Field No. 2-18-90 — Longitude 144° 42.25' E
Unit Av (Sasa Block) — Agana Quad., 1968

Description: Andesite flow exposed in west rim of major hill lying between Spruance Drive and headwaters of Asan River. Site (elev. 500 ft.) can be reached by dirt road entering from Spruance Drive about where the latter reaches its highest elevation, near radio station.

Phenocrysts of clinopyroxene and plagioclase (~An45) and rare orthopyroxene. Average phenocryst size is about 1mm, though some glomerocrysts (groups of plagioclase and pyroxene phenocrysts) reach 4mm diameter. Plagioclase is strongly zoned. Most pyroxene grains are fresh and unaltered, though some are almost entirely replaced by chlorite and/or uralite. There are many broken, angular grains. Phenocrysts comprise about 20% of the rock. The matrix texture is intersertal, with microlites of pyroxene, plagioclase laths, and minor opaques in a glassy matrix. The glass and microlites are virtually unaltered. [Longshore]

Locality R-9 — Latitude 13° 26.60 N
Field No. 10-7-94-2 — Longitude 144° 42.26' E
Unit As-7 (Sasa Block) — Agana Quad., 1968

Description: Altered vitric andesitic tuff exposed in cut-bank (elev. 320 ft.) next to stair way between the Sasa River and U.S. Navy access road, about 250 ft. west of the Sasa fault. Locality is in the Apra Harbor Naval Res. about 1.5 miles southeast of U. S. Navy facility entrance on Marine Drive and near base of Hill 863 ft.

This rock has grain-supported texture, with irregularly shaped clasts averaging less than 0.3mm size. Many different textures are represented in the clasts: some are vesicular, some are flattened pumice, some are prophyritic. All apparently had originally glassy matrixes. There is no apparent grain alignment. Alteration of clasts to chlorite is moderate to complete; there is minor replacement by zeolite in some clasts. Broken, angular plagioclase grains are less than 0.2mm diameter and average about 2-3% of the rock; these grains are fresh and unaltered. Anorthite content of the plagioclase could not be determined. There are only one or two clinopyroxene grains in the slide and these are fresh, unaltered. [Longshore]

Locality R-10 — Latitude 13° 26.62' N
Field loc. 10-7-94-BB — Longitude 144° 41.72' E
Unit As-7 (Sasa Block) — Apra Harbor Quad., 1968

Description: Pink micrite fragments weathering out of dirt- road gutter of new road in Apra Harbor Naval Res. about 1 mile southeast of U.S. Naval Facility entrance on Marine Drive. Road is the southernmost of a complex of access roads. Locality lies just above the headwaters of the Laguas River at 280 ft. elev.

The majority of the rock is very fine-grained calcite, with occasional hazy outlines of microfossils. 15-20% of the rock is broken crystals or altered lithic clasts, most of which are less than 0.2mm diameter. The lithic clasts are altered to chlorite and probably had vitric protoliths. The broken crystals are fresh plagioclase. Scattered sparry calcite may be either shell fragments or replacement of matrix. A few grains of zeolite (stilbite?) are present. [Longshore]

TENJO BLOCK
FOSSIL RECORD

Locality F-7 — Latitude 13° 24.60' N
Field Loc. 10-10-94-3 — Longitude 144° 42.03' E
Unit Aa (Tenjo Block) — Talofofo Quad.,1968

Description: White, sandy tuffaceous micrite forming conspicuous knoll (elev. 599 ft.) on major drainage divide separating Paulana River and headwaters of Ylig River. This locality is about 1 3/4 miles north of old Raceway on Cross-Island Highway. Sample collected from horizon just above reddish-weathering breccia.

Calcareous Nannoplankton: *Coccolithus pelagicus* (R), *C. formosus* (V), *Cyclicargolithus floridanus* (V), *C. pseudogammation* (R), *Dictyococcites antarcticus* (R), *D. bisectus* (R), *D. minutus* (R), *D. scrippsae* (R), *Reticulofenestra dictyoda* (R), *Sphenolithus moriformis* (R), *S. cf. spiniger* (V)

Age: Late Middle Eocene CP14A (=NP16)

Calcareous nannoplankton is moderately abundant and fairly well-preserved in this sample. Although no primary zone-defining species were identified, secondary species such as *C. pseudogammation*, *D. bisectus* and *R. dictyoda* are generally reported as overlapping in Zone CP14A of the Bukry (1973) zonation. A few specimens exhibit calcite overgrowths or recrystallization, suggesting reworking from an older assemblage. However, none of the potentially reworked species is diagnostic of a specific older age. [Kling]

Locality F-7A — Latitude Same as F-7
Field No 1-24-94-3 — Longitude Same as F-7
Unit Aa (Tenjo Block) — Talofofo Quad., 1968

Description: Locality Data same as for Loc. F-7.

Foraminifera: *A. broedermanni* ? (V), *A. pentacamerata* ? (V), *Acarinina spinuloinflata*, *A. spp.* (FW), *Cibicides spp.* (FW), *Dentalina spp.* (FT), *Eponides spp.* ? (FW), *Globigerina senni?* (R), *Globigerina theka sp.* ? (R), *Morozovella spinulosa* ? (V), *Pleurostomella sp.*? (R)

Age: Probable Middle Eocene (P.10-P.14)(=NP14-NP17)

Middle Neritic to Bathyal environment Well indurated lithic, vuggy limestone with rare foraminiferal remains [Kling]

Locality F-8 — Latitude 13° 26.49' N
Field Loc. 2-17-94-2 — Longitude 144° 42.16' E
Unit Ab(u) (Tenjo Block) — Agana Quad., 1968

Description: Green, tuffaceous shale (or mudstone) from approx. middle of alternating, thin, red and green beds exposed at base of major hill (elev. 893 ft.), along south side of U.S. Naval access road, about 1 1/2 miles southeast of U.S. Naval facility entrance on Marine Dr. in Apra Harbor Naval Res. Locality a few feet east of the Sasa Fault.

Radiolaria: *Dictyoprora mongolfieri*, *Eusyringium fistuligerum*, *Lychnocanoma babylonis* group, *Podocyrtis papalis*, *Spongatractus pachystylus*, *Thyrsocyrtis rhizodon*

Age: Late Middle Eocene *Podocyrtis ampla - P. goetheana* Zones (=NP15-NP17) [Sanfilippo]

All of these species range through the middle Eocene *Podocyrtis ampla* through *P. goetheana* Zones. [Sanfilippo]

Locality F-9 — Latitude 13° 26.49' N
Field loc. 11-13-87-1 — Longitude 144° 42.73' N
Unit Ad South (Tenjo Block) — Agana Quad., 1968

Description: Hard, grey, 1 ft. thick, tuffaceous shale in cut bank about 6 ft. south of wire fence surrounding unmanned communication facility (elev; 780 ft.) next to Mt. Alutom Road. This locality is about 2,500 ft. southeast of Nimitz Hill Reservoir.

Calcareous Nannoplankton: *Coccolithus eopelagicus*, *Chiasmolithus grandis*, *Cyclicargolithus floridanus*, *Cyclidiscus protoannulus*, *Dictyococcites bisectus*, *Discoaster barbadiensis*, *D. saipanensis*, *Ericsonia formosa*, *Helicosphaera compacta*, *Helicosphaera heezeni*, *Helicosphaera lophota*, *Sphenolithus obtusa*, *Sphenolithus radians*, *Spenolithus sp.*

Age: Approx. Late Middle Eocene (NP-17) [Huang]

Locality F-9A — Latitude 13° 26.3' N
Field No. 9-6-94-1 — Longitude 144° 42.25' E
Unit Ad South (Tenjo Block) — Agana Quad., 1968

Description: Limestone *clast* from conglomerate bed located near SW base (750 ft.) base of anticlinal ridge (Hill 863 ft.) located about 2,100 ft. northwest of Mt. Chachao. Locality can be reached by old dirt road which branches off (to west) from main Mt. Alutom Road where that road makes major bend, about 1/2 mile south of Nimitz Hill Reservoir.

Nannoplankton: *Coccolithus eopelagicus* (V), *C. pelagicus* (R), *Cyclicargolithus gammation* (c), *Dictyococcites antarcticus* (R), *D. scrippsae* (c), *Reticulofenestra dictyoda* (V), *R. reticulata* (V), R. *samodurovi* (R), *R. umbilica* (v), *Sphenolithus* cf. *S., anarrhopus* (R), *S. cf. S. conicus* (R), *S. moriformis* (R)

Sphenolithus cf. anarrhopus resembles a Paleocene/Early Eocene species (may be reworked).

Age: Probable Middle Eocene (Probable CP14A) (=NP16) [Kling]

Locality F-10 — Latitude 13° 27.26' N
Field loc. 10-16-91-1 — Longitude 144° 44.06' N
Unit Ad North (Tenjo Block) — Agana Quad., 1968

Description: Light-grey, tuffaceous shale in gutter (elev. 670 ft.) of old, unused road that ascends Mt. Macajna about 400 ft. from where this road leaves U.S. Navy Pipeline Road, which in turn, connects to Mt. Alutom Road, approx. 2 miles to south west.

Radiolaria: *Anthocyrtoma sp.* - very rare *Calocycloma ampulla* - moderately rare, *Calocyclas hispida* - rare, *Calocyclas turris* - very rare, *Cryptoprora ornata* (late morphotypes) - rare, *Dictyoprora mongolfieri* - common, *Dictyoprora pirum* (early morphotypes) - very rare, *Eusyringium fistuligerum* - moderately rare, *Lithocyclia aristotelis* - very rare, *Lithocyclia ocellus* group - very rare, *Lophocyrtis*

biaurtia - very rare,*Podocyrtis papalis* - few, *Rhopalocanium ornatum* - rare, *Sethochytris babylonis* - rare, *Spongatractus pachystylus* - rare, *Theocotyle ficus* - rare, *Thyrsocyrtis tetracantha* (morphotypes without feet) very rare, *Thyrsocyrtis triacantha* rare

Age: Latest Middle Eocene (*Podocyrtis goetheana* Zone)
(=NP-17) [Sanfilippo]

Locality F-11
Field Loc. 3-3-91-10
Unit Ad North (Tenjo Block)

Latitude 13° 27.00' N
Longitude 144° 44.70' E
Agana Quad., 1968

Description: White, tuffaceous shale near end of NE-trending dirt road (elev. ~420 ft.) about 200 ft. from Adelup fault-line scarp; locality is about 850 ft. southeast of Corn Memorial on hill above. Dirt road (construction road used to construct power line towers along scarp) can be reached by taking U.S. Navy Pipeline Road which branches off Mt. Alutom Road and then following side roads down to scarp.

Radiolaria: *Calocyclas hispida*, *Eusyringium fistuligerum*, *Podocyrtis* sp., *Sethamphora mongolfieri*

Foraminifera: None

Porifera: Sponge spicules

Age: Middle Middle through Middle Upper Eocene (=NP16-NP18)
Deep water environment. Deposition may have been below the Eocene CCD (~9,600 ft; 3,000m), or foraminifera may have been destroyed through diagenesis (Resig)

Locality F-12
Field loc. 9-21-94-2
Unit Af (Tenjo Block)

Latitude 13° 26.08' N
Longitude 144° 42.51 E
Agana Quad., 1968

Description: White, thin-bedded tuffaceous shale at base of white thin-bedded section; same locality as Locality R-20.

Nannoplankton: cf. *Cribrocentrum reticulatum* (R-F), *Cy. floridanus* (F), *Cyclicargolithus luminis* (F-C), *Dictyococcites bisecta* (F), *Discoaster saipanensis* (R), *Ericsonia formosa* (F), *E. ovalis* (F-C), *S. moriformis* (F-C), *S. obtusus* (R), *Sphenolithus radians*

Age: Late Eocene (CP15-CP16a) (=NP18-NP20) [Wilcoxon]

Locality F-13
Field loc. 2-8-94-1
Unit Af (Tenjo Block)

Latitude 13° 25.71' N
Longitude 144° 42.18' E
Agana Quad., 1968

Description: White, thin-bedded, tuffaceous shale on east side of Tenjo Jeep Trail (behind bushes) to Mt. Tenjo about 1,600 ft. from place where road leaves paved Mt. Alutom Road.

Radiolaria: *Calocyclas turris* (R), *C. hispida* (R), *Dictyoprora mongolfieri* (R), *Lychnocanoma bellum* (R), *Thyrsocyrtis rhizodon* (R)

Diatoms: Trace

Porifera: Sponge spicules

Age: Late Eocene (=NP18-NP20) [Sanfilippo]

Locality F-13A | **Latitude 13° 25.43' N**
Field Loc. 9-7-94-1 | **Longitude 144° 42.70' E**
Unit Af (Tenjo Block) | **Agana Quad., 1968**

Description: Locality is on a narrow, southeast-trending ridge, along Menengon Jeep Trail, about 2/3 mile from place where this road branches off the Tenjo Jeep Trail which in turn connects to the Mt. Alutom Rd. 1/2 mile to the north. Lithology is a white-weathering, brown micrite directly underlying a 5 ft. thick, green tuffaceous sandstone. A prominent knoll is located just to the west, exposing conspicuous, unconformable, red and green beds.

Nannofossils: *Cribrocentrum reticulatum*, *Dicyococcites bisectus*, *Discoaster barbadiensis*, *Discoaster saipanensis*

Age: Late Eocene (NP-18-NP-20) [Huang]

TENJO BLOCK
ROCK SAMPLE RECORD

Locality R-11 | **Latitude 13° 24.98' N**
Field No. 1-27-94-6 | **Longitude 144° 42.02' E**
Unit Aa (Tenjo Block) | **Talofofo Quad., 1968**

Description: Gentle, northward-dipping basalt unit, in south-facing slope (elev. 640 ft.), of Mt. Tenjo, just above conglomerate bed. Intrusive or extrusive origin uncertain. This locality lies essentially at the common corner of the Agat, Apra Harbor, Tenjo, and Talofofo quadrangles.

This rock contains principally fresh plagioclase and clinopyroxene phenocrysts in a matrix of chlorite (which replaced original glass). Small vesicles are entirely filled with chlorite. Phenocrysts are relatively large (compared to 1-25-94-3), with some plagioclase grains reaching 1 mm and pyroxenes almost that large. There is some calcite filling in vesicles and as patchy and vein replacement of the groundmass. A few scattered lithic fragments (all basalt) are present. [Longshore]

Locality R-12 | **Latitude 13° 25.71' N**
Field No. 2-8-94-2 | **Longitude 144° 44.19' E**
Unit Ac (Tenjo Block) | **Agana Quad., 1968**

Description: Tenjo Jeep Trail, which extends along ridge crest from end of paved road leading to Mt. Alutum. Locality is prominent knoll, about 1/2 mile from paved road end, and on west side of Jeep Trail. Sample is a volcanic *clast* from a volcanic breccia with a white, tuffaceous sandstone matrix.

This rock is similar in composition to 2-22-94-2, with a similar mix of plagioclase, clinopyroxene, and orthopyroxene, with similar phenocryst sizes. However, orthopyroxene is more abundant than clinopyroxene in this rock, and there is a mixture of volcanic textures in this slide; angular clasts from less than 0. 4mm size up to more than a centimeter are present. This is likely a product of explosive eruption, such as a pyroclastic flow, mixing basalts with different textures and phenocryst abundances together. [Longshore]

Locality R-13 — **Latitude 13° 25.71' N**
Field loc. No. 2-2-94-1 — **Longitude 144° 44.19' E**
Unit Ac (Tenjo Block) — **Agana Quad., 1968**

Description: Same locality description as Locality F-12. White tuffaceous sandstone.

Most of the rock is equant, angular pumice fragments averaging about 0.3 to 0.4mm, size and randomly oriented. Glass in these clasts is generally fresh, with very little chloritic alteration. Approximately 15-20% of the rock is broken crystal fragments, consisting principally of quartz, plagioclase, hornblende, and minor clinopyroxene. The rock is very well sorted. Based on abundances of minerals present, the rock is a dacitic sandstone. [Longshore]

Locality R-14 — **Latitude 13° 25.97' N**
Field Loc. 2-22-94-7 — **Longitude 144° 42.56' E**
Unit Ac (Tenjo Block) — **Agana Quad., 1968**

Description: White-grey, tuffaceous sandstone forming matrix for volcanic breccia at crest of ridge (elev. 980 ft.) about 650 ft. northwest of Mt. Alutom summit.

This unit lacks a wide variety of rock types. Most clasts are glassy basalt or andesite, with phenocrysts of plagioclase, clinopyroxene, and orthopyroxene. The matrix of the clasts is dark glass, and in some lithic fragments there are abundant plagioclase microlites. Average clast size is about 2mm, though some fragments are more than 6 mm long. Broken grains of plagioclase and pyroxene are abundant. The lithologies in this rock are not highly variable, but there is a considerable variety of textures. This rock has probably been reworked. [Longshore]

Locality R-15 — **Latitude 13° 25.16' N**
Field No. 1-28-94-1 — **Longitude 144° 41.92' E**
Unit Ac (Tenjo Block) — **Apra Harbor Quad., 1968**

Description: Basaltic boulder from possible flow rubble deposit in area about 500 ft. east of Mt. Tenjo (elev. 1,028 ft.).

Large phenocrysts (up to several mm long) of plagioclase, clinopyroxene, and orthopyroxene are in a glassy matrix. There is virtually no alteration, and there are no evident vesicles. The groundmass texture is intersertal. [Longshore]

Locality R-16 — **Latitude 13° 27.12' N**
Field Loc. 3-3-91-5 — **Longitude 144° 44.31' E**
Unit Ad North (Tenjo Block) — **Agana Quad., 1968**

Description: Coarse, pumiceous, tuffaceous sandstone (elev. 625 ft.) from section of thin bedded tuffaceous sandstone and shale which underlies Corn Memorial on ridge, adjacent to Adelup fault, above and southwest of Sinajana. Locality is near top of section about 200 ft. southeast of Corn Memorial site.

This rock contains somewhat coarser clasts than 3-3-91-3, with pumice fragments up to 0.4mm. There is a sprinkling of diatoms in the matrix, and two to three per cent of broken, angular crystals of plagioclase, quartz, clinopyroxene, and hornblende; average crystal size is about 0.1mm. Clear glass comprises the matrix; glass shard morphology is well preserved. A few clasts of andesite, less than 0.2mm across, with microlites of plagioclase, are present. There is minor alteration to chlorite. [Longshore]

Locality R-17 — **Latitude 13° 27.08' N**
Field Loc. 3-3-91-8 — **Longitude 144° 44.13' E**
Unit Ad North (Tenjo Block) — **Agana Quad., 1968**

Description: Series of black basalt boulders (elev. 650 ft.) in a line (in high grass) about 200 ft. east of U.S. Navy Pipeline Road, and 700 ft. southeast of Mt. Macajna. Not certain if intrusion or extrusion.

Phenocrysts are zoned plagioclase (about An55-60) up to 1.8mm long; glomerocrysts of ploagioclase are up to 6mm in diameter. Most crystals are fresh and unaltered; a few show reactions with the groundmass. Some clinopyroxene and orthopyroxene phenocrysts are fresh; others are altered almost entirely to chlorite. The matrix is a mixture of plagioclase and pyroxene and is intergranular. Average groundmass plagioclase size is approximately 0.08mm. [Longshore]

Locality R-18 — **Latitude 13° 27.09' N**
Field Loc. 3-2-94-6 — **Longitude 144° 44 38' E**
Unit Ad North (Tenjo Block) — **Agana Quad., 1968**

Description: Massive to thick bedded coarse tuffaceous sandstone near base (elev. 380 ft.) of tuffaceous sandstone/shale section which extends downward (SE) of Corn Memorial; approx. 150 stratigraphic feet.

This rock consists of a wide variety of clasts that differ from one another in texture and mineralogy. Average clast size is approximately 2mm; clasts are both rounded and angular. Most lithic clasts are glassy and range from basalt with altered glass matrix through andesite to pumice and quartz-rich rocks. Most are fresh and unaltered. Clasts of plagioclase, orthopyroxene, quartz, and clinopyroxene are also present. Due to the great variety of rock types present, this is probably a reworked deposit, from several different source terrains, rather than a pyroclastic flow from a single eruptive event. [Longshore]

Locality R-19 — **Latitude 13° 25.97' N**
Field No. 9-21-94-2 — **Longitude 144° 42.56' E**
Unit Af (Tenjo Block) — **Agana Quad., 1968**

Description: White, thin bedded tuffaceous shale (elev. 975 ft.) located about 1 ft. above ground level near base of thin bedded, graded sandstone and shale section, about 500 ft. south of Mt. Chachao and about 1,400 ft. northwest of Mt. Alutom.

This is a biomicrite, calcite mud (average grain size <0.02 mm), with 3-5% microfossils whose maximum size is about 0.3mm. Approximately 1-2% of the rock is broken and angular plagioclase grains, with a few basalt clasts that average less than 0.2mm diameter. One altered basalt clast reaches 5mm size. [Longshore]

Locality R-20 — **Latitude 13° 26.08' N**
Field Loc. 2-22-94-2 — **Longitude 144° 42.51**
Unit Af (Tenjo Block) — **Agana Quad., 1968**

Description: White, tuffaceous sandstone exposed below crest of south-facing slope (elev. 980 ft.), about 1,300 ft. northwest of Mt. Alutom summit. Locality lies about 4 ft. above base of white, thin-bedded section of graded, tuffaceous sandstone and shale.

This is a mudflow or pyroclastic flow. It consists principally of very irregular, angular, broken clasts of a variety of volcanic rocks, including fresh basalt, altered basaltic glass, and welded ash flow fragments with well developed eutaxitic texture. Broken crystals of plagioclase, clinopyroxene, and orthopyroxene (in descending order) are also present. Average clast size is approximately 2mm, with a maximum size of 6mm. The texture is grain supported. There is some micritic calcite with a few microfossils between the volcanic clasts. [Longshore]

TARZAN FALLS BLOCK
FOSSIL RECORD

Locality F-14 — Latitude 13° 23.30'N
Field Loc. 9-1-94-1 — Longitude 144° 43.32' E
Unit Facpi Fm. (Tarzan Falls Block) — Talofofo Quad., 1968

Description: Grey, calcareous mudstone acting as matrix separating fragments of amygdaloidal pillow volcanic rock or hyaloclastite. Locality (elev. 535 ft.) is at head (crest) of long, northeast-facing, gentle slope, about 800 ft. northeast of highest point of Divide 526 ft. on Cross Island Highway (C.I. H.).

Calcareous Nannoplankton: *Cyclicargolithus floridanus*, *Sphenolithus furcatolithoides* (R), *S. spiniger* (N)

Age: Late Middle Eocene (NP16) [Huang]

Locality F-15 — Latitude 13° 23.68' N
Field Loc. 8-31-94-4 — Longitude 144° 43.07' E
Unit Ab(l) (Tarzan Falls Block) — Talofofo Quad., 1968

Description: Hard, thin bedded, green, calcareous shale taken about 5 ft. above base of thin-bedded 50 ft. thick section forming Tarzan Falls cliff-face. Tarzan Falls is located at base of 3,000 ft. long trail originating at Divide 526 ft. on Cross Island Highway.

Calcareous Nannoplankton: *Chiasmolithus grandis* (V), *Coccolithus eopelagicus* (R), *C. formosus* (R), *C. pelagicus* (R), *Cyclicargolithus floridanus* (F), *C. pseudogammation* (F), *Discoaster deflandrei* (V), *Reticulofenestra dictyoda* (c) *R. hillae* (R), *R. samodurovii* (R), *R. umbilica* (R), *Sphenolithus furcatolithoides* (R)), *S. moriformis* (R), *S. radians* (R), *S. spiniger* (R)

Age: Middle Eocene (CP14A) (=NP16) [Kling]

Locality F-16 — Latitude 13° 22.74' N
Field Loc. 7-13-94-1 (=Hj-1 ofTracey et al., 1964) — Longitude 144° 43.15' E
Unit Ad (Tarzan Falls Block) — Talofofo Quad., 1968

Description: Thick bedded, light grey, micrite bed cropping out on east-facing slope of north-south ridge at elev. 245 ft. Locality can be reached by following old south trending road about 2,700 ft. southward from Divide 526 ft. on C.I.H. to point 70 ft. below and slightly east of locality..

Foraminifera: *Globigerinatheka subconglobata luterbachi*, *Hantkenina* (spines only) *Morozovella spinulosa*, *Pseudohastigerina micra*, *Truncorotaloides collactea*, *T. rohri*, *Turborotalia cerroazulensis* gr.

Age: Latest Middle Eocene (P14) (=Np16 top-NP17 all) [Resig]

Radiolaria: *Dictyoprora mongolfieri*, *Eusyringium fistuligerum*, *Lithocyclia ocellus*, *Podocyrtis chalara*, *Spongatractis pachystylus*, *Theocotylissa ficus*

Age: Latest Middle Eocene (*Podocyrtis chalara* Zone)
(P14) (=NP16 top-NP17 all) [Resig]

Locality F-17 — **Latitude 13° 23.09' N**
Field Loc. 8-13-94-4 — **Longitude 144° 42.80' E**
Unit Ad (Tarzan Falls Block) — **Talofofo Quad., 1968**

Description: White, pumiceous, calcareous sandstone on top of small blunt ridge protruding easterly into major canyon, at elev. 340 ft. Canyon heads at Cross Island Highway about 1,500 ft. west of divide 526 ft. along highway. Ridge can be reached by taking dirt road which turns off Cross Island Highway about 3,000 ft. west of Divide 526 ft. (On C.I.H.). Follow dirt road about 3,000 ft. southward, then turn easterly to end of protruding ridge.

Calcareous Nannoplankton: ***Chiasmolithus grandis*** (R), ***Cribrocentrum reticulatum*** (R), ***Discoaster barbadiensis*** (r), ***Helicosphaera reticulatum*** (r), ***H. compacta***, ***Sphenolithus pseudoradians*** (r)

Age: Latest Middle Eocene (NP17) [Huang]

Locality F-18 — **Latitude 13° 23.08' N**
Field Loc. 8-13-94-2 — **Longitude 144° 42.72' E**
Unit Ad (Tarzan Falls Block) — **Talofofo Quad., 1968**

Description: Massive, tuffaceous micrite is located about 350 ft. northwest of Loc. F-17 overlooking secondary canyon (elev. 300 ft.) . See locality F-17 for location information. Localities F-17 and F-18 are both reached by old dirt road descending (south) from housing area located about 3,000 feet west of Divide 526 ft. on Cross Island Highway.

Calcareous Nannoplankton: ***Cyclicargolithus floridanus*** (c), ***C. reticulatum*** (vr), ***Discoaster barbadiensis*** (r), ***Dictyococcites bisectus*** (R), ***Helicosphaera compacta*** (F), ***H. reticulatum*** (r), ***Reticulofenestra umbilica*** (r), ***Sphenolithus predistentas***

Age: Latest Middle Eocene - Earliest Late Eocene (NP17-NP18) [Huang]

Locality F-18A — **Latitude 13° 24.17' N**
Field Loc. 10-4-94-1 (clast) — **Longitude 144° 42.53' E**
Unit Ad (Tarzan Falls Block) — **Talofofo Quad., 1968**

Description: Limestone clast from limestone-bearing conglomerate located about halfway down (elev. 500 ft.) north-facing slope overlooking headwaters area of Ylig River. Locality can be reached by following northeasterly along old road (about one mile) which originates from old Raceway on Cross Island Highway.

Calcareous Nannoplankton: ***Chiasmolithus grandis*** (vr), ***Cribrocentrum reticulatum*** (R), ***Dictyococcites bisectus*** (A), ***Discoaster barbadiensis*** (R), ***Sphenolithus*** cf ***pseudradians***(?)

Age: Latest Middle Eocene (NP17) [Huang]

Locality F-18B — **Latitude 13° 23.6' N**
Field Loc. 7-18-94-1 — **Longitude 144° 44.1' E**
Unit Ad (Tarzan Falls Block) — **Talofofo Quad., 1968**

Description: Take dirt road originating at Divide: 526 feet on Cross Island Highway, and follow it northeasterly down steep north-facing slope to Ylig River. Locality is a low road cut about 100 feet from river and 10 feet above it. Sample from white, thick-bedded tuffaceous micrite alternating with thick-bedded, brown, cross-bedded sandstone.

Calcareous Nannoplankton: ***Calcidiscis protoannulus*** **(R),** ***Chiasmolithus grandis*** **(r),** ***C. titus*** **(r),** ***Coccolithus pelagicus*** **(C),** ***Cribrocentrum reticulatum*** **(r),** ***Dictyococcites bisectus*** **(A),** ***Discoaster barbadiensis*** **(F),** ***D. deflandrei*** **(r),** ***D. nodifer*** **(r),** ***D. saipanensis*** **(F),** ***Ericsonia formosa*** **(C),** ***Helicosphaera compacta*** **(F),** ***H. reticulata*** **(r),** ***Reticulofenestra umbilica*** **(R),** ***Sphenolithus predistentus*** **(r),** ***S. pseudoradians*** **(r),** ***S. spp.*** **(F)**

Age: Near Middle/Upper Eocene boundary
Uppermost part of NP17 [Huang]

Locality F-19 **Latitude 13° 23.73' N**
Field Loc. 8-31-94-11 **Longitude 144° 43.10' E**
Unit Ae (Tarzan Falls Block) **Talofofo Quad., 1968**

Description: Massive, tan micrite in west bank of the Tarzan River about 35 ft. upstream (elev. 200 ft.) from minor waterfall downstream (400-500 ft.) from Tarzan Falls.

Calcareous Nannoplankton: ***Cribrocentrum reticulatum*****,** ***Dictyococcites bisectus*****,** ***Reticulofenestra umbilica***

Age: Late Eocene (NP18-NP20) [Huang]

Locality F-20 **Latitude 13° 23.41' N**
Field Loc. 9-4-94-2 **Longitude 144° 43.74' E**
Unit Ae (Tarzan Falls Block) **Talofofo Quad., 1968**

Description: White micrite bed in road cut (westside) of dirt road descending to the Ylig River from Divide 526 ft. along Cross Island Highway. Locality (elev. 350 ft.) is about 4,000 ft.NE of this divide on NE-facing slope.

Calcareous Nannoplankton: ***Cribrocentrum reticulatum*****,** ***Dictyococcites bisectus*****,** ***Reticulofenestra umbilica***

Age: Late Eocene (NP18-NP20) [Huang]

Locality F-21 **Latitude 13° 24.23' N**
Field Loc. 7-24-94-2 (clast) **Longitude 144° 43.16" E**
Unit Af (Tarzan Falls Block) **Talofofo Quad., 1968**

Description: Limestone clast taken from limestone-bearing conglomerate at base of high peak (elev. 565 ft.) on major high divide separating Tarzan River and Ylig River. Locality can be reached by following well-used jeep trail originating from old Raceway located on Cross Island Highway and proceeding about 1 3/4 miles northeasterly along it.

Calcareous Nannoplankton: ***Cribrocentrum protoannulus*** **(R),** ***Discoaster barbadiensis*** **(r),** ***Dictyococcites bisectus*** **(F),** ***Discoaster saipanensis*** **(r),** ***Helicosphaera compacta*** **(r),** ***Splenolithus*** **cf.** ***S. obtusus*** **(r)**

Age: Latest Middle Eocene (NP 17 (?)) [Huang]

Locality F-22 — **Latitude 13° 23.97'**
Field Loc. 10-2-94-2 — **Longitude 144° 43.32' E**
Unit Af (Tarzan Falls Block) — **Talofofo Quad., 1968**

Description: Grey-brown micrite (elev. 320 ft.) located along crest of N-S trending ridge about 1,000 ft. north of Tarzan River and about 3,500 ft.west of Tarzan River/Ylig River confluence.

Calcareous Nannoplankton: Cyclicargolithus floridanus (F - C), C. luminis (F - C), *Discoaster barbadiensis* (R), *Dictyococcites bisectus* (R - F), *Discoaster saipanensis* (R), *Discoaster tani* (R), *Reticulofenestra hillae* (F - C), *R. umbilica* (F - C), *Sphenolithus moriformis* (F)

Age: Latest Eocene - Earliest Oligocene (NP20-NP21) [Wilcoxon]

Locality F-23 — **Latitude 13° 25.86' N**
Field Loc. 9-13-94-1 — **Longitude 144° 45.42' E**
Unit Af (Tarzan Falls Block) — **Agana Quad., 1968**

Description: Pale grey laminated micrite at top of section that includes tuffaceous shale, sandstone, conglomerate and breccia exposed in major roadcut at base of grade leading to Leo Palace Resort. Locality is just southwest of bridge over Pago River and can be reached from main road (Route 4) at Ordot, 1 1/2 miles to north.

Calcareous Nannoplankton: *Calcidiscus protoannulus*, *Coccolithus pelagicus* (R), *Cribrocentrum reticulatum* (VR), *Dictyococcites bisectus* (c), *Discoaster barbadiensis* (R), *D. saipanensis* (R), *Ericsonia formosa* (VR), *Reticulofenestra umbilica* (VR), *Sphenolithus* spp. (F)

Age: Late Middle-Eocene - Late Eocene (NP-17 (?)-NP-19) [Huang]

Locality F-24 — **Latitude 13° 23.74' N**
Field Loc. 7-27-94-1 — **Longitude 144° 41.12' E**
Unit Tentatively assigned to Maemong — **Limestone Member (Umatac Formation) (Tarzan Falls Block)**

Description: Thin, graded, grey sandstone and green siltstone outcrop in road cuts adjacent to Talisay Branch Mormon Church (LDS) located on Magazine Road about 400 ft. from its intersection with Cross Island Highway.

Calcareous Nannoplankton: *Cyclicargolithus abisectus* (R), *Dictyococcites bisectus* (R-F), *Discoaster barbadiensis* (F), *Ericsonia formosa* (F), *Sphenolithus ciperoensis* (R), *S. moriformis* (F)

Age: Late Oligocene - Early Miocene (NP24-NN1)
Contains reworked Middle-Late Eocene foraminifers of NP1 age, including *Globigerinatheka subconglobata luterbacherei*, *Morozovella spinulosa*, *Turborotalia cerroazulensis cerroazulensis* [Resig]

TARZAN FALLS
ROCK SAMPLE RECORD

Locality R-21 — **Latitude 13° 23.71' N**
Field Loc. 7-31-94-4 — **Longitude 144° 41.46' E**
Unit Ad (Tarzan Falls Block) — **Agat Quad., 1968**

Description: Knobby-weathering, massive white vitric crystal-tuff exposed at base and on west side (elev. 580 ft.) of major knoll located on ridge, about 3/8 mile east of U.S. Navy Magazine Road. Locality

can be reached using old unused road which climbs upward from Dydazco family home located at end of paved residential street intersecting U.S. N.M. road about 1/2 mile north of U. S. Naval Magazine entrance.

This is a very fine-grained tuff; average grain size is less than 0.2mm. Most clasts are glass, some pumiceous, and very well sorted. Approximately 10-15% of the rock is broken crystals: plagioclase, quartz, clinopyroxene, and orthopyroxene. Crystal grain size also averages less then 0.2mm. A few very fine-grained (andesite?) clasts are sparsely scattered in the slide. There is very little chloritic alteration. The excellent sorting and lack of evidence of reworking indicate a probable air fall tuff. [Longshore]

Locality R-22 — **Latitude 13° 23.52' N**
Field Loc. 8-18-94-2 — **Longitude 144° 41.98' E**
Unit Ad (Tarzan Falls Block) — **Agat Quad., 1968**

Description: Coarse, white, bioclastic, tuffaceous limestone (grainstone of Dunham's classification) occurring as a series of thin beds forming a 3-4 ft. thick section which overlies a massive, green tuffaceous sandstone. Locality (elev. 520 ft.) lies in old road following a major southeast trending ridge leading down 1/2 mile to U.S. Naval Magazine and the Maemong River.

The rock is composed of approximately 60% carbonate fragments, mostly rounded and about 0.3mm diameter, and about 40% volcanic fragments of the same size. Sorting is good, and the rock is grain-supported. Most fragments are rounded. Most of the carbonate grains are fossil fragments. The volcanic clasts have a variety of textures, including hyalopilitic (all altered glass), to single broken crystals (mostly plagioclase, but with some fresh pyroxene crystals). Most volcanic grains contain some glass, and in most, the glass is altered; in some clasts, the glass is fresh. All volcanic clasts appear to be basalt. [Longshore]

Locality R-23 — **Latitude 13° 24.52' N**
Field Loc. 1-24-94-1 — **Longitude 144° 42.15' E**
Unit Av (Tarzan Falls Block) — **Talofofo Quad, 1968**

Description: Basalt, apparently in situ, occurs as an elongate pile of blocks (N 60 W trend). Locality is 2/3 mile north of Cross Island Highway from place on C.I.H. where old Raceway is located. Basalt accumulation lies adjacent to fault that truncates numerous green dikes/or sills. Intrusive or extrusive origin is uncertain.

This is a highly vesicular flow. The only discernable original mineral is plagioclase. If there were any other phenocrysts or matrix ferromagnesian minerals, they were replaced by chlorite. That this was a glassy flow, with only plagioclase microlites and no original ferromagnesiam phenocrysts. Most vesicles and fractures are filled with chlorite and/or chalcedony and/or calcite and/or zeolites. Groundmass glass has altered to chlorite in most places. Texture is intersertal. The high vesicularity and fairly large size of the vesicles argue either for shallow water or subaerial eruption. [Longshore]

Locality R-24 — **Latitude 13° 24.69' N**
Field Loc. 1-27-94-7 — **Longitude 144° 42.30' E**
Unit Av (Tarzan Falls Block) — **Talofofo Quad., 1968**

Description: Outcrop (elev. 400 ft.) consists of a jumble of glassy basalt breccia (somewhat aligned) near the base of a north-facing slope (of east-west trending ridge) about 3/4 mile northeast of old Raceway on Cross Island Highway. Intrusive or extrusive origin is uncertain.

This rock has only minor alteration. The primary alteration product is chlorite, which has replaced the groundmass in some places and filled scattered vesicles. Calcite fills some vesicles and occurs in sparse, minor patches in the matrix. Most vesicles, however, are not filled. The rock consists of several

different rock textures, all glassy; some clasts have plagioclase microlites, and some do not. Few clinopyroxene crystals are evident. the matrix between clasts is (or was) glassy. This rock may be a hyaloclastite, resulting from submarine eruption. [Longshore]

BOLANOS BLOCK
FOSSIL RECORD

Locality F-25 — Latitude 13° 19.86' N
Field Loc. 10-7-94-3 — Longitude 144° 39.56' E
Unit-Facpi Fm. (Bolanos Block) — Agat Quad., 1968

Description: White calcareous matrix in interpillow areas of a massive, cliff-forming, dismembered pillow lava or hyaloclastite deposit next to the Agat - Umatac highway. Locality (elev. 500 ft.) is in headwaters area of the Sella River and directly overlooks Sella Bay, about 1/4 mile northwest of Unit Ah outcrop on highway.

Calcareous Nannoplankton: *Coccolithus pelagicus* (R), *Cyclicargolithus floridanus* (R), C. *pseudogammation* (R), *Dictyococcites antarcticus* (R), D. minutus (R), *D. scrippsae* (R), **Discoaster delicatus* (v), *Sphenolithus moriformis* (R), *S. spiniger* (R), *S. spp.* (F)

Age: Late Middle Eocene (NP16)

Comments: This assemblage indicates a Middle Eocene Zone (CP-14A). The single specimen of *D. delicatus*, a species restricted to the Paleocene, probably is reworked from older deposits.

Age: CP14A (=NP16) [Kling]

Locality F-26 — Latitude 13° 19.63' N
Field Loc. 8-5-90-3 — Longitude 144° 39.69' E
Unit Ah (Bolanos Block) — Agat Quad., 1968

Description: Section of thin-bedded micrite, tuffaceous sandstone, conglomerate, and green tuffaceous shale (elev. 500 ft.) forming major road cut on east side of Agat/ Umatac highway, about 1/4 mile northwest of Cetti Bay Overlook, and 4 miles south of Agat. Locality is 6 feet above base of section in thin-bedded micrite.

Calcareous Nannoplankton: *Campylosphaera dela* (R), *Chiasmolithus grandis* (R), *C. solitus* (r), *C. titus* (R), *Coccolithus pelagicus* (A), *Discoaster barbadiensis* (c), *D. deflandrei* (F), *D. saipanensis* (c), *Ericsonia formosa* (F), *Helicosphaera intermedia* (r), *Reticulofenestra* sp (c), *R. umbilica* (r), *Sphenolithus furcatolithoides* (F), *S. spiniger* (c), *Striatococcolithus* sp. (F)

Age: Late Middle Eocene (NP16) [Huang]

Locality F-27 — Latitude 13° 19.63' N
Field Loc. 8-5-90-1 — Longitude 144° 39.69 E
Unit Ah (Bolanos Block) — Agat Quad., 1968

Description: Same as Loc. F-26. Fossil locality is 1 ft. above base of section in thin bedded micrite.

Planktonic: *Acarinina* cf *broedermanni* (rare), *A. bullbrooki*, *Globigerina cryptomphala*, *Globigerinatheka* spp. (abundant), *Hantkenina* sp. (spine only), *Morozovella lehneri* ((rare), M. *spinulosa*, *Truncorotaloides collactea*, *T. libyaensis - haynesi*, *Turborotalia cerroazulensis* (*frontosa*, *possagnoensis*, *pomeroli*)

Age: Late Middle Eocene; Probably P12 *Morozovella lehneri* Zone.

Primitive forms of T. cerroazulensis end in P12 and more advanced forms evolve there.

Ap.: A partly recrystallized foraminiferal ooze with abundant radiolarians, Benthic foraminifera consist of deep water forms such as *Cibicidoides*, *Pleurostomella* and compose 1% or less of the assemblages, typical of a deep sea ooze. [Resig]

Locality F-27A
Field Loc. 10-19-91-1
Unit Ah (Bolanos Block)

Latitude 13° 19.63' N
Longitude 144° 39.69' E
Agat Quad., 1968

Description: Same as Loc. F-26. Sample taken 3 ft. above base of section.

Planktonic: *Acarinina spinuloinflata* (R), *Chiloguembelina cubensis* ? (c), *C. martini* ? (c), *Globigerinatheka index tropicalis* (R), *G. index index (*R), *G. subconglobota s.l.* (F), *Hantkenina dumbeli* (F), *H. mexicana* ? (R), *Morozovella lehneri* (c), *M. spinulosa* (A), *Planorotaloides renzi* (F), *Pseudohastigerina* spp. (c), *Subbotina frontosa frontosa* ? (R), S. *inaequispira* (R), *Truncorotaloides haynesi* ? (R), *T. rohri* (A), *T. topilensis* (c)

Benthic: *Nodogenerina* sp. (R), *Pleurostomella* sp. (R)

Age: Late Middle Eocene CP-14A (=NP16)
Bathyal [Kling]

Calcareous nannoplankton: *Chiasmolithus consuetus* (R), *Coccolithus eopelagicus* (F), *C. formosus* (v), *C. pelagicus* (F), *Cyclicargolithus pseudogammation* (c), *Dictyococcites bisectus* (R), *Discoaster barbadiensis* (F), *D. sp.* (R), *Fasciculithus tympaniformis*(R), *Reticulofenestra dictyoda* (F), *R. hillae* (R), *R. samodurovi* (R), *R. umbilica* (R), *Sphenolithus furcatolithoides* (R), S. *radians* (R), S. *spiniger* (R), S. *spp.* (R), *Thoracosphaera sp.* (F), *Zygrhablithus bijugatus* (R). *F. tympaniformis* and some possibly earlier forms of *Sphenolithus* indicate reworked Paleocene and perhaps Early Eocene.

Age: Middle Eocene CP-14A (=NP-16) [Kling]

Locality F-28
Field Loc. 8-29-94-5
Unit-Ad (Bolanos Block)

Latitude 13° 22.40' N
Longitude 144° 39.47' E
Agat Quad., 1968

Description: White, cherty micrite in series of exposures (elev. 160 ft.) along old road leading from end of Finile Road upward along crest of northwest-trending ridge which borders the Gaan River. Locality is about 3,000 ft. SE of intersection of Route 2 and Finile Rd.

Calcareous Nannoplankton: *Calcidiscus protoannulus* (F), *Chiasmolithus* cf. *c. grandis* (r), *Dictyococcites bisectus* (c), *Discoaster barbadiensis* (R), *D. saipanensis*, *Ericsonia formosa* (R), *Psedotriquetrorhabdulus inversus* (R), *Sphenolithus obtusus* (r)

Age: Late Middle Eocene (NP17) [Huang]

Locality F-29 — **Latitude 13° 22.43' N**
Field Loc. 8-29-94-2 — **Longitude 144° 39.59' E**
Unit Af (Bolanos Block) — **Agat Quad., 1968**

Description: About 600 feet east and slightly north of Loc. F-28 at elev. 190 ft. Lithology is a 6 inch-thick grey, calcareous, lithic, tuffaceous sandstone overlying a reddish-weathering volcanic breccia; it lies 3,500 ft. southeast of Finile Rd. and Marine Drive intersection. Bed has a northwesterly strike and 18 northeast dip.

Calcareous Nannoplankton: *Chiasmolithus titus* (F), *Cyclicargolithus floridanus* (A), *Dictyococcites bisectus* (F), *Discoaster deflandrei* (F), *D.* cf. *D. saipanensis* (r), *Ericsonia formosa* (F), *Helicosphaera compacta* (R), *Reticulofenestra umbilica* (R), *Sphenolithus radians* (r) ?

Age: Near Oligocene/Eocene boundary (NP20-NP21) [Huang]

Locality F-29A — **Latitude 13° 22.40' N**
Field Loc 8-29-94-2 — **Longitude 144° 39.47' E**
Unit Af (Bolanos Block) — **Agat Quad., 1968**

Description: As for Loc. F-29.

Planktonic: *Globigerina* cf. *ampliapertura*, *G. cryptomphala*, *G. tripartita*, *G. venezuelana*, *G. yeguaensis*, *Hantkenina alabamensis ?*, *Turborotalia cerroazulensis cerroazaulensis*, *T. cerroazulensis cunialensis*

Benthic: Amphistegina sp., Gyroidinoides sp., Oridorsalis sp., Pararotalia sp., Pleurostomella sp., Pullenia sp.

Age: Late Eocene - Early Oligocene (mid P16-P17) (=NP19-21)

Remarks: The age is based on the total range of *Turborotalia cerroazulensis cunialensis*,. *T. cerroazulensis cerroazulensis* is particularly abundant. The planktonic assemblage consists generally of large species. No radiolarians were noted. The benthic foraminifera are relatively abundant, suggesting deposition at about middle bathyal (500-1,000m) depths. Some of the genera represented are *Gyroidinoides*, *Oridorsalis*, *Pleurostomella*, and *Pararotalia* indicating the site lay downslope from a bathymetric high. [Resig]

Locality F-30 — **Latitude 13° 20.18' N**
Field Loc. 11-16-91-4 — **Longitude 144° 39.10' E**
Unit - Maemong Limestone Member — **Agat Quad., 1968**
(Umatac Fm.; Tracey et. al., 1964) (Bolanos Block)

Description: White-grey, thin bedded, tuffaceous, calcareous sandstone and shale section near base of Maemong Limestone Member deposit (elev. 700 ft.) which forms major, bluff-forming outcrop above and about 1,300 ft. east of Agat/Umatac highway. This locality is locality DH-11 of Tracey, et. al., (1964) and lies directly above newly-built scenic lookout overlooking Sella Bay. Sample was taken from outcropping rock in deep jungle-covered gorge at headwaters of Asamafines River.

Calcareous Nannoplankton: *Coccolithus pelagicus* (F), *Cyclicargolithus floridanus* (A), *Discoaster deflandrei* (R), *Ericsonia fenestrata* (R), *Helicosphaera euphatis* (VR), *Sphenolithus ciperoensis* (F), *S. distentus* (R), *S. moriformis* (c)

Age: Late Oligocene (NP24) [Huang]

Locality F-31 — **Latitude 13° 20.18' N**
Field Loc. 10-1-91-2 — **Longitude 144° 39.10' E**
Unit-Maemong Limestone Member — **Agat Quad, 1968**
(Umatac Fm.) Tracey et al., 1964 [Bolanos Block]

Description: Micrite is at very top of section described in Loc. F-30 (= DH-11 of Tracey, et al., 1964)

Calcareous Nannoplankton: *Coccolithus pelagicus* (r), *Cyclicargolithus floridanus* (A), *Discoaster deflandrei* (r), *Sphenolithus ciperoensis* (F), *S. moriformis* (A)

Age: Late Oligocene (NP25)

Comment: Nannofossils very abundant (Huang)

Locality F-32 — **Latitude 13° 20.6' N**
Field Loc. 10-1-91-2 — **Longitude 144° 39.52' E**
Unit-Facpi Volcanic Member — **Agat Quad., 1968**
(Upper Flows), Tracey, et. al., 1964 [Bolanos Block]

Description: Section of rhythmically alternating thin bedded red claystone and grey sandstone resting directly on cliff-forming deposit of the Maemong Limestone Member (thin bedded lithic sandstone and reddish, sandy, calcareous tuffaceous shale). Outcrop occurs at elev. 880 ft. at point where slope "flattens-out" to make bench, about 1,800 ft. east of Agat/Umatac highway, at point where radio station entrance meets highway.

Foraminifera: Foraminifera are abundant in the sample but are poorly preserved, so that specimens break apart when the "sandstone" is disaggregated. Internal molds of foraminiferal chambers are seen throughout. Planktonic foraminifera appear to be more abundant than benthic, but may be more easily infilled and preserved.

The rock appears to consist mostly of skeletal debris that is almost impossible to identify because preservation is so poor. I saw a few echinoid spines (?). Grains of a dark mineral are frequent.

Age: The planktonic foraminifera seen are all globigerinid morphologies - a couple of specimens picked from the rock are like *Globigerina sellii* or *G. tapuriensis* suggesting an Oligocene age or possibly younger. Spiny globorotalids such as are frequent in Eocene deposits were not seen.

Or: the deposit site was not really shallow because of the abundance of planktonics. [Resig]

BOLANOS BLOCK
ROCK SAMPLE RECORD

Locality R-25 — **Latitude 13° 19.63' N**
Field Loc. 10-17-94-4 — **Longitude 144° 39.69' E**
Unit-Facpi Fm. (Bolanos Block) — **Agat Quad., 1968**

Description: Sample of basalt collected 6 ft. below base of Unit Ah composed of white thin bedded micrite, tuffaceous sandstone, conglomerate, and green tuffaceous shale (loc. F-27) on Agat-Umatac highway. Locality is 1/4 mile north of Cetti Bay Overlook, and 4 miles south of Agat.

Clinopyroxene and rare orthopyroxene phenocrysts lie in an intersertal matrix of plagioclase microlites and altered glass. Pyroxene grains are less than 0.3mm diameter; most are fresh though some are altered to chlorite. No plagioclase phenocrysts remain, though there are some elongate concentrations of chlorite that are probably replaced plagioclase. Vesicles are not abundant, and they are filled with chlorite. Groundmass plagioclase laths are less than 0.05mm long and appear to be altered only slightly; the laths are weakly aligned. Interstitial glass is altered to chlorite. There is some patchy calcite, and a calcite vein 0.4mm thick crosses the slide. [Longshore]

Locality R-26
Field Loc. 11-4-91-1
Unit-Ah (Bolanos Block)

Latitude 13º 19.63' N
Longitude 144º 39.69' E
Agat Quad., 1968

Description: White, hard, dense biomicrite collected from point about 30 stratigraphic feet above base of section exposed on Agat/Umatac highway about 1/4 mile north of Cetti Bay Overlook. Unit Ah section here rests unconformably (?) on Facpi Fm. basalt (Loc. R-25)

Abundant microfossils are in a micrite matrix. About 5% of the rock is inorganic constituents: fine-grained volcanic clasts with a variety of textures, broken intermediate plagioclase, and clinopyroxene. There are scattered pockets of zeolite that may represent alteration of volcanic clasts, and some clasts are altered to chlorite. [Longshore]

Locality R-27
Field Loc. 11-8-91-1
Unit-Maemong Limestone Member (Umatac Fm.) (Bolanos Block)

Latitude 13º 20.18' N
Longitude144º 39.10' E
Agat Quad., 1968

Description: Hard, grey, dense, thin-bedded fossiliferous micrite at top of Maemong section (Loc. F-30) forming major cliff-forming outcrop (elev. 880 ft.) about 1,000 ft. northeast of Agat/Umatac highway, above headwaters of Asmafines River.

Micrite with scattered calcareous and siliceous fossil fragments. The majority of the rock is very fine-grained lime mud (micrite); calcareous microfossils and some sponge spicules are sparse in most of the rock. Some layers, generally less than 2mm thick, are rich in fossils. Fresh plagioclase and clinopyroxene grains and fine-grained lithic clasts (altered to chlorite) are rare; grains are <0.2mm diameter. [Longshore].

NOTES

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PLATE A:

GEOLOGIC MAP OF CENTRAL AND SOUTHWEST GUAM

Plate A

SOPAC TECHNICAL REPORT #353

GEOLOGY AND STRATIGRAPHY OF CENTRAL AND SOUTHWEST GUAM: An Eocene / Oligocene Volcanic Arc

With special emphasis on the Alutom Formation

Frank H. Kilmer
University of Guam 1986 - 1991

May 2003

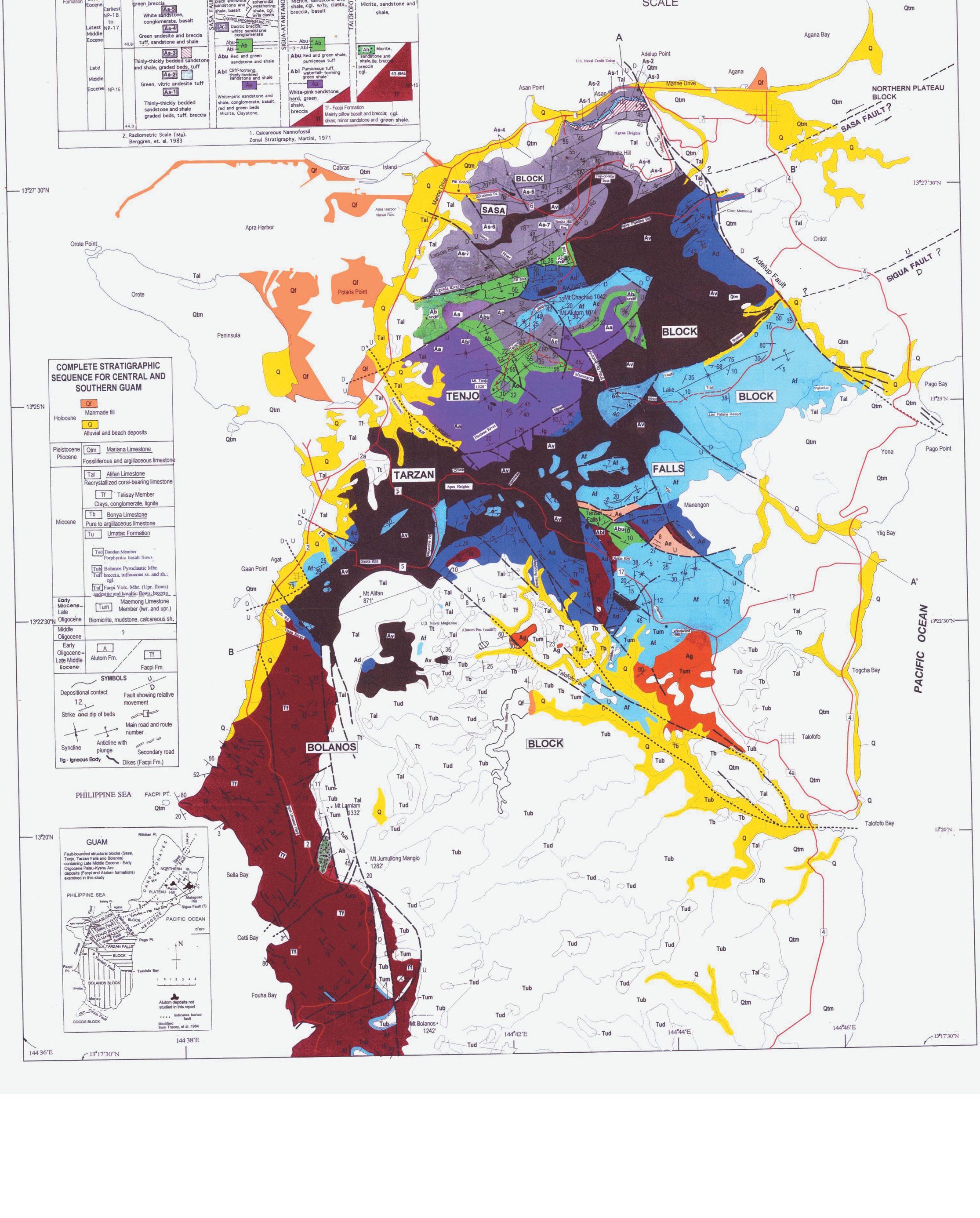
0 1 2 miles
SCALE

Stratigraphy of the Alutom Formation

Rock Unit	AGE	1 Ma 2	SASA BLOCK	TENJO BLOCK	TARZAN FALLS BLOCK	BOLANOS BLOCK
Mahaic Member Ag	Early Oligo	NP21-23 32.0 / 34.0	As-7 Biomicrite, sandstone siltstone, shale; cgl. w/ls. clasts, tuff, breccia	Af Micrite, white sandstone and shale, graded beds, breccia	Ag Tuffaceous calcareous shale; Af Micrite, sandstone and shale, cgl. w/s. clasts, tuff, breccia; Ae Micrite, white sandstone green shale, breccia	Af Breccia, sandstone and shale, cgl./w clasts, limestone
Alutom Formation	Late Eocene	NP-20	Av Green pillow andesite Sandstone and shale, breccia	Av Pillow andesite, sandstone and shale, breccia	Av Green, pillow andesite, sandstone and shale, breccia and conglomerate	Av Breccia, sandstone and shale
	Early Late Eocene	NP-18 37.0	As-6 Sandstone, shale, conglomerate green breccia	Ad(N) Radiolarian shale, black and white sandstone and shale, basalt; Ad Micrite and spheroidal weathering shale, cgl. w/ls clasts	Ad Micrite, sandstone and shale, cgl. w/ls. clasts, breccia, basalt	Ad Micrite, sandstone and shale,
	Latest Middle Eocene	Earliest NP-18 to NP-17	As-5 White sandstone, conglomerate, basalt; As-4 Green andesite and breccia tuff, sandstone and shale	Contact concealed/Unc.(?); Ac Dacitic breccia, white sandstone conglomerate	Abu Ab Abl	Ah Micrite, sandstone and shale,ite, breccia breccia cgl. 43.8Ma NP-16
	Late Middle Eocene	NP-16 40.6	As-3 Thinly-thickly bedded sandstone and shale, graded beds, tuff; As-2 Green, vitric andesite tuff; As-1 Thinly-thickly bedded sandstone and shale graded beds, tuff, breccia	Abu Red and green sandstone and shale; Abl Cliff-forming, thinly-bedded sandstone and shale; Aa White-pink sandstone and shale, conglomerate, basalt, red and green beds Micrite, Claystone,	Abu Red and green shale, pumiceous tuff; Abl Pumiceous tuff, waterfall- forming green shale; Aa White-pink sandstone hard, green shale, breccia	Tf - Facpi Formation Mainly pillow basalt and breccia; cgl. dikes; minor sandstone and green shale.
		44.0				

SASA FAULT; SIGUA-ATANANO FAULT SYSTEM; TALOFOFO FAULT ZONE

2. Radiometric Scale (Ma). Berggren, et. al. 1983
1. Calcareous Nannofossil Zonal Stratigraphy, Martini, 1971



COMPLETE STRATIGRAPHIC SEQUENCE FOR CENTRAL AND SOUTHERN GUAM

Holocene	Qf	Manmade fill
	Q	Alluvial and beach deposits
Pleistocene Pliocene	Qtm	Mariana Limestone: Fossiliferous and argillaceous limestone
Miocene	Tal	Alifan Limestone: Recrystallized coral-bearing limestone
	Tf	Talisay Member: Clays, conglomerate, lignite
	Tb	Bonya Limestone: Pure to argillaceous limestone
	Tu	Umatac Formation
	Tud	Dandan Member: Porphyritic basalt flows
	Tub	Bolanos Pyroclastic Mbr. Tuff breccia, tuffaceous ss. and sh.; cgl.
	Tuf	Facpi Volc. Mbr. (Upr. flows) andesitic and basaltic flows; breccia
Early Miocene–Late Oligocene	Tum	Maemong Limestone Member (lwr. and upr.): Biomicrite, mudstone, calcareous sh.
Middle Oligocene		?
Early Oligocene–Late Middle Eocene	A	Alutom Fm.
	Tf	Facpi Fm.

SYMBOLS

Depositional contact; Fault showing relative movement (U D); Strike and dip of beds (12); Main road and route number; Syncline; Anticline with plunge; Secondary road; Ig - igneous Body; Dikes (Facpi Fm.)

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PLATE B:

DETAILED STRATIGRAPHY OF THE ALUTOM FORMATION

DETAILED STRATIGRAPHY OF THE ALUTOM FORMATION

Plate B SOPAC TECHNICAL REPORT #353

Frank H. Kilmer

May 2003

Stratigraphic sequence adapted from (1) Tracey, Jr. et al. (1964), (2) Tayama, R. (1952), and (3) Reagan and Meijer (1984), except as noted

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PLATE C:

GEOLOGIC SECTIONS A – A' & B – B'

Plate C

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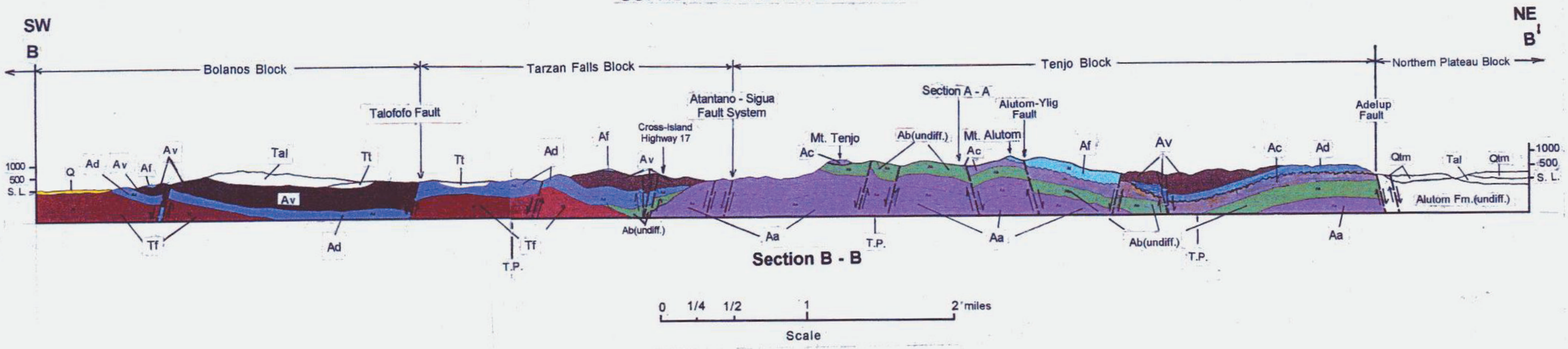

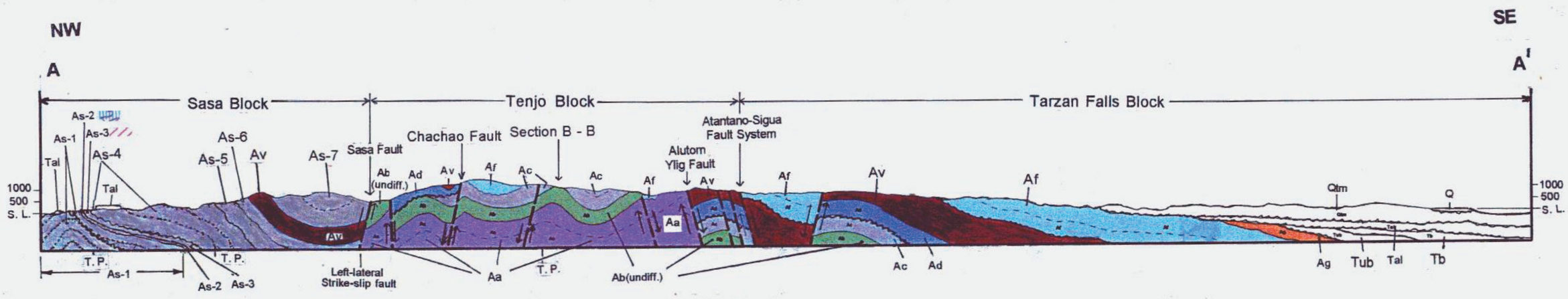

T.P. = Section turning point

See Plate A (Geologic Map) for names of formations

Frank H. Kilmer

May 2003