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EFFECTS OF TYPHOON PAMELA ON THE CORAL REEFS OF GUAM

Richard H. Randall and Lucius G. Eldredge
The Marine Laboratory
University of Guam
P. O. Box EK
Agana, Guam 96910

ABSTRACT

Guam, the southernmost island of the Mariana Islands, is likely to encounter a significant typhoon every seven years. During the last thirty years two typhoons have passed directly over Guam--Karen (11 November 1962) and Pamela (21 May 1976). Pamela had maximum winds of 120 kt (145 estimated), minimum sea level pressure of 930 mb, a speed of movement at 7 kt, a diameter of 20 nautical miles, and 33 inches of rainfall during the typhoon passage. The typhoon had its greatest effect along the shoreline where erosion removed many bands of beach deposits and where shoreline vegetation was defoliated. Relatively little damage occurred along the adjacent reef-flat platforms and reef margins. Some unconsolidated materials were shifted. The growing tips of some foliaceous corals fragmented. On the reef front a number of corals were overturned by the storm waves.

KEY WORDS: Typhoon, Coral Reef, Guam.

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RICHARD H. RANDALL AND LUCIUS G. ELDREDGE

Introduction

Guam, as the southermost island in the Mariana Islands, is likely to encounter a significant typhoon every seven years based on historical evidence from 1948 to 1975 (1). The island lies within the development zone for typhoons (> 64 kt), tropical storms (34-63 kt), and tropical depressions (> 34 kt). During this 28-year period, seventy cyclones of at least tropical-storm strength have passed within 180 nautical miles of Guam. The majority of the storms originate east of 150 E and south of 15 N in the Truk-Kwajalein area.

A total of twenty-eight cyclones have seriously affected Guam. Three very strong storms have passed over Guam since 1900. Although not as well documented as the others, the first one was in November 1900 with estimated winds exceeding 140 kt (160 mph) with gusts over 175 kt (205 mph). During the last thirty years only two storms have passed directly over Guam--Karen (11 November 1962) and Pamela (21 May 1976).

During the early formative stages, typhoon Pamela began as a weak cyclonic circulation center first noticed on 13 May about 230 miles NE of Truk. A tropical depression warning was issued on 14 May. The disturbance was upgraded to a tropical storm on 15 May and located 75 miles northwest of Truk where it began tracking on a southerly loop around the island. The storm had typhoon strength (70 kts) by 16 May and passed close to Truk, causing considerable damage on 18 May. The typhoon continued to move northwest, crossing its original path, and headed toward Guam at 7 kt forward speed and with winds at 130 kt (150 mph) with gusts to 160 kt (185 mph). The eye passed over Yona, Guam, at the center of the island on the afternoon of 21 May. Surf on the eastern and southern shores was very high and broke seaward of the reef margin and again at the shoreline from large translatory waves passing over the reef-flat platforms. Because of the northwest track of the typhoon across the island, greatest damage was inflicted on the southern and eastern shores and reefs. The southern coastal areas in particular sustained greater damage than any other.

Data compiled by Fleet Weather Central/ Joint Typhoon Warning Center Guam, for typhoon Pamela as it passed over the island reported maximum winds at 120-145 kt (estimated), minimum sea level pressure at 930 mb, speed of movement at 7 kt in a northwest direction, diameter of the eye at 20 nautical miles, and 33 inches of rainfall during the typhoon's passage (27 inches max. during a 24 hr. period).

Few studies have been carried out on the effects of typhoons on reefs. Banner (2) described the effect of typhoon Ophelia on atoll reefs at Jaluit, Marshall Islands, and McKee (3) examined the sediments following the same storm. Emery (4) briefly outlined the effects of three typhoons--Allyn (1949), Hester (1952), and Nina (1953)--at Guam. The most recent typhoon study describes the tropical cyclones affecting Guam, outlines the tracks of the major ones, but does not give environmental aspects of the storms (1). British Honduras reefs have been surveyed following hurricane Hattie in 1961 (5,6).

Typhoon Effects Along the Shoreline

Typhoon effects along any one part of the coastal area varied considerably because of the direction of the typhoon track across the island, local differences in shoreline orientation, absence or presence of adjacent fringing or barrier reefs, and shoreline composition and topography. Least disturbance was found along rocky shores and those protected by barrier reefs, whereas the greatest changes occurred where unconsolidated deposits make up or veneer the coastal region.

Of the rocky shorelines bordered by fringing reef platforms the low raised limestone terraces 2.0 m or less in height sustained the greatest damage, those at increased elevations showed correspondingly moderate to mild damage, and the high cliffs and headlands revealed only slight or localized damaged. The upper surface of the low terraces consist of an irregular jagged and pinnacled topography produced mostly by solution and phytokarst erosion. Depending upon the degree of salt-spray exposure, the seaward part of the terrace, consisting of a zone 2-15 m wide, is somewhat grooved and abraded by wave erosion, and is barren of conspicuous vegetation, although the outer millimeter of rock is penetrated by various species of filamentous algae giving it a dark grey color. The inner terrace zone is generally covered by a low (< 1.0 m) prostrate growth of Pemphis acidula and scattered sedges, 2-20 m wide, grading into a region of more pronounced and diverse strand vegetation, a narrow band of beach deposits, or steep rocky slopes and cliffs.

The most conspicuous effect of the typhoon on these low terraces was the complete defoliation and removal of the upper two-thirds of the Pemphis acidula growth, leaving the twisted and gnarled branch stumps and rootstocks protruding from the bare limestone. Coarse gravel and coral-algal rubble carried by waves from the adjacent reef-flat platforms was abundantly trapped in holes, depressions, and protruding Pemphis branches at some locations (Figs. 1 and 2). Where beach and strand vegetation development occurred immediately landward of the low terraces, the deposits were severely cut and vegetation undermined and washed away at many locations while at other places the vegetation was partly buried by fresh deposits from the adjacent reef-flat platform (Fig. 2). From a distance the barren outer part of the terraces appeared to be little affected, but closer inspection revealed that considerable erosion had taken place in the removal of numerous (up to 100/m^2) small protruding pinnacles 1-4 cm high (Fig. 1), occasional hydraulic plucking of larger masses of rock up to a meter in diameter and 30 cm thick (Fig. 3), and the scouring by sediments of the outer grooves and pinnacles.

Higher limestone terraces bordering the shore generally lack associated beach deposits and support a taller and more diverse growth of vegetation than the lower terraces. Even so, those up to 15 meters above sea level showed evidence of inundation by waves in the form of erosion or deposition of deposits on the eastern and southern shores.

About one-fourth of the shoreline along Guam's coast is bordered by narrow cut bench platforms, 3-50 m wide, which are actively being cut into the adjacent rocky shores. The upper bench surface is generally slightly higher than mean high-tide level, depending upon the normal degree of wave assault encountered, and consists of a raised outer zone of rimmed terrace pools and an inner zone which forms a shallow depressed moat of water along the rocky shoreline. The steep to vertical seaward face of the bench platforms are irregularly cut by narrow cracks and open channels, locally undercut, and irregularly indented where large sections have been removed by slumping or wave erosion. Fringing reef development is lacking along these benches, and the seaward slopes are quite steep to depths of 20-50 m. Fleshy benthic and articulated calcareous algae dominates the upper bench surfaces, the bench face, and a mixture of calcareous algae and scattered corals veneers the lower seaward slopes.

Typhoon effects along the rocky shores bordering cut benchs were most evident in the stripping away of vegetation on raised terrace platforms and cliff faces up to 15 meters above sea level and severe damage to vegetation from salt spray at higher elevations. Mass slumping of 1-5 meter wide sections of the cliff face was also commonly observed and an occasional large slump was encountered at several locations as shown in Figure 4. A terrace 6-8 m above mean sea level along the northeast coast was completely stripped of vegetation, except for a tangle of basal branch stumps and rootstocks, for a distance of 100 meters inland where it abutted against a steep limestone slope (Fig. 5). At the same terrace, fresh pieces of coral, calcareous algae, and rubble eroded from the seaward margin of the bordering cut-bench platform, were transported upward over a vertical cliff face at the shoreline and across the 100 meter wide platform to the base of the steep slope. Terrace deposits at this height above sea level and distance from the shoreline could be interpreted as contemporaneous with the terrace itself and lead to eroneous age determinations, if dated. Freshly killed pieces of coral up to 10 kilograms or more in weight were found tossed upon the surface of a terrace ten meters above sea level along a narrow cut-bench platform at the southern end of the island. At Pago Point on the east side of the island a large angular block about 4 m in diameter was wedged out of the cliff face and bounced along a narrow cut-bench platform for 200 meters before coming to rest. Erosion of small protruding projections from the face of bare solution pitted and pinnacled limestone cliff faces was commonly observed, similar to that described for the low terrace shown in Figure 1.

Almost all the beaches were significantly altered by wave erosion, particularly those along the eastern and southern coasts. Where low terraces border the coast large amounts of beach deposits were carried inland, in some instances over 100 meters. Highway 4 along the southern coast was locally covered with beach deposits up to 30 cm thick. At places these deposits were located 100 m or more from the shoreline and had been transported across terrain densely populated with strand and coconut vegetation. At numerous locations along the rocky southern and eastern coasts narrow bands of intermittent beach deposits, a meter or more in thickness were completely removed, exposing bare scoured bedrock (Fig. 6). Previously buried limestone terraces and cut bench platforms up to 2 m high were exposed at many places by wave erosion along low coastal beach terraces.

Typhoon Effects on the Reefs

Considering the rather significant effect of the typhoon on the coastal shoreline regions it was surprising to find relatively little damage along the adjacent reef-flat platform and reef margin zones. During normal conditions tradewind waves and swell build up and break into rolling surf in the reef margin zone but with the increased height of typhoon generated waves they break farther seaward in deeper water over the reef front and adjacent shallow submarine terraces.

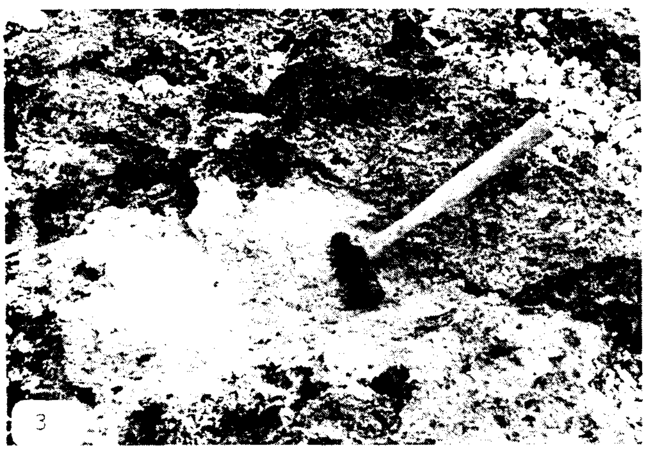
Principal typhoon damage on the reef-flat platforms consisted of minor redistribution of unconsolidated deposits and the addition in local areas of new deposits principally composed of fresh broken coral derived from the reef margin and reef front zones (Fig. 7). Smaller sized sediments, such as sand and gravel, were found to be more stable than larger rubble and boulders. Many parts of the inner reef-flat platforms along eastern, southern, and western coasts support seagrass beds which normally tend to trap and accumulate considerable amounts of sand and gravel sized sediments around their root structures. Little evidence of erosion was indicated by the lack of exposed roots and rhizomes. Intact benthic algae such as Halimeda and Avranvillea which grow and anchor themselves by large holdfasts in habitats of unconsolidated reef deposits also showed little evidence of erosion of sand-sized sediments in other regions lacking extensive seagrass beds. Scattered rubble and boulders in these same sand-gravel seagrass habitats, though, usually showed evidence of being moved about, many of which were left in an overturned position exposing the normally shaded and submerged communities attached on the underside to bright sunlight and low tide exposure. Much of the foul air noticed on the reefs several days after the typhoon was caused by the decomposition of these benthic communities exposed on overturned rocks. A few weeks after the typhoon these overturned rock surfaces were more conspicuously evident because of recolonization by green-colored algae. A striking example of the stability of inner reef flat sand deposits compared to large boulders was found on the reef flat between Inarajan and Agfayen Bays where a large reef block 1.3 x 0.5 x 0.5 meters was rolled shoreward across a sand and seagrass bed for 50 or more meters leaving a gouged out trail in the seagrass bed which was the only evidence of its disturbance.

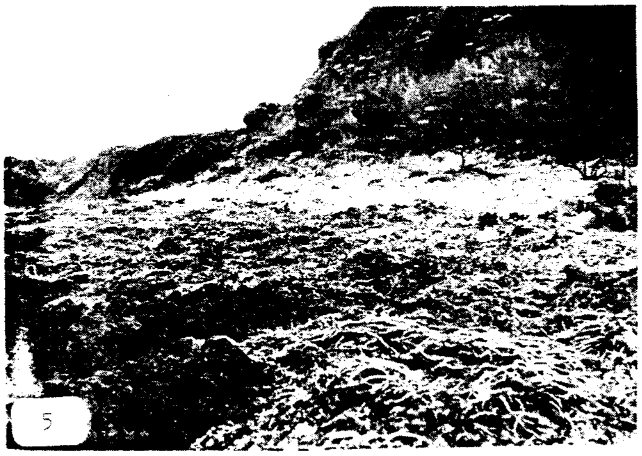
Although corals are poorly distributed on eastern and southern reef-flat platforms, the few local areas where rich development is present were not significantly damaged by the typhoon. The only damage observed was in the form of fragmentation of branching and foliaceous growth forms by the local movement of boulders and rubble. Similar observations to a smaller extent were found on the western and northern reefs where more extensive reef flat coral development is found. Foliaceous colonies of Psammocora contigua, Pavona decusata, Pavona divaricata, finely branched clumps of Pocillopora damicornis and Porites cocosensis were more commonly fragmented with the larger more stoutly branched arborescent (staghorn) growth forms of Acropora less frequently fragmented. Storm and typhoon waves are effective in promoting colonization of unstable sandy substrates by transporting fragments of living corals there which have a greater chance of survival because of their larger size than small newly settled planula which are more easily covered by shifting sediments. Large corals with massive growth forms were seldom damaged, especially if firmly cemented to the reef surface. The few overturned coral colonies observed were generally found to be poorly attached or growing loose on an unconsolidated deposit (Fig. 8).

The most recently deposited limestone on Guam (Merizo Limestone) forms local raised patches up to 1.8 m high on the present reef-flat platforms and along the shoreline. Some of these low deposits are solution sculptured and at places consist of isolated mushroom-shaped pinnacles a meter or so wide at the top and considerably less at the base, sometimes just a few centimeters. Our observations revealed that only one of these pinnacled remnants was toppled by the storm. It is suspected that some of the large reef blocks up to a meter or more in diameter, which are commonly scattered over the reef-flat platforms, are derived from these remnant limestone patches instead of being eroded from the reef margin and transported there by storm waves. An inspection of all the reef-flat platforms around the island revealed that only six new reef blocks, a meter or more in diameter, were eroded from the reef margin or reef front and transported up onto the reef flat during typhoon Pamela. Because of their projecting relief, waves passing over the reef flat were able to dislodge reef blocks of considerable size if they were not secondarily cemented in place by encrusting algae (Fig. 9).

On the forereef slopes typhoon effects were minimal in the reef margin zone itself, except for the breaking of numerous branches on many ramose corals, the removal of intact corals and ledges at some places which overhang surge channel walls, and the scouring and abrasion of the outer ends of surge channel walls and floors by the back-and-forth movement of typhoon waves and boulders, rubble, and sand. Major structural damage to the reef margin framework was confined to the toppling of a few isolated pillars and irregular projections of coral-algal growth. No damage to the fundmental structure of the reef margin framework was found at any location as was described by Stoddart (5,6) where entire buttresses were at places stripped away by storm waves.

Typhoon damage was more intense and widespread on the deeper forereef slope zones with more fragmentation of coral branches (Fig. 10), breaking loose of entire coral colonies (Fig. 11), and some minor damage to the structural framework in the form of slumping and toppling of large coral colonies and coral-algal knobs and pinnacles. Branches were snapped off from large stoutly developed coral colonies to depths of 20 meters (Fig. 12). Much of the fragmentation and damage to coral colonies was induced by large massive colonies breaking loose and rolling around as shown in Figure 11. At several locations individual coral colonies were found with broken branches at depths to 30 m (7).





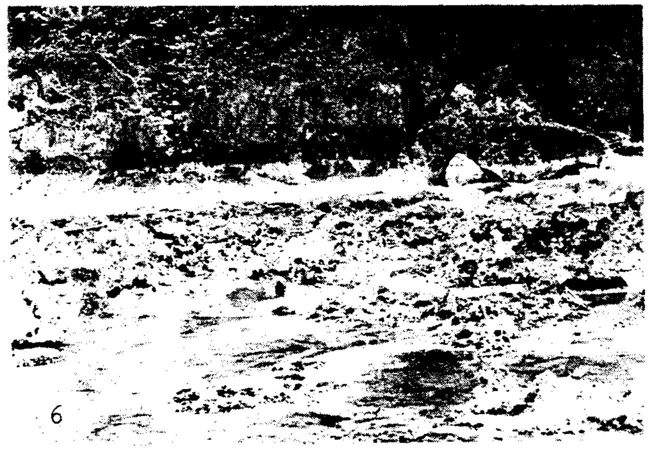


Figure 1. Low pinnacled limestone terrace along the southern coast showing erosion of numerous small projections (white areas) along the barren outer part and the remains of low Pemphis acidula scrub which has trapped fresh rubble from the adjacent reef on the inner part.

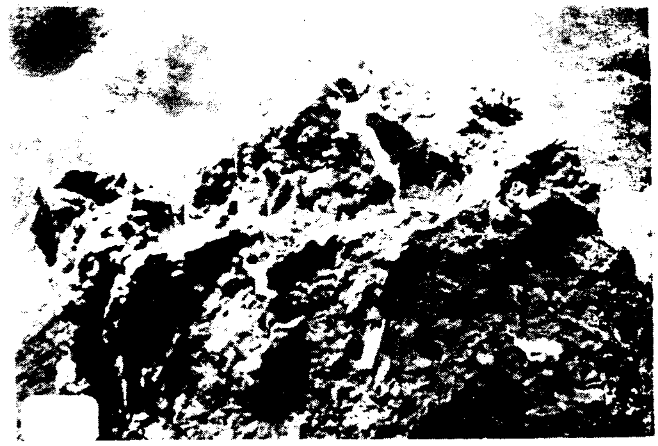
Figure 2. Southern shoreline showing new growth of Pemphis acidula on a low limestone terrace at the left and the nearly complete removal of the strand vegetation and deposition of new rubble deposits on the right.

Figure 3. Hydraulic plucking of limestone from a low terrace along the southern coast.

Figure 4. Slumping of cliff face along the northeast coast; largest blocks are 8-10 m in diameter.

Figure 5. Limestone terrace 6-8 meters above mean sea level and 100 m wide which has been mostly stripped of vegetation along the northeast coast.

Figure 6. Shoreline along the east coast after a narrow band of beach deposits over a meter in thickness and 10-20 meters wide was removed by wave erosion.



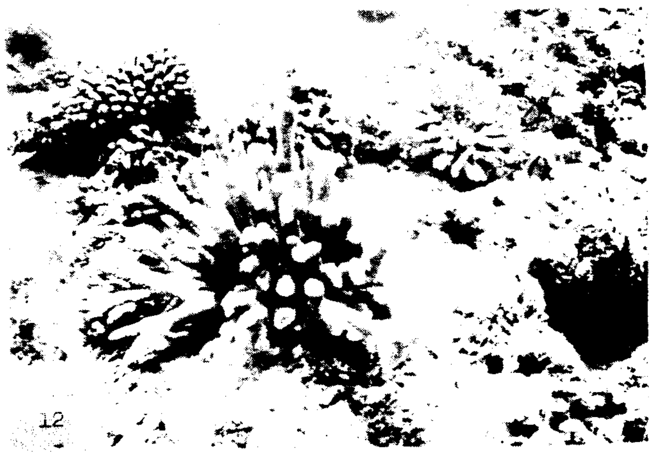


Figure 7. Fresh coral fragments deposited on the outer reef-flat platform along the southern coast.
Figure 8. Colonies of Porites cocosensis overturned by waves on a shallow sand and rubble-floored lagoon shelf at the southern end of the island (depth about 1.5 m).
Figure 9. Large reef block overturned by waves on the western side of the island.
Figure 10. Millepora platyphylla colony (0.7 m across) in position of growth on the reef front (5 m depth) with thick projecting plates broken off by typhoon waves.
Figure 11. Massive Porites lutea colony (.7 m diameter) broken loose from the reef front (depth about 5 m).
Figure 12. Pocillopora eydouxi colonies (largest 0.5 m diameter) in position of growth on a submarine terrace (depth about 12 m) showing branches broken off by typhoon waves.

Discussion and Summary

The region of breaking waves is located at the seaward edge of the reef-flat platform in the margin zone when normal tradewinds are blowing and is apparently well adjusted to this rather constant water agitation, breaking waves, and surf from low to moderate waves and swell. During tropical storms and typhoons associated waves are considerably higher and the zone of breaking waves is shifted seaward into deeper water of the reef front or submarine terrace zones depending upon the wave magnitude and bottom characteristics. This seaward shift of wave energy dissipation results in little damage to the structural integrity of the reef margin channel and buttress system. Damage here is mostly confined to the outer part of the reef margin by fragmentation of branching corals on the upper buttress surfaces and local removal of coral-algal growth which shelves outward over the upper margin of the surge channels. The inner shoreward part of the reef margin suffered practically no structural damage and fragile branching corals such as Acropora variabilis growing on surge channel walls and floors and in open pools were for the most part not damaged. Structural damage and coral fragmentation on the reef margin was overall less intense where surge channel and buttress systems were well developed. Apparently surge channel and buttress topography acts as a more effective baffle in dissipating wave energy with less structural reef damage and coral fragmentation than the relatively smoother topographic relief where such development is lacking at the reef margin. A direct correlation was found between reef margin and reef front zones where poor channel and buttress development occurred or was lacking and the accumulation of freshly fragmented coral branches transported upon the adjacent reef flat platform.

With a corresponding seaward shift of wave energy dissipation during typhoons, the deeper but somewhat less adjusted reef front and shallow adjacent submarine terraces becomes the principal locus of structural reef damage and coral fragmentation. Coral colonies in these zones are somewhat larger and the topographic relief somewhat more irregular in the form of coral-algal knobs and pinnacles which expose a considerably greater surface area to the infrequent typhoon waves. Scouring and abrasion, both in the reef margin and reef front zones, are effective in maintaining the surge channels. Intervening coral-algal growth between these surge channels form the massive wave resistant structures which give rise to the conspicuous buttress-and-channel systems often described.

In conclusion it appears that the reefs of Guam are well adjusted to unpredictable storm waves generated by typhoons. Other than superficial damage to the veneer of living corals and algae, structural damage to the fundamental reef framework is minimal.

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