

UNDERWATER DEMOLITION TEAMS AND THE GEOMORPHOLOGICAL AND
ECOLOGICAL EFFECTS OF A WORLD WAR II AMPHIBIOUS LANDING ON A CORAL
REEF IN THE PACIFIC

By

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ABSTRACT

Human conflict can alter the geomorphological characteristics of landscape. These traces of war are cultural heritage, and in some cases, may be the last physical manifestations of war. As such, they can offer important insights into human actions and their consequences. In a bitterly contested action during World War II, United States Marines landed on the western beaches of Peleliu on 15 September 1944. The violence associated with this landing altered reef geomorphology. Explosions from artillery shells, mines, and bombs, all contributed to changing the offshore reef structure. In particular, Underwater Demolition Teams used explosives on the reef's edge to remove obstacles for landing craft. Traces of this Underwater Demolition Teams activity may still be evident in the form of craters on the reef.

Archaeogeomorphology is the field of study concerned with anthropogenic changes to landscape. Anthropogenic changes in geomorphology may disturb the ecology of a coral reef by

altering environmental conditions, which in turn affect coral species composition. Through a comparison of disturbed and non-disturbed areas, this thesis examines the archaeogeomorphological and ecological effects of a World War II amphibious invasion on the coral reefs of Peleliu in the Republic of Palau. Additionally, ecological effects are placed within a warfare ecology framework. Finally, this thesis provides a historical analysis of Underwater Demolition Teams, with a particular focus on their actions at Peleliu within the context of a Key terrain, Observation and Fields of fire, Cover and concealment, Obstacles, and Avenues of approach and withdrawal analysis (KOCOA).

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To Susan, Jonah, and Luka

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I took scientific diving as a biology graduate student in the spring semester of 2000. And I remember discovering that I was immersed in a sea of maritime archaeology students taking the class with me... “You study shipwrecks? WHAT? I didn’t know this field existed!” What an amazing discovery!

Of course, at the time I had no idea what a huge part the Maritime Studies Program would play in my life... I’ve had the distinct pleasure of supervising diving in some 32 field schools and helping to train more than 300 scientific divers – the vast majority Maritimers. It has been an amazing journey - every class of grad students is full of incredible people, and it has been an honor to work with them and to get to know them. In short, the faculty, staff, and students of the Program have absolutely enriched my life, and with this degree, I’ll be joining them - which means the world to me.

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Chapter 1. Introduction

Human conflicts can leave geomorphological traces on the landscape, and these traces are cultural heritage (De Matos-Machado et al. 2015). Geomorphological alterations to the landscape caused by conflict, or preparation for conflict, are manifest in a variety of forms. People construct features for defense, such as bunkers, trenches, and earthworks. Explosives such as bombs, artillery, and mines leave craters in the landscape (Hesse 2014:13-16). Roads are constructed for the movement of military forces, and vehicles leave tracks in different environments (Gilewitch 2003:128, 136-137). These remnants of conflict have been characterized as the last witnesses of war, and along with architectural heritage, monuments, and cemeteries, should be considered in research and in the implementation of cultural heritage policy (Gehyle et al. 2018:55, 63).

In September 1944, as part of “Operation Stalemate II,” the United States (U.S.) conducted an amphibious landing against Japanese forces on the island of Peleliu in Palau. The invasion of Peleliu was thought necessary to secure the eastern flank of U.S. forces for the invasion of the Philippines, and indeed, nine days after the assault phase of the landing on Peleliu ended, General Douglas MacArthur invaded Leyte in the Philippines (Hough 1950:1).

Amphibious military operations consist of the shipboard movement of troops across water and the subsequent landing of those troops on a shore (Alexander 1997:xi). U.S. forces conducted hundreds of such operations in the Pacific region during World War II (Alexander 1997:5). Often — particularly in the Central Pacific — these landings were undertaken in areas that were heavily fortified. Land masses there tended to be small, and suitable sites for landings were limited. Tactical surprise was thus nearly impossible to achieve, and amphibious attacks

very often had to be performed against prepared defenses (Heinl 1983:191; Alexander 1997:4). The landing on Peleliu was conducted against such prepared defenses and it was a violent and bloody affair.

The violence associated with the landing at Peleliu changed reef geomorphology (Colin 2009:372; Browne 2016:58). The invasion beaches at Peleliu were heavily mined by Japanese forces, and although many mines were deployed incorrectly and failed to explode, others succeeded in destroying amphibious vehicles and killing troops (Alexander 1997:114; Moran and Rottman 2004:40). Additionally, Japanese defenders deployed hundreds of obstacles in the water along the beachfront in the form of range markers, steel tripods, and wooden posts (Burke 1944c:1). U.S. Navy Underwater Demolition Teams (UDT) used explosives to remove these obstacles in key locations (Burke 1944c:1; Logsdon 1944:1). The geomorphological structure of the reef itself helped determine how the battle was fought. The fringing reef around Peleliu prevented large vessels from approaching the beach – only tracked or wheeled vehicles could cross due to the shallow water depth. Additionally, large boulders were present in some areas. As such, UDT teams used explosives to blast passages for landing craft to cross the reef, as well as to destroy naturally occurring boulders (Logsdon 1944:1). Furthermore, invading U.S. forces were heavily shelled by Japanese artillery and mortars as they moved across the reefs to the beach. At least 26 tracked landing vehicles (LVT) were destroyed by such fire (Gailey 1983:69). More than half of the 30 Sherman tanks sent ashore were hit by shells before reaching the beach – although only three were put out of commission (Hough 1950:37). Finally, some 48 fighter-bombers conducted a continuous attack on the beach areas until U.S. troops landed (Gailey 1983:68). It is conceivable that some of their ordinance hit reef rather than Japanese targets.

Other potential causes of reef geomorphological change were landing vehicles and tanks that came ashore during the battle. Some 223 LVTs, 72 LVT(A)s (armored tracked landing vehicles armed with a turret mounted cannon), and 30 waterproofed M4A2 (Sherman) medium tanks crossed the reef and landed on the beaches of Peleliu during the assault (Hough 1950:31; Alexander 1997:138; Moran and Rottman 2004:30). All these vehicles crossed the outer reef on their way toward the beach. Many made multiple trips across the reef as they transited back and forth carrying Marines. LVTs can float and move through the water, but likely contacted reef in shallow areas. Unlike LVTs, the M4A2 tanks did not float and instead came ashore using a novel technique. Columns of tanks followed a single LVT guide across the reef top. When the LVT began to float, the tanks would stop, then resume movement when the LVT guide found shallow areas where tanks could transit (Gayle 1996:16). Boulders and obstructions on the reef in the southern zone of the invasion area also forced LVTs to move in columns as they approached the beach (Hough 1950:45-46). Any single LVT undoubtedly left tracks of crushed coral behind while columns of tracked vehicles surely left more defined tracks.

Geomorphological changes to reefs can affect coral reef species composition by influencing the structural complexity of coral reefs, and indeed, reef structural complexity is one of the driving forces determining coral reef ecosystem functionality (Burns et al. 2015:2). A study performed on craters from bombing in a coral reef system in Puerto Rico determined that loose coral substrate resulting from the pulverization of coral during explosions precluded corals from naturally recolonizing the craters. Fish community structure also appeared to be negatively affected by changes to benthic community structure and spatial heterogeneity brought about by bombing (Hernandez-Delgado et al. 2014:195). These effects are local, but depending on the density of reef craters, could have significant impacts to the overall health of a reef.

Although the landings on Peleliu occurred more than seventy years ago, their geomorphological and ecological effects may still be present. This thesis examines potential geomorphological and ecological effects of the World War II invasion of Peleliu on the island's coral reefs. The reefs occupying the main Marine landing area on the western side of Peleliu were surveyed, and areas of disturbed reef were documented using photogrammetry, global positioning systems (GPS), and analyzed using geographic information systems (GIS). Researchers from the University of Hawaii used this information to compare coral species diversity in disturbed and undisturbed areas, and their results are incorporated into this thesis. Additionally, researchers from non-profit organization Ships of Exploration and Discovery Research, Inc. (Ships of Discovery) produced a Key terrain, Observation and Fields of fire, Cover and concealment, Obstacles, and Avenues of approach and withdrawal analysis (KOCOA) as part of a grant funded archaeological survey examining the Peleliu invasion beaches. That KOCOA analysis are built upon in this thesis to gain a better understanding of the activities of UDTs, and the routes used by Marines to navigate the reef and other barriers to invasion.

This thesis will involve the integration of several distinct approaches to examining the geomorphological, archaeological, and ecological traces of conflict, and as such, is a transdisciplinary endeavor. Conflict archaeogeomorphology is concerned with changes to topography brought about by conflict, and is a subfield of archaeogeomorphology, a wider field of study focusing on anthropogenic changes to landscape (Hesse 2014:12-13). The examination of the influence of the Peleliu invasion on coral reef geomorphology is conducted under the principles of conflict archaeogeomorphology. Furthermore, conflict archaeogeomorphology is a subfield of conflict archaeology. Conflict archaeology is concerned with the archaeology and interpretation of conflict sites and has recently begun to encompass the archaeology of other sites

that play important roles in conflict including military support facilities, camps, bases, arsenals, and logistic support processes (Scott and McFeaters 2011:104).

Using a KOCOA terrain analysis to interpret human actions on a battlefield falls under the discipline of conflict archaeology has aided in reconstructing historic battlefields and human decision making (Bleed and Scott 2011:48). KOCOA is also intimately related to the geographic setting present at any given battlefield, and as such is a component of military geography.

Military geography is a discipline that considers the interplay between geography and military technology as it relates to the conduct of military operations (Peltier and Percy 1966:18,20).

Finally, warfare ecology seeks to apply ecological theory, methods, and empirical studies to the examination of the ecological impacts of three stages of war: preparations for war (Stage 1), war itself (Stage 2), and postwar activities (Stage 3). Each stage of warfare generates anthropogenic ecological consequences, and as such, warfare ecology treats biophysical and socioeconomic systems as highly coupled (Machlis and Hanson 2008:730). Machlis and Hanson (2008:730) characterize the ecological effects of war as being distinguished by “immense and concentrated energy flows, severe disturbances, habitat destruction,” and “deliberate death (including but not limited to human death).” Postwar conditions include degraded landscapes and ecosystem services (Machlis and Hanson 2008:730). Examining the coral species diversity in disturbed areas of the Peleliu reef in relation to that of undisturbed areas encompasses ecological changes from Stages 2 and 3 of warfare taxonomy.

This thesis synthesizes data gathered using research methods associated with conflict archaeogeomorphology, conflict archaeology, military geography, and warfare ecology. All of these data are incorporated for the creation of an integrated, transdisciplinary interpretation of the Peleliu landing site.

Research Questions

This thesis seeks to answer the following question: What are the geomorphological and ecological effects of the invasion of Peleliu on the coral reef of the invasion beach? Answering this primary question will entail consideration of the following individual questions:

1. How did the activities of UDTs at Peleliu relate to a KOCOA terrain analysis of the Peleliu invasion?
2. Are areas where UDT blasts occurred on the reef discernable from undisturbed areas not subject to blasts?
3. Do the geomorphological characteristics of disturbed areas differ from those of undisturbed areas?
4. Does coral reef species diversity and percentage cover differ between disturbed areas and undisturbed areas?

This study is the first known effort to characterize the effects of UDT explosions on a coral reef and has meaning and significance at both a cultural and ecological level. The activities of UDTs during the invasion of Peleliu created lasting geomorphological and ecological changes to the fringing reef of the island. These are the lingering physical manifestations of the actions American forces took to invade Peleliu and as such, may have value for those interested in how the battle was fought as well as for those interested in the current condition of the coral reef, which has recovered coral diversity since the war. This ecological recovery may be of particular import for Palauans themselves. The marine environment plays an important role in Palauan

culture, identity, and spirituality, as reflected in “the many legends, songs, chants, and oral traditions that have been passed down through generations” (Brugh 2007:55).

This thesis contains 6 chapters. Chapter 1 is an introduction that incorporates background information and questions to be answered by the thesis. Chapter 2 provides historical background including a description of the geography of Peleliu, a narrative history of the Battle of Peleliu, and a history of the evolution of amphibious warfare in the Central Pacific. Chapter 3 provides the disciplinary framework in which the thesis is set including discussions of military geography, conflict archaeogeomorphology, and warfare ecology. This chapter also describes the methods used to determine the geomorphological and biological characteristics of disturbed and undisturbed fringing reef off the invasion beaches as well as those used to conduct historical research. Chapter 4 provides a literature review of UDTs. Chapter 5 includes an analysis of the UDTs active at Peleliu, and a discussion of UDT actions at Peleliu within the context of a KOCOA analysis. This chapter also incorporates the results of the reef characterization, a discussion regarding these results, and places changes in Peleliu reef ecology due to UDT activities into a warfare ecology framework. Chapter 6 provides concluding remarks and suggestions for further research.

Chapter 2. Historical Background

Peleliu is part of the Palau archipelago, which consists of some 100 islands that occupy a land area of approximately 479 square kilometers (km). Palau lies about 965 km to the east of the Philippines, and 965 km due north of New Guinea. The most northerly island in the archipelago, Kayangel Atoll, lies approximately 145 km from the most southerly island of Anguar (Rottman 2001:398). The geological sources of the islands are varied. Some islands are composed of volcanic materials, while others are the products of biogenic activity. Most of the larger islands such as Babeldaob, Arabesang, and part of Koror, are volcanic in origin and are composed of basalt. The Rock Islands are uplifted and considered high limestone islands, while most of Peleliu and Anguar are low limestone platform islands. Two atoll islands are located in the north of the archipelago. Low platform islands, such as Peleliu, are generally flat and typically low in elevation – some 5-15 meters (m) above sea level. Some low platform islands including Peleliu have raised limestone ridges, and may be referred to as compound islands. All the islands in the archipelago rest on a bed of basalt (Colin 2009:2,11).

Barrier reefs are shallow, relatively continuous structures that separate open ocean waters from deep lagoons. They are either exposed, or barely covered by water during low tides. The barrier reef in Palau is quite extensive and runs on the west side of the archipelago southward from the Kayangel Atoll toward Peleliu – a distance of 170 km. The barrier reef becomes an outer fringing reef at Peleliu, and borders the island to the east, south, and west. Like barrier reefs, fringing reefs are also shallow, but they do not enclose deep lagoons. Rather, areas within outer fringing reefs remain shallow (Colin 2009:30-31).

The west side of Peleliu, where the invasion occurred, consists of a narrow shelf with a steep vertical escarpment descending to great depth. These shelves are rocky and exhibit low

coral growth and diversity – 10% coral coverage by 20 different coral species. It is possible that some of this lack of diversity and coverage is related to significant wave activity. Because the edge of the shelf is several meters below the surface and does not cause waves to break, it affords little protection from wave action to narrow shelf areas inshore (Colin 2009:65-66).

Battle of Peleliu Historical Narrative

The situation in the Pacific theater of operations was extremely complicated in the summer of 1944. Multiple operations against Japanese forces were planned by the U.S. Army and Navy. The most significant of these was the invasion of the Philippines by Army forces under General Douglas MacArthur. To secure MacArthur's flanks during that invasion, two assaults were planned; the first was the capture of Morotai by the Army, and the second, the capture of the Palaus in the Western Caroline Islands by the Navy and Marine Corps. The codename for the Palau operation was Operation STALEMATE and it involved securing the entire island group. However, Army forces designated for STALEMATE had been committed to Operation FORAGER in Saipan, and were still engaged there, as the island had taken longer to secure than anticipated. Additionally, it was determined that invading Babeldaob, a large heavily garrisoned island, was potentially unfeasible. For these reasons, plans for STALEMATE were modified, and redubbed STALEMATE II. Under STALEMATE II, Babeldaob would no longer be invaded. Instead, only the islands of Peleliu and Anguar would be targeted in Palau (Gailey 1983:15-17).

Marine leadership assumed that the invasion of Peleliu would be relatively short and swift. They knew that approximately 10,000 Japanese soldiers were on the island but were unaware of the extent of the fortifications and the efficacy of the island's topography for defense.

Japanese forces under Colonel Kunio Nakagawa prepared a multi-layered defense in depth against amphibious invasion, which incorporated both beach defenses and offensive attacks from reinforced positions. This strategy had not been employed previously in the Pacific theater and was unanticipated by U.S. forces. Nakagawa designated one Japanese battalion for this purpose, other battalions were ordered to refrain from forcing a decisive engagement with counterattacks. Instead, they would mount a campaign of endurance resistance – attempting to kill as many U.S. troops as possible. Given this, and the lack of air and naval reinforcements due to earlier U.S. bombing campaigns, Japanese forces constructed elaborate *Fukkaku* positions — that is, underground honeycombed defensive positions resistant to bombardment — where they could shelter and from which they could launch attacks (Alexander 1997:109-110, 114).

Much of southern Peleliu was flat and difficult to defend. However, along the northern edge of the island ran a series of steep limestone ridges and canyons known as the Omleblochol and referred to as Umurbrogol by U.S. forces (Price and Knecht 2012:3). Nakagawa had this area extensively fortified; he summoned mining and tunnel engineers to the island to construct *Fukkaku* positions. More than 500 caves were excavated in this area with alternate exits – some of which were five or six stories deep. Steel doors were constructed at various locations to shelter heavy weapons, and all caves had interlocking fields of fire (Alexander 1997:111). U.S. forces were unaware of the extent of these fortifications prior to invasion.

The 1st Marine Division was charged with the assault on Peleliu. The Army 81st Division was to capture Anguar, and act as a reserve for the 1st Division on Peleliu. Many of the Marines in the 1st Division were veterans of Guadalcanal and Cape Gloucester (Solomon Islands), but neither of those landings were fiercely opposed. The 1st Division consisted of 26,417 men, but no more than 10,000 of these Marines would be engaged in the actual fighting

on Peleliu. The other Marines were in support positions making the ratio of Japanese forces to fighting Marines roughly one to one (Gailey 1983:23).

The landing beaches were located on the southwestern portion of the island, and shielded by a protective shallow reef, which was 700 yards (yds) (300 m) wide in some places. The northern section of the invasion beach was divided and designated White Beaches 1 and 2. The southern section was similarly divided and designated Orange Beaches 1, 2, and 3 (FIGURE 2.1). The 1st Division consisted of three regiments – each tasked with a different objective. All three regiments landed abreast of each other. The 1st Marine Regiment were to land on White Beaches 1 and 2. They drove inland from the beach and then turned north to attack the Umurbrogol. The 5th Marine Regiment landed on Orange Beaches 1 and 2, then moved to the eastern Peleliu beaches – securing an airfield in the process. Capturing this airfield quickly was one of the major objectives of the invasion. The 7th Marine Regiment landed on Orange Beach 3, secured the flank of the 5th Marines, then moved to secure the southern end of the island. It was understood among the commanders of the invasion, that the 1st Marines had the most difficult task to accomplish (Gailey 1983:22).

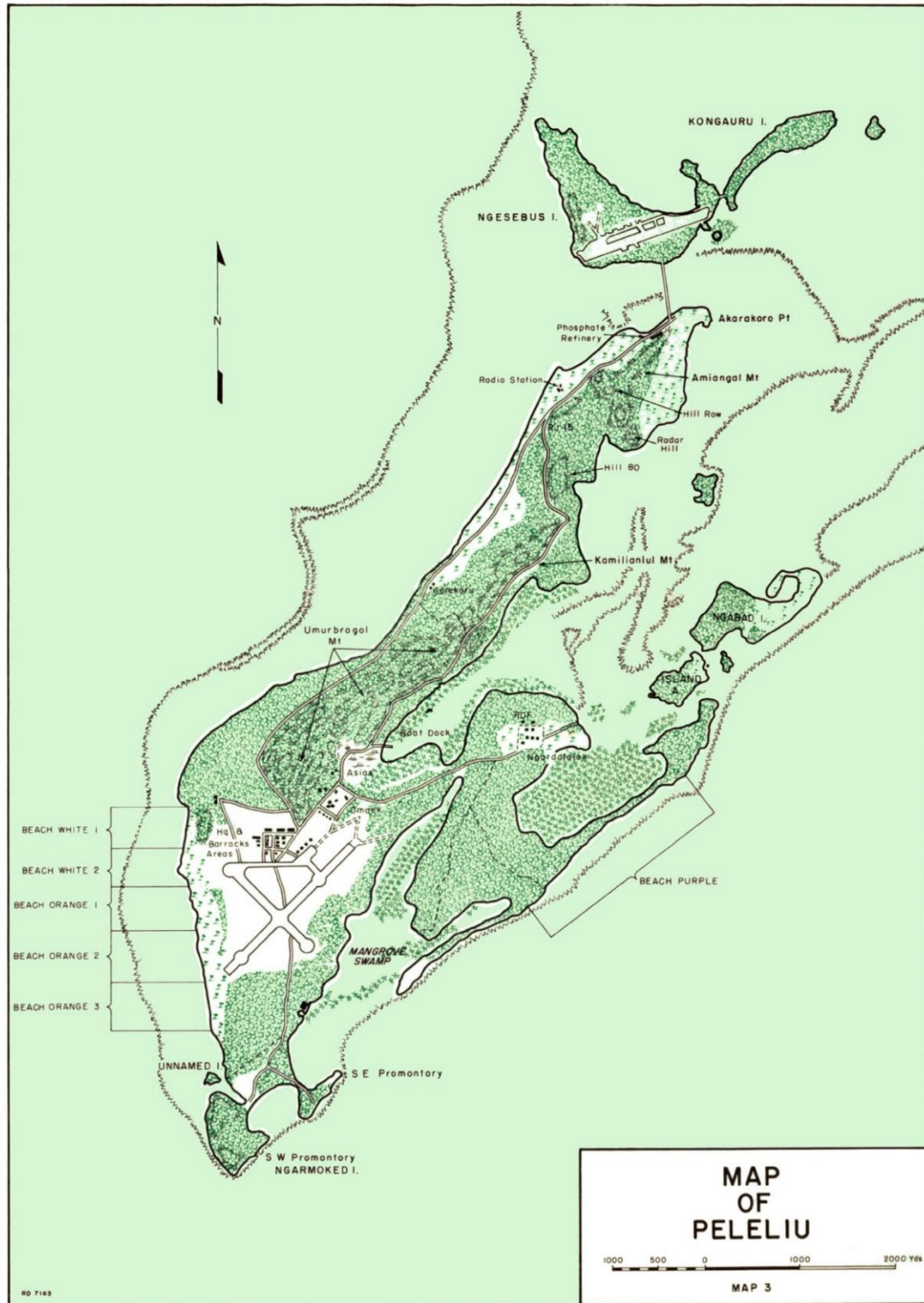


FIGURE 2.1. Map of Peleliu. White and Orange invasion beaches are located on the western side of the island (Hough 1950:13).

D-Day for the invasion itself was scheduled for 15 September 1944. To neutralize opposing forces, the Navy bombarded Peleliu for three days beginning on 12 September. The fire support group designated for Peleliu consisted of three battleships, three heavy cruisers, and nine destroyers. These vessels were tasked with targeting aircraft, the airfield, gun emplacements, and personnel concentrations. Additionally, planes from nearby escort carriers carried out bombing runs on the beaches prior to the invasion. Interestingly, less weight of metal was fired at Peleliu during three days of bombardment than in the three-hour bombardment of Tarawa in the Gilbert Islands (now Kiribati). Various actions in World War II, including Tarawa, demonstrated that disciplined and dug-in forces could survive terrific bombardments. This was the case at Peleliu (Gailey 1983:25-26).

Navy UDTs 6 and 7 were tasked with surveying the invasion beach and using explosives to remove obstacles and blast channels through the reef for landing craft. On the morning of 12 September, under cover fire from various destroyers, swimmers from Team 6 and Team 7 reconnoitered the Orange and White Beaches respectively (FIGURE 2.2). This was during low tide however, and there was not sufficient water over the reefs of the White Beaches to protect the men from snipers and machine guns mounted in pillboxes on the beach. Still, the teams managed to chart the southern two-thirds of the Orange Beaches. They discovered that the approaches to the Orange Beaches were quite rough, and replete with boulders and coral mounds. They also discovered steel tetrahedrons and large coconut log structures — akin to large sawhorses — strung with barbed wire. Rounding out the array of human-made obstacles positioned by the Japanese forces, were wire fences strung on posts and “spiders” —three posts banded together in the middle (Fane and Moore 1996:139-140).



FIGURE 2.2. The destroyer USS *Robinson* (DD-562) provides covering fire support for UDT swimmers clearing beach obstacles off White Beach prior to the Marine Corps landing (Naval History and Heritage Command).

Team 7 found various obstacles positioned off White Beach including rusted tetrahedrons, and a double row of wooden posts some 75 yds (75 m) from the beach. They also noted that rock filled log cribs and concrete cubes were present in the sand above the high-water mark. Additionally, they observed a trench for snipers and an anti-tank ditch in this area. These they left to Marine demolition squads to destroy, as they were far enough from the water's edge to be unassailable without protective armor in the form of tanks or LVT(A)s. Finally, they

determined that deep potholes noted in aerial photographs were actually patches of seaweed, and that the approaches to the White Beaches were generally flat and smooth (Fane and Moore 1996:139).

Team 6 returned to the Orange Beaches early on the morning of 13 September. They blasted two channels through boulders for wheeled landing craft — DUKWs — to pass. Further south on the “drying reef,” they blasted a ramp for tank landing ships (LSTs) and the construction of a pontoon causeway (FIGURE 2.3). Later that night they returned to the beach to blow up a line of tetrahedrons, wire fence, and wooden sawhorses. Finally, on the afternoon of 14 September, they blasted more ramps and boulders. This concluded UDT Team 6’s pre-assault activities (Fane and Moore 1996:140-141).



FIGURE 2.3. UDTs detonate 8,000 lbs. of tetrytol on the reef off Peleliu on September 14, 1944 (Defense Department Photo (Marine Corps) 149522).

The transport ship carrying Team 7 was sent northward in order to tow several boats to a safe anchorage in the Kossol Passage. They did not return until 14 September, but one night was sufficient time for the team to blast obstacles on White Beach. In addition to crawling ashore and attaching explosives to posts loaded with barbed wire, team members positioned tripods with range markers to be used in the next day's invasion. Team 7 performed their last demolition on Peleliu six days after D-Day, when they blasted some 300 yds (300 m) of posts and tetrahedrons off the White Beaches (Fane and Moore 1996:141,143).

On D-Day, a half hour before the assault was set to commence, naval support craft began bombarding the invasion beach from 1,000 yds (1,000 m). The plan was for Marines to approach the beach in successive waves, led first by LVT(A)s, followed one minute later by the first wave of troops carried in LVTs. A second wave of troops followed seven minutes later. Tanks accompanied the fourth wave and successive assault waves included DUKWs. Transports were positioned 16,000 yds (16,000 m) off the beach, and Marines boarded landing craft, vehicle, personnel (LCVPs) from these vessels to be carried to the reefs edge. There they transferred to LVTs, which had been offloaded by LSTs. Carrier aircraft commenced bombing the beaches ahead of the landing. LVTs crossing the reef were immediately brought under heavy fire – particularly from the flanks, but also from heavy artillery in the highlands, and from light artillery and mortars behind the beach. The first Marines reached the beach around 08:30 A.M., and the following waves occurred on schedule. Confusion reigned on the beaches. The first waves simply knew they needed to get off the beaches where they were exposed and seek cover (Gailey 1983:67-73).

One particularly problematic area was a promontory approximately 30 feet (ft) (9 m) high located on the extreme left of the White Beaches. This feature, known as “The Point,” was a

fortified mass of coral seemingly untouched by naval gunfire. It contained numerous pill boxes outfitted with heavy machine guns and 45-mm cannon that poured enfilading fire across the White Beaches. This redoubt had to be neutralized before the Marines could advance. A company of Marines performed a flanking maneuver, and in savage fighting, systematically destroyed each pillbox, and made their way to the top of The Point. The enfilading fire ceased (Hunt 1946; Gailey 1983:74-75).

Marines were able to move relatively quickly off White Beach 2 to the edge of the airfield, where they established a defensive position. Marines from Orange Beach 1 and 2 also made rapid progress to the edge of the airfield, where they set up defensive positions. Many Marines slated for Orange Beach 3, ended up landing on Orange Beach 2 due to heavy fire from their southern flank. A good deal of confusion and determined defense by Japanese forces prevented the Marines who had landed on Orange 3 from securing the southern end of Peleliu by nightfall. Marine artillery landed in the afternoon — so the Marines now had heavy guns as well as tank support. This firepower was used to help stop a major counterattack across the airfield by Japanese tanks and infantry. D-Day ended with the various Marine units having achieved all their objectives except securing the southern portion of the island (Gailey 1983:76-87). Marine casualties were heavy — they totaled 1,111, with 209 dead. Japanese forces had suffered the loss of approximately one of their five battalions (Gayle 1996:18-19).

The fighting continued on subsequent days, with Marines assaulting heavily fortified positions, particularly on the left. Vicious fighting occurred in and around the Umurbrogol, some of it involving hand-to-hand combat (Galey 1996:20-21). The airfield was captured on the second day of the battle (D+1). To accomplish this, the 5th Marines had to charge across the open, flat, coverless airfield in the face of heavy Japanese fire. U.S. planes began using the field

on D+5 (Gayle 1996:25). By D+3, the 7th Marines had captured the southern portion of the island, and by D+5 the 5th Marines had secured the eastern sections of Peleliu (Moran and Rottman 2004:58-63). Reducing the main pocket of Japanese resistance in the Umurbrogol was much more difficult. By D+5, elements of the 7th Marines had joined the 1st Marines in efforts to take the Umurbrogol. On 23 September, the Army 81st Division was brought in to relieve the battered 1st Marines. U.S. forces changed their tactics at this point and transitioned from using direct frontal assaults to employing siege techniques involving the use of massive firepower directed at small areas combined with incremental advances. The Umurbrogol pocket was isolated from Japanese forces in the north by 26 September, and by 30 September, northern Peleliu was secured. The Army took over Peleliu operations entirely on 30 October, and the remaining units of the 1st Division boarded transports and sailed for Pavuvu. At this point, approximately 1,000 Japanese soldiers were still alive on Peleliu in the Umurbrogol pocket. On 27 November, the pocket was secured, and hostilities ceased (Gailey 1983:132-182).

The 1st Marine Division suffered 6,786 total casualties, with 1,300 killed in action. The 1st, 7th, and 5th Marines sustained casualty rates of 53.7%, 46.2%, and 42.7% respectively (Gailey 1983:170). Army casualties on Peleliu totaled 1,393, of which 208 were killed in action. Nineteen Japanese prisoners were taken as the only survivors from the Japanese garrison on Peleliu (Moran and Rottman 2004:89). More than 14,000 men from both sides died on Peleliu (Gailey 1983:171).

The Evolution of Amphibious Warfare in the Central Pacific during World War II

Amphibious tactics were used extensively throughout World War II by U.S. forces in both the European and Pacific theaters – indeed, every major U.S. assault during the war was proceeded by amphibious action (Whitehouse 1963:viii). U.S. amphibious doctrine evolved throughout the war, as did the technology used to mount amphibious operations – so that no two invasions were executed in precisely the same manner. This evolution was predicated on lessons learned from previous assaults, and each battle presented different challenges based on military resources available, disposition of the enemy, and variations in environment, among other factors (Rottman 2004:5-7). The progression of amphibious actions at Guadalcanal, Tarawa, Peleliu (described previously), and Iwo Jima demonstrate this evolution.

U.S. armed forces engaged in amphibious warfare prior to World War II. Colonial Americans participated in amphibious actions launched by the British in both 1745, during King George’s War, and in 1758, during the French and Indian War. These operations “constitute early pillars to the amphibious traditions that developed in the history of the United States” (Ohls 2017:XV). Having an amphibious capability was thought to be important enough by the U.S. government that the Continental Congress authorized the creation of the Marine Corps on 10 November, 1775 – a mere three weeks after authorizing the Navy. These Marines were meant to fight both at sea and on land (Nihart 1983:49). The Marine Corps was too small to mount major operations on its own until World War II but did participate in large joint operations with the Army and Navy and performed smaller operations on its own prior to that. The Marines did not become the primary U.S. amphibious force in readiness until the post-World War II era (Ohls 2017:5-6).

By the mid-twentieth century, many believed that amphibious warfare was a technique of the past and no longer viable. Modern armament such as machine guns, mortars, and artillery

were thought to preclude the success of any opposed landing force. A quote by one military critic in 1939 expressed this reasoning: “A landing on a foreign shore in the face of hostile troops has always been one of the most difficult operations of war. It has now become almost impossible...” The disaster at Gallipoli was the source for much of this thinking (Frank 2005:20). Indeed, two U.S. Army war colleges specifically taught that amphibious landings were an impossibility following Gallipoli (Friedman 2015:84).

Some did not believe Gallipoli signaled the end of amphibious action as a sound strategy. Lieutenant Colonel Earl Hancock “Pete” Ellis was a Marine and a theorist who focused on amphibious warfare. He thought amphibious warfare would play a vital part in the future of U.S. military operations, particularly in the Pacific. Ellis was active during a time when the role played by Marines was questioned and changing (Friedman 2015:1-2). Marines had always been stationed on ships and formed raiding parties when necessary. They also guarded Navy bases. Some felt that this shipboard role was anachronistic (Friedman 2002:4). Additionally, Marines were placed alongside the Army to fight in World War I. If Army soldiers and Marines were essentially interchangeable, why have a Marine Corps at all (Friedman 2015:2)? A new role for the Marines emerged, however. In the twentieth century, U.S. Navy operated as forward defense. As such, it needed advanced bases for support. Marines could be used to seize bases if necessary. This would be particularly important in a war with Japan, where the vast distances of the Pacific were at play (Friedman 2002:4). In Ellis’ estimation, taking islands for forward Navy bases would be necessary if such became a reality. This could only be accomplished through amphibious action. Ellis wrote “Advanced Base Operations in Micronesia” in 1921 – this document envisaged just such a situation and laid the groundwork for the Marines acting in the capacity of “amphibious force projection” (Friedman 2002:5, 2015:82).

In the late 1920s, the Marine Corps began emphasizing training for amphibious war, and a manual for this type of warfare was produced. The manual was adopted in revised form by the Navy and published as the “Landing Operations Doctrine” in 1938 (Friedman 2002:6). The Army adopted the same manual in 1943 (Rottman 2004:5). A Fleet Marine Force was formed in 1933. This group specifically trained and was equipped for amphibious war (Friedman 2002:6). Interestingly, the Army did not begin doing this sort of training until 1940, although they would conduct more amphibious actions in World War II than the Marines. The Marines did, however, perform more landings against heavily fortified targets. Often Army troops would be used to replace Marines once the landing phase of such an operation was complete (Rottman 2004:6).

After World War II began, the Army was responsible for landings that led into continental campaigns – which was essentially every action that occurred in the Atlantic. The Navy was responsible for landings in the Pacific, and the Marines operated there – particularly in the Central Pacific. In addition to the European theater, the Army conducted amphibious operations in the South Pacific in such locales as New Guinea and the Philippines. One exception to Army invasion in the South Pacific was Guadalcanal which was a Marine operation — only they were prepared to launch such an invasion in 1942 (Friedman 2002:9).

Amphibious exercises between 1935 and 1941 helped develop naval fire support strategies related to specific ship types and capabilities. For instance, it was determined that destroyers were best able to provide close-support fire missions for attacking beach defenses. Cruisers and battleships were better able to provide deep support by attacking enemy artillery positions and disrupting communications and supply lines (Lorelli 1995:15).

The Navy’s current stock of ship’s boats used for landings did not perform well during these exercises, and it became apparent that new specialized craft was necessary for landing

large numbers of men rapidly. A dizzying array of new vessel types were produced before and during the war. Many of these vessels were born of a “Special Boat Plan” which was developed in 1938. Andrew Higgins designed a shallow draft vessel with a bow ramp according to Marine specifications. This became the LCM (Landing Craft, Mechanized), which could carry a large tank. A boat hulled, tracked vehicle – the LVT (Landing Vehicle, Tracked) – was similarly designed with Marine input by Donald Roebling. LVTs could cross shallow reefs that would stop other craft with deeper draft (Lorelli 1995:25). Marines used LVTs extensively throughout the war, and more than 6,000 were eventually produced (Rottman 2004:19). An amphibious version of the standard 6 x 6 wheeled drive truck was also developed – the DUKW. This vehicle was equipped with a dual drive system consisting of a rudder and propeller as well as wheels. It could cross coral reefs similarly to the LVT. Both the Army and Marine Corps used this amphibious truck. It could carry artillery and other cargo and be outfitted with an A-frame so that it could unload cargo from other vehicles. One of the DUKW’s primary missions was removing wounded men to ship hospitals. Some were even equipped with Rockets for fire support missions. More than 21,000 were produced by 1945 (Ladd 1976:146-149; Doyle 2013:135).

The Marines conducted the first amphibious attack of the war in August 1942, on Guadalcanal, an island in the Gilbert chain (now Kiribati) where the Japanese were building a forward airbase (Bruce 1999:186). The operation was challenging because U.S. forces did not control the sea, and therefore communications were not secure. Further, there was very little intelligence regarding the island, and planning for the invasion was done hastily. Estimates for the number of Japanese forces on the island ranged from some 3,000 to more than 8,000. Command and control of the operation was *ad hoc*. The admiral in overall command of the operation never left New Caledonia to go to Guadalcanal. The expeditionary force commander,

Admiral Frank Fletcher, who was on the scene, was aware that the three carriers he had in the area contained the only U.S. striking power in the Pacific and was loathe to risk his ships – even though they could provide the only air cover for the Marines. Admiral Kelly Turner was the amphibious force commander and had only learned he would be participating in the invasion in July. No one on his staff had any experience with amphibious operations. The Marine 1st Division, assigned to make the landing under General Alexander Vandegrift, was understaffed and personnel were not fully trained. Vandegrift thought he would have six months for training in preparation for the assault, but only had six weeks. The process of loading the transports was inefficient and disorganized. Ships launched for the invasion without complete loads, and a good deal of supplies including vehicles, ammunition, and rations were left behind (Lorelli 1995:44-46).

At the only meeting of the commanders prior to the invasion, Fletcher stated that he would only provide two days of air cover instead of five, before removing his carriers. Vandegrift argued against this, but to no avail. The Marines were put ashore in waves controlled by destroyers – which meant the destroyers involved could not provide fire support. After action reports condemned this practice for being wasteful of resources. Air support communications were hampered by inadequate radio facilities on the only ship with this capability, and the ground forces had no communication with the air. Nonetheless 11,000 Marines landed without meeting substantial resistance. Supplies were brought ashore quickly – too quickly in fact for them to be dispersed to dumps. They subsequently piled up haphazardly on the beach. Japanese raids further confused the situation. Eventually loaded boats began to back up on the beach, and they and their supplies were made more vulnerable to air assault. Marines assigned to combat

roles did not assist with moving supplies. Despite these various issues, U.S. forces prevailed at Guadalcanal some six months later (Lorelli 1995:46-56).

The invasion of Tarawa in the Gilbert Islands occurred in November 1943. The task force supporting the invasion was far stronger than at Guadalcanal. Rather than having three carriers to provide air cover, there were 17. Gunfire cover was provided by 13 battleships, several cruisers, and some 40 destroyers, although some of these vessels would be assigned to support the simultaneous invasion of the island of Makin. Tarawa had an airfield and was heavily fortified. Aerial reconnaissance units photographed these defenses, and accurate assessments regarding what the invasion force would face were made. A shallow fringing reef surrounded the island that had to be transited. Tide tables were consulted, and locals were interviewed regarding the nature of the tides. Intelligence gatherers learned from these interviews that there could be “dodging tides” present when tides did not rise to the level expected. The invasion commanders determined that the first three waves of the assault would go ashore in LVTs, but the rest would be in LCMs and LCVPs (Landing Craft, Vehicle, Personnel) – there were not enough LVTs to accommodate the entire landing force. General Holland Smith, who commanded the Marines, requested a longer ship bombardment than what was planned, as well as the fortification of a nearby island with artillery. Both requests were denied. There were plenty of supplies – enough rations for 30 days as well as a 10 day supply of ammunition. However, there were no hospital ships. Attention was paid to controlling gunfire support and air cover. Each battalion on the ground had an air liaison and a gunfire control party. Multiple ships had radio equipment to communicate with air support as well as fighter-director teams assigned (Lorelli 1995:164-169).

Most of the gunfire and bombing prior to the assault was ineffectual. For instance, although cruisers put a good deal of weight of metal onshore, they fired from positions too far

offshore to provide pinpoint accuracy on gun emplacements, and so were largely ineffective. The deployment of troops was delayed because transports had to move away from the beach to avoid Japanese gunfire, and Marines then loaded slower than anticipated. Eventually the LVTs made their way toward shore. The first two waves arrived fairly intact, but the third and subsequent waves were met with devastating fire. The tide was not high enough for LCVPs in the fourth wave to cross the reef. Marines had to offload and wade to shore under heavy fire for 800 yds (800 m). The results were catastrophic. Marines fell in scores. Despite preinvasion plans, communication from the shore was poor. Too many radios failed or were destroyed – water easily ruined radios at this point in the war. Gunfire spotters, however, were able to effectively call in fire from ships. Supply craft could not cross the reef until the tide rose, but some were able to access a pier that bisected the reef, and unloaded cargo hand-to-hand onto the beach. This was a slow process. There was little communication between the beach and supply transports, and sometimes loads came ashore that were unwanted by the Marines – they needed artillery, and they resorted to offloading some pieces by hand from stranded landing craft. Two days later, the fighting on Tarawa ended, with the U.S. victorious (Lorelli 1995:170-176).

The assault on Iwo Jima began in February 1945. This battle may be considered the apogee of amphibious war in the Pacific — it was a large operation that involved three divisions of Marines and took place in the face of determined Japanese resistance. Okinawa was a larger operation, but other than Kamikaze activity, the beach landing there was essentially unopposed (Lorelli 1995:305, 284). Photo reconnaissance revealed that the island was heavily fortified. Operational control of the landing force resided with Major General Harry Schmidt. He requested ten days of naval bombardment prior to the landing but was denied this request in favor of three days. The campaign in the Philippines was competing for ships and ammunition,

and there simply was not enough ammunition for a ten day bombardment. The Navy also refused a request to concentrate all its fire support on the landing beaches. Instead, the entire island was to be targeted (Lorelli 1995:280-281).

Previous experience at Tarawa influenced planning for Iwo Jima. Armored LVTs with heavy guns had been developed since Tarawa, and these LVT(A)s were to comprise the first wave of attack. These vehicles quickly exited the landing beaches and split the defenders. Tanks, some equipped with new flamethrower mounts, and artillery then landed in quick succession. The seven landing beaches were composed of loose volcanic ash, so tracked vehicles were necessary for maneuvering. Additionally, Marston matting was deployed by troops to give firmer footing for vehicles. Three naval construction battalions landed to help clear beaches and build exits. Heavy casualties were expected, and three hospital ships were present (Lorelli 1995:283).

Gunfire and aerial support were well planned. The squadrons of one carrier were dedicated to spotting for gunfire support vessels and artillery. A Marine officer who specialized in naval gunfire was positioned as part of the staff on the fleet flagship. Additionally, a Marine fighter squadron that specialized in air to ground support was also to be present. More than 233 ships composed the task force for the attack. Some 724 targets were listed for destruction prior to the landing, and a daily list was to be kept recording the progress of the preinvasion bombardment (Lorelli 1995:283-286).

UDTs performed beach reconnaissance two days before the invasion. Twelve LCI(G) (Landing Craft, Infantry, Guns) provided gunfire cover for the UDTs. Defending Japanese forces fired on these vessels, and all 12 vessels were damaged to one degree or another. The UDT investigation was a success however, and they determined that there were no underwater

obstructions or mines to interfere with the landing. Unfortunately, they also concluded that the beaches were firm. They were decidedly not (Lorelli 1995:286).

Additional aerial reconnaissance revealed that there were more gun emplacements on the island than previously determined. The Navy responded by expending all their ordnance during the preinvasion shelling, other than that reserved for the landing itself. They also concentrated fire more heavily on the landing beaches, and some ships came within 2,500 yds to gain better accuracy (Lorelli 1995:286).

The morning of the invasion, the Navy delivered the highest concentration of bombardment on any landing beach up to that point. Marines occupied their LVTs 4,000 yds (4,000 m) offshore and moved toward the beach. New LCSS (Landing Craft Support, Small), which were outfitted with rocket launchers supported the landing. These LCSSs fired volleys of some 10,000 rockets onto and behind the beaches. When the Marines reached the beach, they realized the ground was not solid at all. Even the tracked LVTs could not gain purchase, and men sank ankle-deep. The assault quickly bogged down. The defenders began shelling the Marines with accurate fire. However, the landings were timed very well, and within short order 9,000 troops were on the beach. Casualties mounted though. Even tanks had difficulties moving and became ready targets for Japanese artillery. Ultimately, it was the Marine infantry who made progress expanding the beachhead. The beaches themselves became covered with a tangled mess of equipment and disabled LVTs, but the system for landing supplies continued to function (Lorelli 1995:288-289). DUKWs landed behind the LVTs and were forced to deflate their tires to 5 psi to move on the beach. They successfully moved artillery inland. More than 50% of these DUKWs were lost in the first five days of fighting on Iwo Jima (Lorelli 1995:289-290; Doyle 2013:210).

Despite the chaos on the beach, commanders understood what was happening there. Radios had improved since Tarawa, and ground forces were better able to communicate. Also, units had more assigned communications personnel, so casualties had less of an effect on communications than they had on Tarawa. On the second day, larger vessels came to the beach to offload supplies, but they too had trouble with the loose substrate – their anchors, typically used to prevent broaching, could not gain purchase. LVTs and DUKWs were invaluable for transiting cargo from these ships to shore (Lorelli 1995:291).

Fighting on Iwo Jima continued until March. Despite all the difficulties on shore, the systems of communication and fire support worked efficiently. Vast quantities of supplies were landed and effectively dispersed despite continuous shelling and the loose ash. Close air support by Marine and Navy pilots continued throughout the operation, and eventually Army fighter pilots joined them once the airfield was captured and occupied. Iwo Jima was a success under incredibly difficult conditions (Lorelli 1995:292-293).

The changes in amphibious warfare from the disorganized chaos of Guadalcanal, the casualties and horror of Tarawa, and the success at Iwo Jima, demonstrate a clear evolution in planning, intelligence, command and control, supply, and technology. Intelligence prior to the landing at Guadalcanal was practically nonexistent. The U.S. forces had little idea how many defenders they would face, or where they were located. And although there was little resistance from Japanese forces at the landing beach there, the lack of organization in supply made the entire operation vulnerable to Japanese airpower. Intelligence was better at Tarawa. Aerial photography clearly indicated where Japanese defensive strongpoints were. And efforts were made to determine the tides and land accordingly – although these efforts ultimately failed. A contributing factor to that failure was that there were too few reef-crossing LVTs available for

the invasion. Communications from ship to shore were also improved. Multiple ships were equipped with radios to communicate with aerial support and men ashore, although ship-to-shore communications still suffered due to casualties among radio personnel and equipment failure. At Iwo Jima, communications between ship, shore, and ground forces were maintained despite the harsh conditions ashore. Improved radios and personnel changes at the unit level facilitated this. UDT teams were employed to gather intelligence. There were adequate numbers of LVTs for the invasion, augmented with new LVTAs and DUKWs. The evolution of amphibious warfare contributed a great deal to the ultimate victory of the United States in the conflict.

Chapter 3. Disciplinary Framework and Methods

Introduction

The actions of UDTs and the resulting disturbance to the reef environment from explosive detonations may be considered and analyzed from a variety of perspectives. This section will discuss three fields of academic study that provide insight into the aforementioned phenomena – military geography, conflict archaeogeomorphology, and warfare ecology. These disciplines address respectively how battles are fought in specific geographical areas, the expression of these battles in the altered geomorphology of battlefields, and the impact of war-making on ecology.

Conflict Archaeogeomorphology

Human activities can alter the topography of landscape, and the study of these alterations is the focus of archaeogeomorphology, a subfield of geomorphology (Thornbush 2012:327). War is one such human activity that may produce drastic changes in geomorphology. The study of the changes wrought by war is conflict archaeogeomorphology, a subfield of archaeogeomorphology that deals with the intersection of conflict archaeology and geomorphology (Hesse 2014:12). Conflict archaeogeomorphology is a relatively new field of study and was first introduced in a paper published in 2014 by Ralf Hesse, who is currently employed by the State Office for Cultural Heritage in Germany (Gehyle et al. 2018:56).

Geomorphology, as a discipline, is concerned with landforms and their development, as they are shaped by such forces as erosion, weathering, and deposition (Selby 1985:8). These geomorphological processes may result from abiotic or abiotic forces. Biogeomorphology

specifically considers the role of organisms in geomorphological process. For instance, biogeomorphological studies have focused on topics such as the influence of vegetation on erosion rates, and the weathering of rock by lichens and pigeon droppings (Viles 1988:1-3). Zoogeomorphology is a subdiscipline of biogeomorphology that specifically examines the role animals play in shaping geomorphology (Butler 1992:179). Examples include the erosion caused by grizzly bears in mountainous terrain and the creation of trails by deer in salt marshes (Butler 1992; Keusenkothen and Christian 2004).

Conflict archaeology focuses on human behavior during war through the interpretation of the archaeological record at conflict sites. This record is a line of evidence that may either corroborate, or alternatively contradict, historical records and oral histories (Scott and McFeaters 2011:121).

Conflict archaeology as a discipline has grown substantially since the 1990s, and the field has evolved rapidly (Scott and McFeaters 2011:104; Hesse 2014:11). Battlefields were the primary focus of conflict archaeology in the early portion of the field's existence – but more recently conflict archaeologists have begun considering other sites where combat did not take place, but that nevertheless supported military activities in some capacity. These sites include bases, arsenals, military support facilities, and prisoner of war camps. Conflict archaeologists deal primarily with historical archaeology, although some take interest in prehistoric conflict (Scott and McFeaters 2011:104-105,107).

Archaeogeomorphology has a longer history than conflict archaeogeomorphology, but is also a relatively recent field of inquiry (Thornbush 2012:328). Dr. M. J. Thornbush, a geographer at the University of Oxford, credits the American archaeologist LuAnn Wandsnider with the first use of the word archaeogeomorphology in a paper published in 1992 (Wandsnider 1992:290;

Thornbush 2012:328). After Wandsnider's use of the term, it did not appear again in published literature until its revival by Thornbush in 2012 (Thornbush 2012:327).

The term archaeogeomorphology has been interpreted to mean a variety of different things. Wandsnider did not define the word in her seminal 1992 publication, but she did suggest that archaeogeomorphology was related to scale, in that standard geomorphological studies used scales of time too large to be of use to archaeologists, and that the use of archaeogeomorphology would ameliorate this, presumably by using finer temporal scales to consider phenomena. In this way, critical information associated with landscape site formation and system condition would emerge (Wandsnider 1992:290).

Thornbush provides an expansive, and not particularly straightforward, definition of archaeogeomorphology. In her estimation, archaeogeomorphology is a cultural geomorphology that “encompasses material culture, including historical archaeology and cultural heritage research, comprising stoneworks, such as historical buildings and monuments” (Thornbush 2012:326-327). The examination of the weathering of stonework of monuments for instance, would benefit from the cultural geomorphological perspective contained within archaeogeomorphology (Thornbush 2012:327). Much of Thornbush's research focuses on the weathering of Oxford stone and the preservation of historic buildings constructed of this material at Oxford University (Thornbush 2013). Archaeogeomorphology can include studies that are primarily geomorphological in nature, but with some connection or application to archaeology. Archaeogeomorphology, with its cultural geomorphological approach, also includes how cultures modify landforms at a variety of scales up to that of landscape. She states that this includes social perception, which is culture-dependent. She notes further, that archaeogeomorphology is not temporally constrained, but should include historical archaeology,

and that it is primarily urban – as this is where human influence is most evident (Thornbush 2012:327). Thornbush maintains that archaeogeomorphology is a subdiscipline of applied geomorphology that examines cultural landscapes (Thornbush 2013a:16).

Scholars, particularly those involved in the study of conflict archaeogeomorphology, have embraced an archaeogeomorphology definition that includes the impacts of humans on geomorphology and in the transformation of landscape (Schmidt 2012; Hesse 2014; De Matos-Machada et al. 2015; Gheyle et al. 2018). For instance, one study examined anthropogenic landscape features of ancient settlements in the middle and lower Amazon. Substantial earthworks were found including ditches, mounds, incised roadways, ponds, and depressions that were probably trails or passageways. Researchers surveyed and mapped these features using GPS and a total station, and digital elevation models (DEM) were produced from the survey findings. Using the revealed patterns of roadways and mounds, archaeologists generated hypotheses for the use of space to perform various functions — such as living and activity areas, refuse disposal areas, and traffic areas (Schmidt 2012:358-360). These anthropogenic geomorphic features altered the local environment in a variety of ways. They changed erosion and sedimentation patterns and added to the heterogeneity of the environment. Depressions changed soil moisture levels and probably influenced vegetation patterns. The documentation of geomorphic features in this case has led to a greater understanding of the human use of space, movement, and use of resources in ancient settlements (Schmidt 2012:363). Schmidt (2012:355-356) characterizes his use of GPS, topographic mapping, and archaeological excavations as an archaeogeomorphological approach to his research.

Conflict archaeogeomorphology then, is a discipline primarily combining aspects of conflict archaeology and geomorphology. Bomb craters, defensive earthworks, tunnels, and

trenches are some of the geomorphological features created during conflict, and among other features, have been the focus of conflict archaeogeomorphological studies. These alterations in geomorphology are the expressions of human action and conflict on the earth itself. As such, they are part of the cultural heritage, and indeed these landscapes may be the last witness to war (De Matos-Machada et al. 2015; Gheyle et al. 2018).

Hesse's (2014) seminal paper on conflict archaeogeomorphology elucidates the importance of technology to the field. Archaeologists are creating high-resolution DEM more frequently to quantify human caused changes to the earth's topography. Hesse (2014:12) characterizes the use of DEM as being indispensable in the study of past conflicts. DEMs are produced with the aid of a variety of instruments. According to Hesse (2014:12), airborne Lidar (light detection and ranging) is a tool employed by researchers to quickly attain high-resolution topographic data sets for very large areas. Lidar uses lasers to penetrate any vegetation canopy that might be present over a site, and filtering algorithms are then applied to the resulting sequential signal returns so that non-surface points – vegetation – are removed from the resulting data set. Airborne or satellite synthetic aperture radar may also be used to acquire surface data. Multi-view photogrammetry may be used to acquire data in a similar fashion, although typically over much smaller areas. Modern computers capable of processing enormous amounts of data have democratized the use of such technologies, which were heretofore unavailable for most researchers (Hesse 2014:12).

Hesse (2014:13) notes that until the early-modern period, geomorphological changes resulting from conflict were typically related to defensive structures. The advent of high-powered explosives in the modern era has led to what Hesse refers to as 'industrial' warfare. In addition to defensive fortifications, industrial warfare directly produces such features as craters

from bombs, mines, and artillery. These features can now be efficiently detected and mapped using DEM. Additionally, industrial warfare produces indirect topographic changes such as rubble piles – as in the case of heavily bombed cities during World War II – which can be massive, as well as alterations in geomorphological processes due to topographic changes wrought by conflict (Hesse 2014:16-17).

Many studies that employ a conflict archaeogeomorphological perspective have been conducted in World War I and II battlefields. For instance, Gheyle et al. (2018) integrated Lidar and historical aerial photo interpretation to determine the extent and preservation of the topographic remnants of World War I on a landscape scale in Belgium (Gheyle et al. 2018:57). Using these techniques, they were able to link known sites, previously thought to be isolated, with other features in the area. They ultimately sought to document and analyze the density, diversity, and distribution of wartime topographical disturbances. Further, heritage management in Belgium is proposing a UNESCO nomination for the former front zone in Belgium, focusing on architectural heritage, commemorative monuments, and military cemeteries. The authors contend that this focus is overlooking surface and archaeological remains and is missing an opportunity to “acknowledge the conflict landscape in its totality” (Gheyle et al. 2018:55,57). They acknowledge that data sets maintained by the Flanders’ Great War Heritage reference landscape features such as small portions of trenches and preserved crater fields – but argue that these features are considered in isolation (Gheyle et al. 2018:57). By demonstrating links between geomorphological features in the larger landscape, the research conducted by Gheyle et al. (2018:57) fills this gap.

The researchers conducted their study in the former area of the front around Ypres. Massive battles between the Allies and Germans took place in Flanders, near Ypres, in 1914,

1915, and 1917 (Gheyle et al. 2018:56). This fighting left topographic marks on the surface of the land in the form of craters, trenches, and dugouts. However, according to Gheyle et al., these features are no longer readily apparent, and their volume is typically underestimated – they tend to be a “. . . largely unknown part of war heritage” (Gheyle et al. 2018:56). Raw Lidar data from the study area was converted into 20 cm digital terrain models in order to observe preserved war features in great detail. The authors used this data in conjunction with more than 18,000 aerial photographs, taken between 1914 and 1918, to compare what was present during the war with what is present now (Gheyle et al. 2018:57).

The results of this study indicate that traces of the war are omnipresent in the landscape – to a far greater degree than heretofore realized (Gheyle et al. 2018:63). Indeed, more than 12% of the 33 km² study area is covered by traces of the war (Gheyle et al. 2018:60). Additionally, Lidar data revealed many previously unknown sites, a large portion of which are quite well preserved. All of this radically changes the authors’ understanding of the conflict landscape (Gheyle et al. 2018:66).

This new understanding has important implications for cultural heritage managers, who have typically concentrated on architectural heritage and commemoration monuments. The authors of this study strongly recommend that the “holistic landscape” be considered in research and in heritage management, and they intend to present the results of their research to both the authorities responsible for the management of these sites of conflict, as well as the general public (Gheyle et al. 2018:66).

Using photogrammetrically derived digital terrain models (DTM) and historical and modern photographs, Valjavec et al. (2018) examined four sites in Slovenia to document geomorphological traces of war at four locations in Slovenia. Two sites contained features from

World War I, and two sites contained features from World War II. The researchers used ArcGIS to georeference historic photos. Additionally, the authors created historical DTM using World War II aerial photography. Many reconnaissance photographs from that war were taken using stereoscopic cameras, which allowed for photogrammetric stereoimage processing of the images. Photos from World War I were not taken with stereoscopic cameras, so creating DTM from those images was not possible and photos had to be interpreted visually. Lidar was used to scan the entirety of Slovenia between 2011 and 2015, and the authors created present-day DTM from that data (Valjavec et al. 2018:386-388,391).

These DTM revealed geomorphological traces of war at two of the researchers four study sites. Extensive World War I trench systems – more than 111 kilometers – remain in the area of the Kras Plateau in southwest Slovenia. Trenches were also found in the Sotla River valley in southeastern Slovenia. These were part of the German fortification of the border between Germany and Croatia during World War II (Valjavec et al. 2018:388-389).

No such geomorphological features were found at the researchers' other two study sites however – despite evidence from historical photos that trenches and craters were present in one of the areas during in 1917, and that a former World War II German railway with an associated embankment was present in the 1950s (Valjavec et al. 2018:388). The authors note the loss of this cultural heritage and refer to it as “intangible war geoheritage” (Valjavec et al. 2018:389). The presence of forest appears to have protected some conflict heritage from destruction. Areas used for or built over contained this heritage only in intangible form. Additionally, the authors note that in areas with hard rock such as dolomite or limestone, preservation of geomorphological traces occurred to a greater degree than in those areas with soft rocks such as flysch, or in areas with loose, unconsolidated soils (Valjavec et al. 2018:392).

The authors conclude by suggesting that the application of photogrammetry techniques to historical photographs – such as World War II stereoscopic photographs of Slovenia – allows for the development of a detailed view of conflict landscapes and conflict geomorphology. Further, they state that the study of anthropogeomorphological traces of war is a transdisciplinary endeavor involving archaeogeomorphology (which they characterize as combining elements of geomorphology and archaeology), military geography, and peace and conflict studies and that this sort of collaborative research holds great potential for “finding, documenting, and ultimately acknowledging war geomorphological traces as geoheritage” (Valjavec et al. 2018:385).

De Matos-Machado et al. (2015, 2017) used Lidar to examine the World War I battlefield of Verdun. The goal of their research was to conduct an archaeogeomorphology survey of the landscape and create an inventory of conflict-induced landforms. These included both humanmade structures, such as trenches and bunkers, and those created by fighting itself, such as bomb and mine craters. They also sought to quantify the ecological effects of these landforms (De Matos-Machado et al. 2015, 2017). Their research then, contained elements of ecology as well as archaeogeomorphology. They created a DTM of the battlefield which covered 10,000 hectares of the landscape with centimeter-level accuracy. The battlefield is covered in forest and was heretofore relatively inaccessible to large-scale archaeogeomorphological analysis. The authors were able to determine that most of the landforms created during the conflict were hollow, such as craters and trenches, and created habitat for animals and plants that had not existed at these sites prior to the war. These features also collect water and become wetland sites with associated flora and fauna. Additionally, the researchers were able to quantify erosion rates at the site. The authors conclude by noting that, although the prewar landscape was almost destroyed, it now has strong environmental potential. This research led to the battlefield’s

inclusion in the European Natura 2000 network and several other ecological networks (De Matos-Machado et al. 2017).

Conflict archaeogeomorphology is a growing field of study and can provide new insight into human behavior in conflict, and into how wartime changes in geomorphology affect the landscape. It is a transdisciplinary field that combines elements of geomorphology, archaeology, geography, and conflict studies (Hess 2014:11). New technologies including Lidar and photogrammetry, particularly when used in conjunction with historical aerial photos, provide researchers with the ability to analyze the geomorphological characteristics of landscape in greater detail than ever before (Gehyle et al. 2018:56; Hess 2012:12). The results of conflict archaeogeomorphology studies illustrate the importance of geomorphological features for understanding past conflicts, and the preservation of those features should be considered by managers of cultural heritage (Gheyle et al. 2018:66).

Military Geography

Military geography is a broad, complex discipline that may be defined in a variety of ways. At the most basic level, military geography is a science that examines the influence of geography upon military operations (O’Sullivan 2001:1). Geography in this sense includes “the location, characteristics, and distribution of environments, peoples, forces, and things” as they affect military operations and command decisions (Peltier and Pearcy 1966:7).

Military geography then, is both a social science and a physical science (Peltier and Pearcy 1966:8). Economic, social, and political considerations fall under the purview of the subject, but so too do concrete elements such as topography, weather, sea conditions, and general climate – the “environmental matrix” or “operational matrix” within which battles are fought

(Peltier and Pearcy 1966:10, 12; Collins 1998:4). The discipline may be theoretical in nature and consider such topics as the effect of militarism (ideologies that prioritize military solutions to conflict) and military activities on “social and spatial relations” (Rech et al. 2015:48; Woodward 2005:720). However, military geography may also be an applied geography, particularly for tactics and terrain (Peltier and Pearcy 1966:19,62).

Tactics may be defined as “the employment of units in combat so that their ordered arrangement and maneuver will bring about maximum effectiveness and military victory. Further, tactics concerns bases of operation, movement in the presence of the enemy, deployment, and the use of weapons” (Peltier and Pearcy 1966:62). Modern soldiers use information gleaned from sources such as topographic maps, aerial and satellite photos, and verbal descriptions to inform themselves of landscape detail, and the probable disposition of opposing forces. This process is known as terrain analysis. Terrain analysis, which has been part of U.S. Army curricula since the 19th century, considers a variety of components, or geographical elements, that are militarily significant in a particular battlespace and uses them to inform tactical decision-making (Peltier and Pearcy 1966:63-64; O’Sullivan 1991:24-25; Bleed and Scott 2011:48).

There are generally five geographic elements, or “war fighting factors” typically considered in terrain analysis (sometimes these elements are grouped in six categories, but they generally contain the same basic elements) (O’Sullivan 1991:25; Collins 1998:8; Passmore et al. 2018:18; Carrell et al. 2020:53). They are (Carrell et al. 2020:53):

1. Key Terrain and Decisive Terrain
2. Observation and Fields of Fire
3. Cover and Concealment
4. Obstacles
5. Avenues of Approach and Withdrawal

These factors are known collectively by the acronym KOCO A (or sometimes COCO A, OAKOC, or OCOKA depending on the ordering and wording of the various components) and are used to predict “options that enemies might adopt” as well as to formulate “friendly courses of action” (Collins 1998:9, Passmore et al. 2018:18, U.S. Department of the Army 2019:3-6).

Key Terrain and Decisive Terrain

Key Terrain is terrain that, if held, would provide an advantage to a combatant. They are typically features that dominate the landscape and provide tactical advantages such as good observation, cover, or firing positions. Examples include high ground, choke points, landing areas, navigable routes, and significant infrastructure such as bridges or intersections (O’Sullivan 1991:25; U.S. Department of the Army 2019:4-10; Carrell et al. 2020:53). Decisive Terrain is terrain that must be controlled for a given mission to succeed (U.S. Department of the Army 2019:4011; Carrell et al. 2020:53).

Observation and Fields of Fire

Observation is the condition that allows a force the ability to see friendly and enemy personnel, and key aspects of the environment. Fields of Fire is the area that can be covered effectively by weapons. Observation and Fields of Fire are related and are determined by line of sight, which is the unobstructed path from a soldier’s weapon and is a straight line from one point to another. Environmental conditions, such as light availability and weather, can affect both conditions (Carrell et al. 2020:53; U.S. Department of the Army 2019:4-7).

Cover and Concealment

Cover is protection from fire and Concealment is protection from observation. Features that provide Cover and Concealment include walls, embankments, trees, tall grass, weather conditions such as snow and fog (U.S. Department of the Army 2019:4012).

Obstacles

Obstacles are anything that obstructs the movement of a force. These may be natural, or human made. Examples include rivers, lakes, wetlands, steep slopes, thickly wooded areas, rubble, minefields, and craters. Human settlements may also serve as Obstacles (O’Sullivan 1991:27; U.S. Department of the Army 2019:4-12).

Avenues of Approach and Withdrawal

Avenues of Approach and Withdrawal are routes to and away from Decisive and Key terrain. These routes include roads, paths, valleys, and navigable waterways. If multiple routes are available, they are prioritized based on a variety of factors including access to Key Terrain, ease of movement and the ability to sustain the route for logistical support. Features of the route such as road and bridge capacity, slope, and the loadbearing capability of the ground are considered when choosing an Avenue of Approach (O’Sullivan 1991:26; U.S. Department of the Army 2019:4-8).

Researchers have adopted KOCO A to help analyze and interpret historic battlefield sites (National Park Service 2016:1; McKinnon et al. 2020:8-11). Examples of battlespaces investigated using KOCO A terrain analysis are many and varied. They range from that of an

allied air raid during the Normandy Campaign (Passmore et al. 2018), and the lagoon and World War II invasion beaches of Saipan (Katz 2015), to a Revolutionary War battlefield at Monmouth, New Jersey (Sivilich and Silivich 2015), an ancient Roman battlefield in northern Spain (Brown et al. 2017) and an aerial battlefield at Midway Atoll in the Pacific (Roth and McKinnon 2018).

Warfare Ecology

The effects of war on the environment are widespread, complex, and significant, but research into these effects is fragmented by discipline. Ecologists, military planners, military historians, and political scientists approach the subject from varying perspectives and there is “little integration of theory, methods, empirical studies, and policy implications” (Machlis and Hanson 2008:729). Warfare Ecology is a field of study, initially described by Machlis and Hanson (2008), that provides a conceptual framework under which greater synthesis among ecological science, military planning, and “improved rehabilitation of postwar ecosystem services” may develop (Machlis and Hanson 2008:729).

Even ancient and medieval warfare affected the environment in substantial ways. These ecological effects were exemplified by Homer in a passage from *Iliad* — the oldest extant text in European literature — where the god Hephaistos uses fire to burn the banks of a river after a battle and wreaks environmental devastation (Lateiner 2004:11; Hughes 2013:129):

Hera spoke, and Hephaistos set on them an inhuman fire. First he kindled a fire in the plain and burned the numerous corpses that lay there in abundance, slain by Achilles, and all the plain was parched and the shining water was straitened. As when the north wind of autumn suddenly makes dry a garden freshly watered and makes glad the man who is tending it, so the entire flat land was dried up with Hephaistos burning the dead bodies. Then he turned his flame in its shining into the river. The elms burned, the willows and tamarisks, the clover burned and the rushes and the galingale, all those plants that grew in abundance by the lovely stream of the river. The eels were suffering and the

fish in the whirl of the water who leaped out along the lovely waters in every direction in affliction under the hot blast of resourceful Hephaistos (Lattimore 1962:427).

Prior to the advent of explosives and other modern weaponry, the environment was perhaps most affected by war through forest clearing, deliberate burning, or induced flooding. For instance, Trajan's Column in Rome, which commemorates a victory by Roman forces in Dacia, depicts soldiers using axes to fell large numbers of trees to clear roads and to build siege engines (Hughes 2013:135). Mameluke forces burned grasslands in Iraq and Anatolia to deny invading Mongol forces fodder for their horses in both 1262 and 1272 (Smith 1998:61). Mongol forces besieging Baghdad in 655 opened a dike to flood a large area and confound the movement of Arab troops (Gilli-Elewy 2011:364). In ancient China, forces engaged in offensive action would sometimes block the flow of a river by building a dam, then break the dam to flood settlements downstream. Soldiers from the Kingdom of Wu used this tactic to flood the city state of Xu in 512 B.C. Chinese forces sometimes diverted the course of a river to flood opponents as well. In the mid-fifth century B.C., a warlord known as Zhi Bo diverted the Jin River to flood a rival clan's city (Tse 2023:7,11).

The advent of industrial society, particularly after the development of mass production techniques in the mid-nineteenth century, produced a "leap upward in destructive capacity" (Tucker 2004:27). This initially through the production of more powerful explosives and gunnery, and eventually the development of chemical and nuclear weapons. Furthermore, advances in modes of transport, such as steamships and railways, supported the rapid movement of troops and supplies so that the overall scale of warfare increased, along with its concomitant ecological affects (Tucker 2004:27).

The scorched earth tactics used by Union Forces in the Shenandoah Valley and across the state of Georgia during the American Civil War were early examples of the “ecological dangers of the new industrial warfare.” Union soldiers systematically destroyed farms, crops, and livestock in these campaigns (Tucker 2004:27). Additionally, particularly toward the end of the war, soldiers on both sides created vast networks of defensive structures including trenches and breastworks (FIGURE 3.1). Building these constructs led to soil depletion and deforestation in substantial areas of land in and around battlefields (Maudlin 2018:46-51). Destroying food resources of the enemy and constructing defensive fortifications were not new tactics, but the “scale and intensity” of these endeavors was “unprecedented” in the war (Tucker 2004:27-28). However, the ecological devastation wrought by the American Civil War was merely a shadow of that which would occur in the 20th century, an era in which more than 100 million people would be killed in war (Lawrence et al. 2015:443).



FIGURE 3.1. Breastworks outside Petersburg, Virginia. Erosion and deforestation are evident (Mauldin 2018:46).

World War I was the first conflict in which all major combatant nations developed tightly coupled relationships between economic and military institutions — that is “the military-industrial complex finally matured” (Koistinen 1967:403; Tucker 2004:29). This relationship between military commanders, industrial designers, and managers contributed to an unprecedented economic mobilization that broke down “the distinction between both the civilian and military worlds and the private and economic functions” and helped facilitate massive spending for war and defense, along with a concomitant increase in the scale of warfare. The resulting series of nearly endless battles led to unparalleled levels of human death and environmental destruction (Koistinen 1967:378; Tucker 2004:29). Trenches on the Western Front extended for hundreds of miles, and millions of shells were expended along this front that ravaged the countryside leaving a cratered, treeless landscape where once croplands and forests had been present. Chemical warfare at an industrial scale was used for the first time, and battlefields were temporarily poisoned from their use (Tucker 2004:30). Author Dorothee Brantz describes the landscape of the Western Front, with its vast trench systems and cratered topography, in poignant and nearly apocalyptic terms: “The western front gave rise to an environment where men, animals, machines, trees, and the earth were reconfigured into an unrecognizable landscape of total destruction in which death became visible while the living had to stay hidden to survive” (Brantz 2009:78).

Technological advances between the first and second world wars led to even greater levels of environmental destruction in World War II, and examples of this devastation are legion. Fighting destroyed forests in vast swaths of Europe and Asia – particularly on Pacific islands

(such as Palau) where fighting occurred. Additionally, forests not directly affected by combat, such as those of Norway and British Columbia, were harvested to supply timber for various armed forces (Tucker 2004:30-31). The forests of the Philippines were subjected to both the direct consequences of combat and significant levels of deforestation for food production (Bankoff 2009:40-42). Dichlorodiphenyltrichloroethane (DDT) was used in vast quantities to control Malaria in tropical locations during the war, and the buildup of the chemical in birds in particular, “endangered the survival of several species” in the postwar world (Tucker 2004:32). Hundreds of ships were sunk during the war, and subsequent oil spillage caused extensive damage to marine and shore life. Vast quantities of unused chemical weapons were dumped at sea after the war (Lanier-Graham 1993:55-56).

The warfare ecology framework creates a “taxonomy of warfare” useful for delineating the various stages of warfare and their concomitant ecological effects. The first stage of the taxonomy is preparation for war. This stage involves such activities as training, research and development, testing, manufacturing, stockpiling, and the positioning of materials and troops for war. Ecological effects may include chemical contamination, residual unexploded ordinance (UXO), landscape cratering, deforestation from construction for roads and airfields, and soil compaction and erosion (Machlis and Hanson 2008:730-732).

War itself is the second stage of the warfare ecology framework. This stage may include bombing, small-weapons firing, the use of incendiaries, chemical and biological weapons use, mine deployment, and even tactical oil spills and defoliation. The resulting ecological effects may include the destruction of arable land, habitat degradation, soil compaction and contamination, biodiversity loss, cratering, and the introduction of invasive species (Machlis and Hanson 2008:730-732).

The third stage of the warfare ecology framework is postwar activities, which include the lingering effects of the war and the preparation for war. These involve long-term alterations in land use, continued contamination from pollutants, UXO, and degraded ecosystem services among other relevant impacts. Invasive species have also been introduced and become naturalized during the postwar stage (Machlis and Hanson 2008:732).

Note that not all the ecological effects arising from the three stages of warfare are negative. For instance, training areas and buffer zones around military installations may protect habitat, such as an expanse of undeveloped shoreline in Camp Pendleton, California. Fort Bragg in North Carolina contains one of the largest remaining expanses of longleaf pine and associated wiregrass in the world. This ecosystem supports critical habitat for the federally endangered red-cockaded woodpecker (Lucash et al. 2021:2-3). Disturbance from military activities may in some cases enhance biodiversity. For instance, disturbance from tracked vehicles in lupine environments at Fort McCoy, Wisconsin provide habitat for the endangered Karner blue butterfly, and two species of rare insects inhabit disturbed grasslands in a German training area (Machlis and Hanson 2008:52).

Critically, the effects resulting from the various stages of warfare can cascade. That is, they may influence each other and lead to unexpected, complex interactions. Machlis and Hanson (2008) provide several examples of this phenomenon. For instance, the presence of UXO creates hazards within landscape that may cause people to alter settlement patterns. This in turn leads to changes in land use patterns with associated ecological effects. Postwar reconstruction may result in shifting patterns of intensified urbanization. Refugee movements may intensify deforestation due to subsistence requirements. And finally, increased military expenditures may result in less funding for environmental management, which may in turn lead to declines in

ecosystem services (Machlis and Hanson 2008:733). Some of these cascades are evident on Peleliu.

The aforementioned concepts – military geography, conflict archaeogeomorphology, and warfare ecology – combine to provide an intellectual framework through which UDT demolition activities and their effects on the reefs of Peleliu may be analyzed. This analysis is used to answer the research questions posed in this thesis.

Biological and Geomorphological Characterization Methods

The fringing reefs off the invasion beaches of Peleliu were analyzed using structure from motion (SFM) photogrammetry, and the resulting 3D models, in order to determine the effects of disturbance from UDT explosions on coral species presence and reef geomorphology.

Researchers conducted the field portion of this analysis over the course of 8 days from 3-11 April 2018. No field work was conducted on April 9. Sampling was undertaken at disturbed sites off Orange Beaches where UDTs detonated explosives, and at undisturbed sites off White Beaches, where UDTs did not detonate explosives. The latitude and longitude for sites of disturbance were determined by overlaying georectified historical UDT maps, which indicated blast locations, on modern aerial photographs of the invasion beaches in a GIS database (TABLE 4.1, FIGURES 4.1-4.4). Sampling sites were then preselected from this data (TABLE 4.2). The locations of sampling sites for undisturbed reef off White Beaches were chosen randomly (TABLE 4.2) (Carrell et al. 2020:100-101).

TABLE 4.1. UDT Blasting coordinates off White and Orange Beaches.

Site	Latitude (Dec. Degrees)	Longitude (Dec. Degrees)
White Posts South	7.00118	134.22126
White Posts North	7.00212	134.22141
White Barbed Wire South	7.00054	134.22134
White Barbed Wire North	7.00407	134.22213
Orange 3 100' LVT South	6.98930	134.21808
Orange 3 100' LVT North	6.98976	134.21794
Orange 3 130' LVT South	6.99037	134.21773
Orange 3 130' LVT North	6.99082	134.21771
Orange 2 340' LVT South	6.99320	134.21768
Orange 2 340' LVT North	6.99432	134.21757
Orange 1 LCT South	6.99440	134.21742
Orange 1 LCT North	6.99571	134.21703
Orange 1 LVT South	6.99705	134.21682
Orange 1 LVT North	6.99870	134.21687

TABLE 4.2. Location and depths of sites sampled off White and Orange Beaches. Locations for sample sites for disturbed areas off the Orange Beaches were obtained from historical UDT maps. Sample sites for disturbed areas off the White Beaches were chosen randomly.

Date	Site	Depth (ft)	Latitude (Dec. Degrees)	Longitude
4/3/2018	Orange 1 LCT North	60	6.99571	134.21703
4/3/2018	Orange 1 LVT North	45	6.99777	134.21649
4/4/2018	Orange 2 340' LVT South	40	6.99329	134.21729
4/4/2018	Orange 3 100' LVT	45	6.98953	134.21803
4/5/2018	North White Beach Recon	50	7.01385	134.22012
4/5/2018	White Beach Barbed Mid	20	7.00418	134.21815
4/6/2018	White Beach Barbed 2.	20	7.00658	134.2188
4/6/2018	White Beach Barbed 1.	20	7.00544	134.21877
4/6/2018	White Beach Barbed 3.	10	7.00416	134.21852
4/7/2018	Orange 3 130' LVT South	40	6.99062	134.21774
4/7/2018	White Beach Barbed 4.	25	7.70048	134.21715
4/10/2018	Orange 1 LVT South	35	6.99848	134.21663

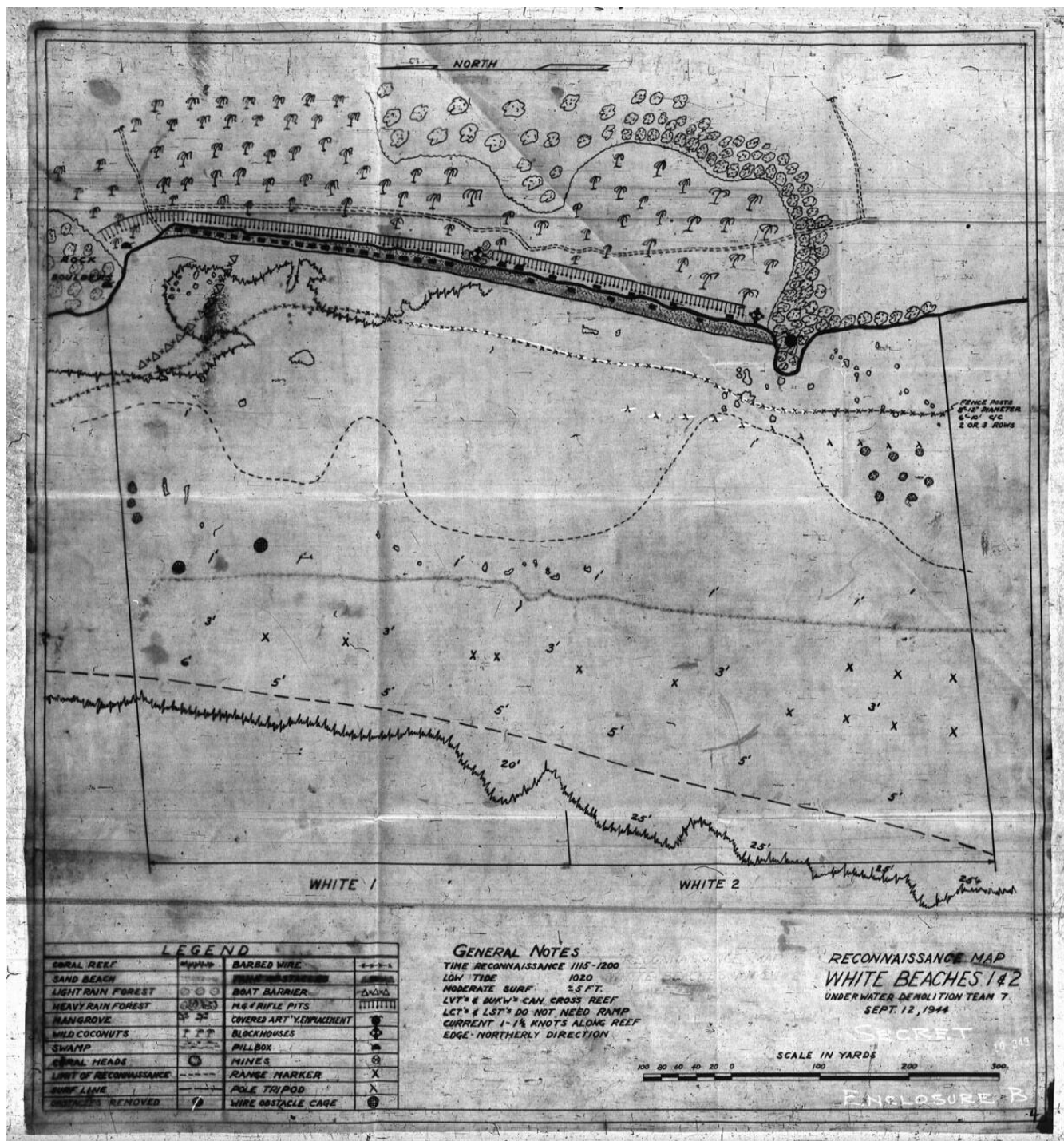


FIGURE 4.1. Map of White Beaches 1 and 2 produced by UDT Team 7 on September 12, 1944 (Burke 1944c:4).

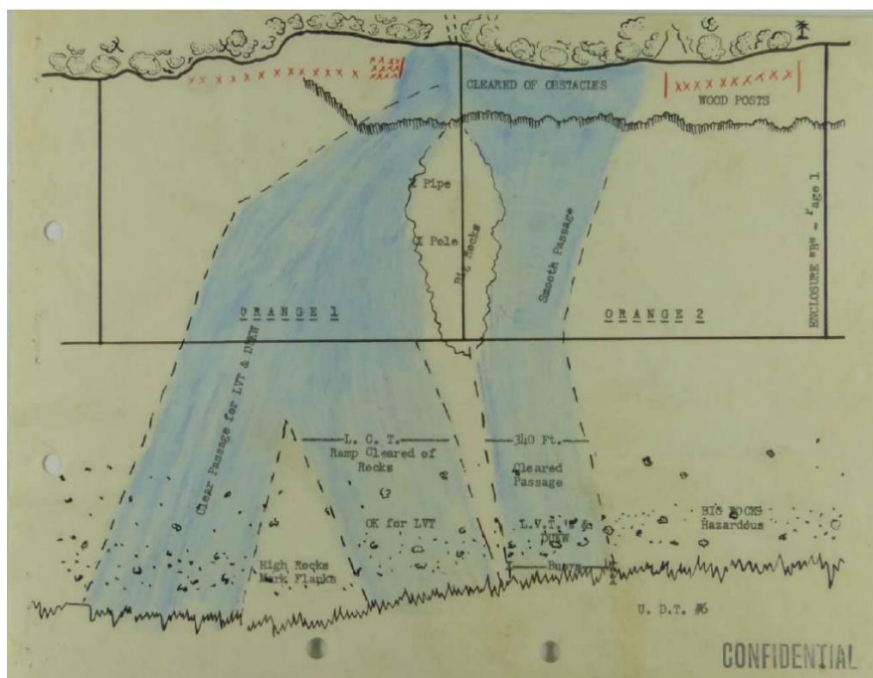


FIGURE 4.2. Map of Orange Beaches 1 and 2 produced by UDT Team 6 on September 12, 1944. Note locations of various passages cleared for LVT and DUKW landing craft (Logsdon 1944:10).

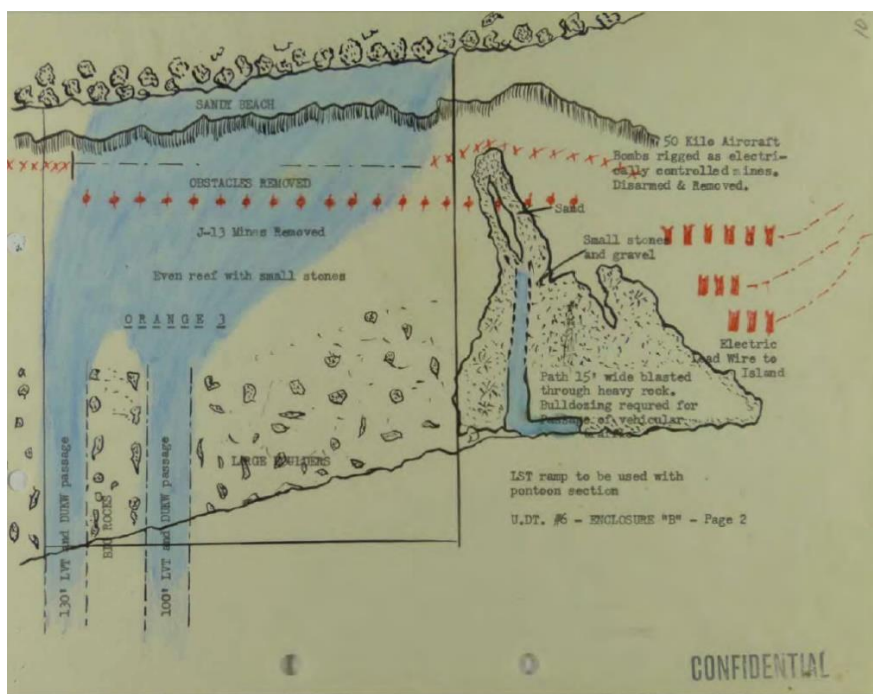


FIGURE 4.3. Map of Orange Beach 3 produced by UDT Team 6 on September 12, 1944. Note location of passages cleared for landing craft (Logsdon 1944:9).

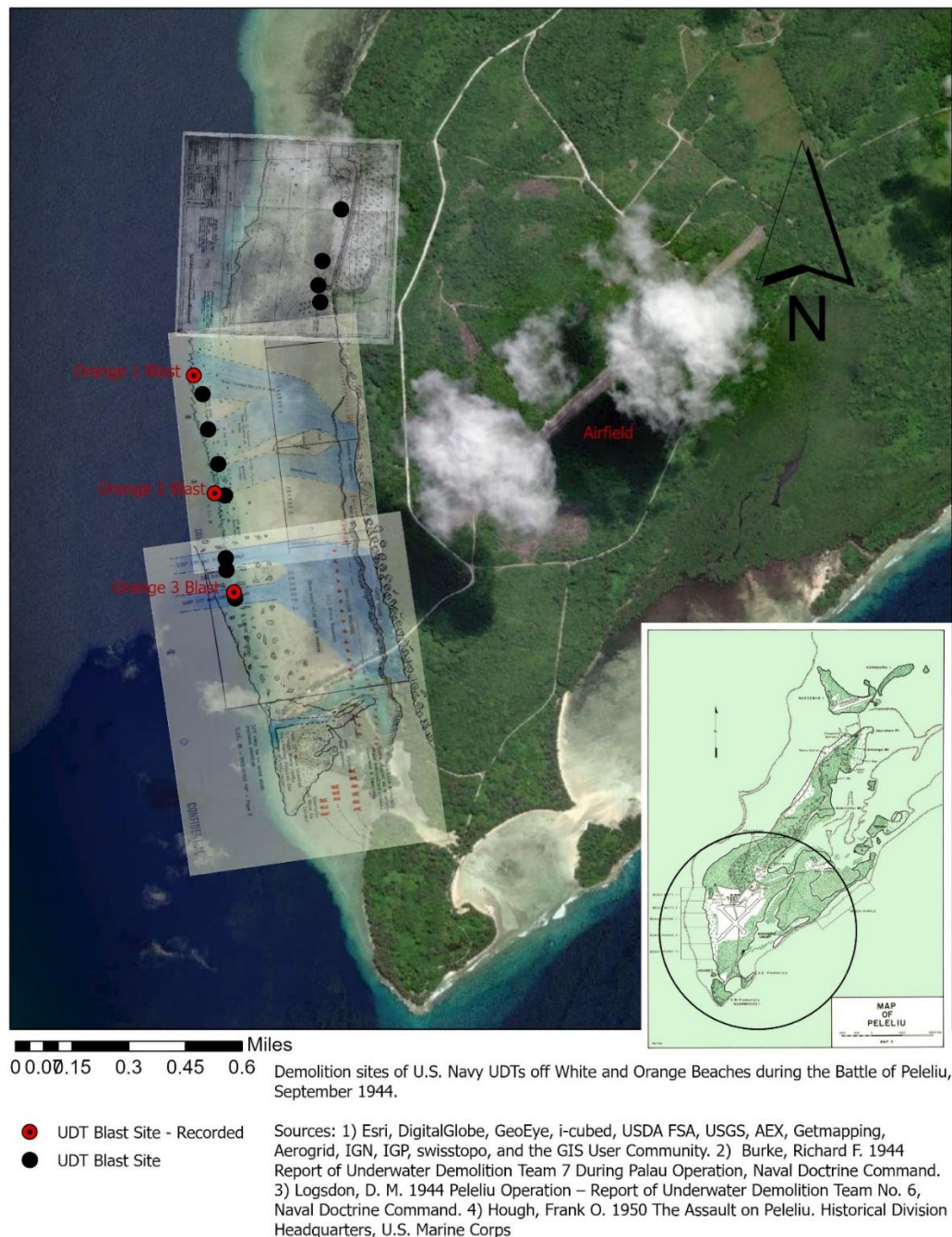


FIGURE 4.4. Map of UDT blast site locations off White and Orange Beaches. Sites are superimposed upon historical UDT maps of the invasion beaches and modern aerial imagery of Peleliu. Three blast Sites documented in their entirety are denoted Orange 1 Blast, Orange 2 Blast, and Orange 3 Blast. These sites correspond to blast sites designated Orange 1 LVT North, Orange 2 340' LVT South, and Orange 3 100' LVT respectively in Table 2. Note that blast sites off Orange Beaches are located along the reef edge at the entrances to landing craft passageways designated in the UDT maps. No UDT detonations occurred at the reef edge off White Beaches.

Sampling was conducted at three isobaths (depth contours) with depths of approximately 40 ft., 20 ft., and 10 ft. respectively at each disturbed and undisturbed site. Sony ILCE-7M2 cameras were used by scuba divers to record six 2 X 2 m plots at each isobath at each site (18 plots per site). A total of 425 reef plots were sampled. Additionally, three blast zones were documented in their entirety (Table 4.2, Figure 4.4) (Carrell et al. 2020:100).

Scale markers were used in each plot as ground control points at known depths to provide X, Y, and Z reference coordinates (Burns et al. 2015:5). Overlapping photographs (70-80%) were taken by divers at each plot from planar and oblique angles. The photos for each plot were then processed using Agisoft Photoscan version 1.4.3 SFM software to create 3D digital reconstructions in a process that involved the creation of 3D point clouds. Point clouds were created from “the projection and intersection of pixel rays from the different positions and oriented images in 3D space” (Carrell et al. 2020:100). A 3D mesh and georeferenced DEM was then created by triangulating and rendering the point cloud with the original imagery (Carrell et al. 2020:100). The resulting 3D orthophotos and DEMs were exported to ArcGIS topographic software “for quantification of coral health, community composition, and metrics pertaining to structural complexity” (Carrell et al. 2020:100).

Historical Research Methods

This thesis incorporates historical information gleaned from both primary and secondary sources. Primary sources were consulted in online databases and in published documents, memoirs, and oral histories. The online archive Fold3 was a significant source for primary documents for this thesis. This archive houses a wide variety of military documents including unit war diaries and after-action reports, which were integral to this thesis.

Secondary sources consisted of books and journal articles. Perhaps the most useful book for this thesis was *Naked Warriors* (1996) by Douglas Fane and Don Moore. This work was particularly helpful in clarifying the somewhat murky history of early demolition activities performed by the Navy in World War II.

Chapter 4. Literature Review of Underwater Demolition Teams

The history and development of UDTs during World War II is complex. According to Admiral Richmond Kelly Turner, the proximate causes for the creation of the teams were the November 1943 invasions of Makin and Tarawa atolls in the Gilbert Islands (Dyer 1972:681, 744). Admiral Ernest J. King, Chief of Naval Operations, believed that the defeat of Japan required the capture of the Marianas. According to King, holding the Marianas would allow U.S. forces to both prevent Japanese forces from accessing the critical oil fields of Borneo and reinforce their hold on the Philippines. Additionally, bombers based in the Marianas would be able to reach the home islands of Japan. The route for the Navy to invade the Marianas led directly through the Marshall Islands, but any attack in the Marshalls exposed U.S. forces to Japanese planes based in the Gilberts. Securing the Gilberts through Operation GALVANIC was considered a prerequisite for an invasion of the Marshalls (Lorelli 1995:162-163).

Admiral Turner was placed in charge of a newly created 5th Amphibious Force in August 1943 (Lorelli 1995:163-164). This Force was responsible for amphibious invasions in the Central Pacific region including those of Operation GALVANIC. GALVANIC entailed landings on Makin, a relatively lightly garrisoned atoll, and Tarawa, a much more heavily fortified atoll. Both invasions occurred on the same day — November 20, 1943 (Lorelli 1995:170).

Makin was defended by only a few heavy guns, and less than 800 men (Morison 1951:122). There were no concrete beach obstacles, barbed wire, or mines positioned to impede U.S. invasion forces, but there were coral pinnacles and boulders some 40 m off the beaches on the ocean-side approaches. These natural obstacles caused many landing craft to strand or broach during the invasion, a number of these had to put to sea again without unloading. Some craft were able to get within 10-12 m of shore but could approach no further. Soldiers had to wade in

from these vessels through swells that sometimes exceeded their height. Intelligence had incorrectly suggested that these obstacles would not impede the invasion. Some areas of the beach were so strewn with rubble that they proved impossible to use. Although Makin was eventually taken by U.S. forces, had there been concerted opposition at the location of ocean-side landings, the results could have been catastrophic (Crowl and Love 1955:77-78). Regarding the Makin landings, Turner had this to say:

My poorest appraisal of beach areas during the whole war was at Makin. It convinced me that we had to have somebody actually walk over the beach approaches and walk up to the beaches before we scheduled landings on them. Air reconnaissance is wonderful, but it wasn't good enough at Makin to provide adequate information in regard to the beaches or the beach approaches. The RED beaches were just plain stink profundo. That's why I pushed the development of Underwater Demolition Teams so hard (Dyer 1972:681).

The invasion of Tarawa took place on the island of Betio. U.S. forces landed on the northern, lagoon side of the island. Although Betio is small — only 3.2 km long and 245 m across at its widest point — it was fortified with nearly 200 heavy guns and some 500 pillboxes at the time of invasion (McKiernan 1983:210). The island is surrounded by a fringing reef, which extends roughly 450 m from the island on the lagoon side (McKiernan 1983:213; Gatchel 1996:122). This reef was subject to an unpredictable tidal regime known as a “dodging” tide, where it was possible low or high tides could be extended for an indeterminant amount of time (Morison 1951:153).

In addition to this natural barrier to invasion, Japanese forces encircled much of the island with iron reinforced concrete pyramid-shaped obstacles. The iron was configured so that it projected outward from the top of the concrete to form “horns”. These obstacles were roughly 1.2 m wide, and their height varied so that they were just high enough to break the water at high

tide depending on where they were placed on the fringing reef. They were positioned approximately midway out on the reef and were arranged to obstruct landing craft and channel them into pre-sited fire zones (Military Intelligence Division 1944:3-4). Additionally, double-aproned barbed wire fences were placed just inshore of the concrete obstacles. These were below the high tide mark and, similarly to the pyramids, were situated to funnel landing forces into direct enfilade fire. Finally, both antipersonnel and antivessel mines were placed on the reef — primarily between the concrete pyramids (Military Intelligence Division 1944:2,5).

The fringing reef, various obstacles, and mines had significant negative effects on the invasion of Tarawa. Though the tide did not rise sufficiently to allow any landing craft, LVTs passed the edge of the reef for nearly 30 hours after the invasion began (Alexander 1997:53). As a result, thousands of men had to wade hundreds of meters across the reef under heavy fire from Japanese forces. Mines accounted for some LVT losses, but Japanese machine gunners sighting along the barbed wire and other obstacles destroyed even more LVTs (FIGURES 4.1 and 4.2) (Morison 1951:186; Alexander 1995:72). Tarawa was eventually taken by U.S. forces. But the landing helped Turner recognize the necessity for better reconnaissance of landing beaches and a means to destroy beach obstacles:

It was after Tarawa in the Pacific, but before Normandy in Europe, that we recognized the imperative need for a better method...that would acquaint us with the true underwater geography between the Line of Departure and the beach, and that would ensure either the removal or safe avoidance of static dangers.

The method adopted was the employment of swimming scouts — Underwater Demolition Teams. It became the duty of these teams to chart the beach approaches, and to find and destroy underwater obstructions that might prevent or even retard the troop landings (Fane and Moore 1996:xii-xiii).



FIGURE 4.1. Two Marines rest on a broken-down M4 “Sherman” tank off the beach at Betio Island after the battle on 22 November 1943. A row of obstacles is visible in the background (Naval History and Heritage Command, <https://www.history.navy.mil/content/history/nhhc/our-collections/photography/numerical-list-of-images/nhhc-series/nh-series/80-G-57000/80-G-57406.html>. Accessed 17 May 2020).



FIGURE 4.2. Marine dead on a Betio Island landing beach. Row of obstacles is visible behind the M4 tank in the background (Naval History and Heritage Command, <https://www.history.navy.mil/content/history/nhhc/our-collections/photography/numerical-list-of-images/nhhc-series/nh-series/80-G-57000/80-G-57405.html>, accessed 17 May 2020).

The difficult landings on Tarawa and Makin beaches were the impetus for the formation of UDTs in the Pacific. Admiral Turner issued a recommendation to the Chief of Naval Operations on 26 December 1943 that UDTs be formed to support amphibious invasions in the South and Central Pacific (Dyer 1972:744).

However, UDTs were not the first U.S. military unit given the tasks of conducting hydrographic reconnaissance and obstacle removal on amphibious landing beaches. Allied forces landed in North Africa in 1942 in an action dubbed Operation TORCH. One goal of this invasion was the capture of an airfield near Port Lyautey in French held West Morocco. The airfield was located upriver from the allied landing beaches along the Oued Sebou River. The mouth of the river was blocked by a cable and net supported by buoys. This obstacle had to be removed before

the destroyer USS *Dallas* could ascend the river and launch an attack on the airfield (Fane and Moore 1996:10; O'Dell 2000:112). Seventeen sailors were chosen for this task, and they became the Navy's first demolition unit. Among them were 10 divers who were involved in salvage operations after the attack on Pearl Harbor. They participated in a brief course of demolition training at the U.S. Naval Amphibious Training Center in Little Creek Virginia, then sent to Morocco. On the night of November 9, 1942, the men ascended the Oued Sebou in a ship's landing boat, and successfully parted the boom using an underwater demolition device known as a velocity cable cutter. *Dallas* subsequently entered the river, and the airfield was taken (Moen 1942:5-6; Fane and Moore 1996:10-12).

The Amphibious Scouts and Raiders (S&R) were also present during Operation TORCH. This joint unit was created by the U.S. Navy and U.S. Army for the purposes of locating and marking beachheads for amphibious invasions in Europe. A school to train the S&R was established at Little Creek, Virginia in July 1942. This school was moved to Ft. Pierce, Florida in January 1943 and the unit became the sole responsibility of the Navy. Personnel were trained to deploy in small boats, find landing beaches under cover of darkness, and guide landing craft to these beaches using signal lights. They participated in landing operations in North Africa, Sicily, Italy, Normandy, and Southern France. They also served in the Pacific and performed missions during the invasions of the Marshall Islands, New Guinea, and Philippines (Liptak 2014:4-13).

Admiral King promulgated an order that established the Naval Combat Demolition Units Project in May 1943 (Bureau of Naval Personnel Training Standards and Curriculum Division and United States Atlantic Fleet Amphibious Training Command 2019:1). King's order established a temporary group designated Naval Demolition Unit 1 (NDU1) (Fane and Moore 1996:13; Liptak 2014:22). This Unit was tasked with clearing beach obstacles during the

invasion of Sicily in Operation HUSKY in July 1943. NDU1 was comprised of 18 men from the Naval Construction Battalions (Seabees) (O'Dell 2000:34). They reported to the Naval Amphibious Training base at Solomons Island, Maryland in May 1943, where they trained to blow channels through sandbars using explosive hose and to place explosive charges on underwater beach obstacles from rubber boats (Fane and Moore 1996:13-14). No underwater obstacles were encountered during the invasion of Sicily however, and NDU1 was used to demolish terrestrial obstacles instead (Lipstack 2014:22).

Admiral King's May order also called for the development of permanent demolition teams, whose purpose would be to remove natural and human-made underwater obstacles to amphibious invasion. The Navy established a combat demolitions school at the Naval Amphibious Training Base in Ft. Pierce, Florida in June 1943 to train these teams (Fane and Moore 1996:13,17). The teams came to be known as Naval Combat Demolition Units (NCDUs) (Taylor 1997:292).

Lieutenant Commander Draper Kauffman, founder of the Naval Bomb Disposal School, was charged with establishing the new demolition school and a training regimen for NCDUs. Kauffman recruited instructors for the school from the Bomb Disposal School and NCU1 (Fane and Moore 1996:14-17). Only volunteer students were accepted into the school. Initially they came entirely from the Construction Battalion but were later drawn from any branch of the Navy (Bureau of Naval Personnel Training Standards and Curriculum Division and United States Atlantic Fleet Amphibious Training Command 2019:1).

Training was intense and arduous. Rather than swim to their targets, teams were expected to operate from small rubber boats known as LCRs (Landing Craft, Rubber) and in shallow water. As such, they trained wearing full combat gear including helmet, boots, full uniform, and

bulky life vest. Kauffman adapted physical conditioning techniques from the S&R, who shared the Ft. Pierce base. He compacted the S&R eight-week physical training program into one Introduction Week — dubbed “Hell Week” by students. The trainees spent hours each day and night during Hell Week running and handling LCRs. On the final day of the week, students were subjected to intense live explosive concussion. Typically, 30-40% of the students dropped out following this week (Fane and Moore 1996:18-20).

Students had to pass a swim test, but otherwise swimming skills were not emphasized in the early days of NCDU training. Rather, trainees learned to approach obstacles in LCRs under cover of darkness, and when the water was shallow enough for wading, they attached explosives by hand to obstacles. The primary focus of training was learning how to destroy obstacles, but students also practiced hand-to-hand combat, radio communications, coastal silhouette recognition, small boat handling, and hydrography. NCDUs were designed to function independently of each other, and each consisted of five men and one petty or commissioned officer. This team structure was determined by the capacity of the LCRs they used. NCDUs were designated with consecutive numbers, beginning with NCDU-1 (Fane and Moore 1996:21-22).

The first class of NCDU trainees at Ft. Pierce was formed into 11 Units that were dispersed throughout the Atlantic and Pacific Theaters following training. One Unit was sent to the Aleutians, and two went to the Southwest Pacific to serve with the Seventh Amphibious Force. Two others were sent to North Africa and eventually participated in the invasion of Southern France (Fane and Moore 1996:24). One Unit went to England, and along with 31 other NCDUs, took part in Operation NEPTUNE, the invasion of Normandy (Bureau of Naval Personnel Training Standards and Curriculum Division and United States Atlantic Fleet Amphibious Training Command 2019:123-124, 134; Fane and Moore 1996:24). Two Units

served in the South Pacific in the Third Amphibious Force under Vice Admiral Theodore Wilkinson (Garand and Strobridge 1971:63; Fane and Moore 1996:24). Three Units went to Hawaii and were eventually incorporated in temporary UDT teams for the invasion of Kwajalein (Fane and Moore 1996:24).

Following Turner's December 1943 recommendation establishing UDTs, two temporary Teams were quickly formed and trained for participation in Operation FLINTLOCK — the invasion of the Marshall Islands. UDTs 1 and 2 were composed of 180 volunteers from multiple services and units including Seabees, NCDUs, Marine Corps, and Army engineers (O'Dell 2000:133). The Teams were trained in techniques of reconnaissance, demolition, and landing craft seamanship at Waimanalo Amphibious Base in Hawaii. The targets used for training drills were modeled on mines and obstacles encountered at Tarawa (More and Fane 1996:25-26).

UDTs 1 and 2 were broken up following the successful invasions of Kwajalein and Roi-Namur, and Marine and Army personnel were returned to their parent units while naval personnel were distributed to other UDTs. UDTs were composed entirely of Navy personnel from that point until the conclusion of the war (O'Dell 2000:139; Hawkins 2015:40). The commander of UDT 2, Lieutenant Commander John T. Koehler, was tasked with establishing a permanent UDT training base in Hawaii. Koehler established the Naval Combat Demolition Training and Experimental Base near Kamaole Amphibious Training Base on the island of Maui in February 1944 (Fane and Moore 1996:81; O'Dell 2000:139). UDTs began training at the new base in early April 1944 (O'Dell 2000:140).

Turner requisitioned all available NCDU teams being trained at Ft. Pierce for "advanced" UDT training at Kamaole beginning in March 1944. Six-person NCDU teams were reorganized into 100-person UDT teams upon arrival at the base (Fane and Moore 1996: 25,40; Hawkins

2015:41). Twenty-seven UDTs were trained at Kamaole before the war ended. The vast majority of UDTs were composed of enlisted who first underwent training at Ft. Pierce (Hawkins 2015:41). Additionally, most of the NCDUs from the European Theater were eventually transferred to the Pacific Theater and incorporated into UDTs following the invasion of France (Office of the Chief of Naval Operations 2013:1-1). Nearly all the NCDUs operating in the Pacific Theater were also eventually integrated into UDTs. Only six units continued to operate under the NCDU designation throughout the war (Liptak 2014:25-26; Hawkins 2015:35).

Over the course of six weeks, UDT personnel in Hawaii were trained in coral blasting, hand-placing demolition charges, conducting hydrographic surveys while swimming, boat handling, and the coordination of ship fire support. Additionally, a greater emphasis was placed on swimming than it had been at Ft. Pierce, and trainees were required to be proficient long-distance ocean swimmers. Swimming requirements included the ability to swim for 2 miles (3 km) in exposed water conditions, handle 25-pound (11 kg) demolition charges while staying afloat, and surface-dive to a depth of fifteen feet (5 m) (Fane and Moore 1996:82, 89; Dwyer 1998:72).

These skills were necessary for UDTs to accomplish their primary mission, which was to remove natural and human-made obstacles that could impede amphibious landing operations. UDTs engaged in a variety of tactics to accomplish this mission. They conducted pre-assault underwater reconnaissance to identify and mark obstacles and to familiarize themselves with the characteristics of invasion beaches. Sometimes they marked channels that could be used during an assault. They undertook pre-assault demolition tasks during daylight hours under cover of naval gunfire, or in darkness using stealth and concealment. Sometimes they conducted demolition operations concurrently with an assault. Finally, UDTs engaged in post-assault

demolition to clear beaches and harbor areas once the objective was secured (Bureau of Naval Personnel Training Standards and Curriculum Division and United States Atlantic Fleet Amphibious Training Command 2019:3-4).

Following their formation in 1943, UDTs participated in every major amphibious action in the Pacific during World War II. Their activities culminated with the invasions of the Japanese islands of Iwo Jima and Okinawa in 1945. One-hundred swimmers from four UDTs performed reconnaissance on the beaches of Iwo Jima on January 17. Part of their mission included collecting sand samples which were used to determine if the beaches could support wheeled vehicles. Two Team members were killed during this operation. Casualties were much heavier among the crews of the 12 LCI(G)s (Landing Craft Infantry, Guns) providing close-in fire support for the UDTs. Shore-based fire from Japanese forces killed 47 personnel, sank one ship, and put the other 11 “out of action” (Hawkins 2015:41; Milligan 2021:177-180). The following night, a Japanese bomber dropped two 500-pound (226 kg) bombs on a transport carrying UDT 15 killing 18 team members and wounding another 23. This was the largest toll of casualties suffered among the teams in the Pacific during the war (Fane and Moore 1996:184-185).

Nearly 1,000 team members from 10 UDTs participated in the invasion of Okinawa. These team members accomplished a wide variety of tasks including sinking some 400 plywood “suicide” boats hidden in caves along the coast, blasting channels for landing craft, and clearing thousands of wooden posts from landing beach approaches. One swimmer guided a line of tanks to the beach by wading ahead of them and acting as a “human depth gauge” while dressed “in nothing more than a swimsuit and a helmet” (Milligan 2021:181).

More than 3,000 team members served in UDTs during World War II, and they were the most heavily decorated naval unit in the war. These awards included “two navy cross medals,

150 Silver Star Medals, 750 Bronze Star medals, and numerous purple hearts” (Hawkins 2015:42). Indeed, there were 231 UDT casualties in the war, with 83 killed in action (Dockery 2001: 42). Interestingly, and perhaps in testament to their effectiveness, the UDTs were the only special operations unit not disbanded after World War II (Milligan 2021:186).

Chapter 5. Results and Discussion

Introduction

This section presents the results of a historical analysis of the UDTs participating in the invasion of Peleliu, and an analysis and discussion of those team's actions at Peleliu within the context of KOCOAs. Additionally, it provides the results and a discussion of the reef characterization efforts described in the methods chapter. 3D models are presented, and the structural complexity and benthic community composition of disturbed blast zones are analyzed and compared to undisturbed sites. Benthic community diversity and percentage cover indices are calculated and compared across disturbed and undisturbed sites. Finally, it places the ecological effects of UDT actions on the reef within the context of warfare ecology.

UDTs at Peleliu

Three UDTs were originally designated to conduct reconnaissance and demolition duties at Peleliu. These were UDT Able, UDT 6, and UDT 7. Historical and archival research, as outlined in the methodology chapter, was conducted to develop histories for each team and detail their activities both before and after the battle for Peleliu.

UDT Able

UDT Able was formed from several NCDUs that were sent to the South Pacific to conduct operations at Guadalcanal, Green Island, and Emirau Island (Dockery 2001:103). Donald M. Walker was a member of NCDU 13, one of the units from which UDT Able was formed. According to Walker, NCDU 13 first went to the Solomon Islands in 1944, where they helped the Bureau of Ordnance develop solid fuel rockets for use in invasion fire support

(Dockery 2001:103). Later that year, they assisted UDT 4 during the invasion of the Marianas. Following that NCDU 13 was combined with other NCDUs into UDT Able with no formal commissioning (Cunningham 2007:105). UDT Able was unique among the teams in being designated with a letter rather than a number. It is possible this unique designation was used because the unit was formed from NCDUs composed of early graduates of training at Fort Pierce (Dockery 2001:103-104).

Following their formation, UDT Able was tasked with demolition and reconnaissance duties on Orange Beach 3 at Peleliu (Nimitz 1945:46). On September 12, the team was aboard USS *Noa* near Peleliu, when the vessel collided with USS *Fullum*. *Noa* was abandoned before sinking, and there was no loss of life. However, UDT Able lost all their gear, and could not participate in the invasion. UDT 6 took over UDT Able's responsibilities for Orange Beach 3 (Nimitz 1945:46; Cunningham 2007:105).

After Peleliu UDT Able was sent to Hawaii where the unit was broken up and individuals were assigned to newly forming UDTs 11, 12, 13, 14, 15 and 16 (Dockery 2001:104). Walker was appointed executive officer for UDT 13. He later earned the silver star for actions at Iwo Jima (Cunningham 2007:106).

UDT 6

UDT 6 was commissioned in May 1944 after undergoing training first at Camp Peary, Virginia, and then at the Naval Combat Demolition Training and Experimental Base in Maui, Hawaii. The unit was composed entirely of sailors from naval construction battalions (Seabees). Following training they were sent to the Mariana Islands to participate in the invasions of Saipan and Guam as part of Operation FORAGER, although the unit was held in reserve for both the

invasions. They did however conduct demolition operations at Guam. On July 27 and 28, 1944, UDT 6 blasted a channel through the reef at Dadi Beach so that LSTs could offload supplies. They used 36 tons of tetrytol for this operation (Fane and Moore 1996:122; King 2024a).

Peleliu was the next action for UDT 6. The Team conducted reconnaissance of the reefs off Orange Beaches 1, 2, and 3 on the morning of 12 September, and found many natural and human-made obstacles requiring removal. They commenced blasting activities to remove boulders on the morning of 13 September and returned to the reef that night to remove enemy obstacles. Their last pre-assault action entailed blasting boulders on the reef on the afternoon of 14 September. All this work was done “under constant machine gun and sniper fire” from Japanese forces (Hutson 1944:2).

The unit performed additional demolition and reconnaissance tasks in the post-assault phase of the battle. These activities included removing natural obstructions on the reef off Orange Beach 3, creating a ramp for LSTs off Scarlet Beach 1, and conducting a terrestrial reconnaissance in the Scarlet Beach area (Logsdon 1944:2).

On September 26, swimmers from UDT 6 and UDT 8 performed a reconnaissance of the strait between Peleliu and Ngesebus Island in preparation for an assault of Ngesebus by Marines. The goal of the reconnaissance was to determine if tanks could cross the strait or if it was too deep. The swim was approximately three miles across the strait and back, and the teams were under fire from snipers, mortars, and machine guns for the entire length of the swim. There were no casualties, however (Logsdon 1944:2; Fane and Moore 1996:146-147).

From Peleliu, UDT 6 proceeded to the Philippines where they conducted reconnaissance on beaches near Tacloban, the capital of Leyte (Fane and Moore 1996:154). Following these activities in the Philippines, UDT 6 returned to Fort Pierce. In April 1944, most of the team

members were transferred to the training staff at Fort Pierce. A small group of veteran team members became the nucleus for a newly reorganized UDT 6, which began cold water training in preparation for the invasion of Japan. The war ended prior to the planned invasion, and UDT 6 was decommissioned on 2 November 1945 (King 2024a).

UDT 7

Similarly to UDT 6, UDT 7 was composed entirely of Seabees, and was commissioned following training at Fort Pierce and the Naval Combat Demolition Training and Experimental Base in Maui, Hawaii in May 1944 (Dockery 2001:107; King 2024a). Following training, UDT 7 participated in Operation FORAGER and the invasion of Saipan on 14 June 1944. The unit was transported to Saipan onboard USS *Brooks*, a World War I era four-stack destroyer that had been converted to an Assault Personnel Destroyer (APD) (Fane and Moore 1996:92). For this conversion, two stacks and a fireroom were removed to create room for transporting troops. APDs were commonly used to carry UDTs in the Pacific. When engaged in this purpose, they carried four LCPRs (Landing Craft Personnel, Ramp) used by UDTs for reconnaissance operations (Fane and Moore 1996:86) (FIGURES 5.1-5.3).



FIGURE 5.1. USS *Brooks* DD 232 in 1920 prior to being converted to an APD. Note the four stacks (Maritime Quest 2024: http://maritimequest.com/warship_directory/us_navy_pages/destroyers/pages/alpha_pages/b/brooks_dd232_page_1.htm). Accessed 21 January 2024.



FIGURE 5.2. USS *Brooks* APD 10. Vessel in 1944 post conversion to an APD. Note the two stacks and the LCPR carried midships (Maritime Quest 2024: http://maritimequest.com/warship_directory/us_navy_pages/destroyers/pages/alpha_pages/b/brooks_dd232_page_1.htm). Accessed 21 January 2024.

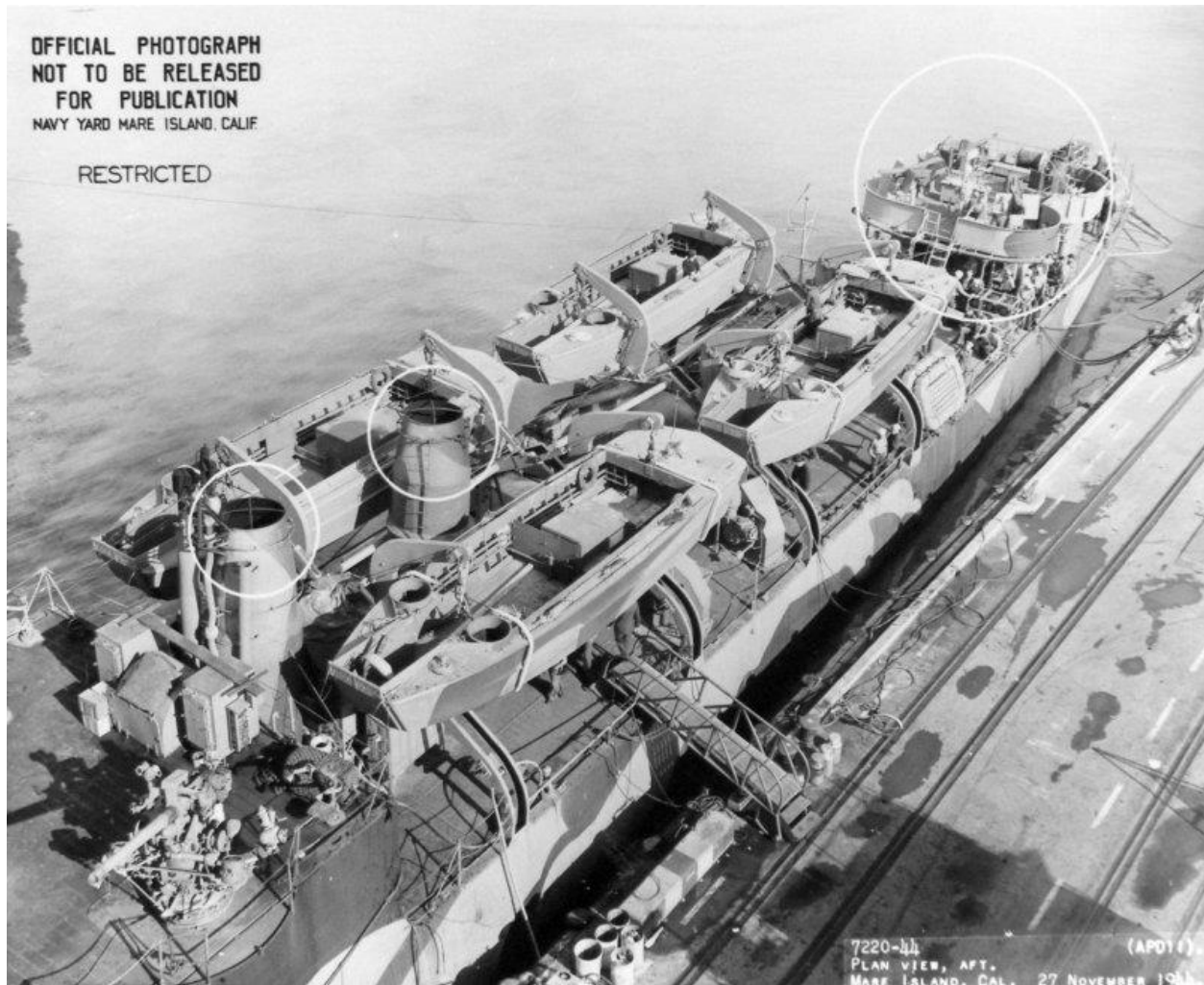


FIGURE 5.3. USS *Gilmer* (APD 11) in November 1944 carrying 4 LCPRs. *Gilmer* carried UDT 5 to Saipan for Operation FOREGER (NavSource Online 2024: <http://www.navsource.org/archives/10/04/04011.htm>). Accessed 21 January 2024.

UDT 7 was tasked with the reconnaissance and removal of obstacles on four invasion beaches at Saipan. These beaches were designated Blue 1, Blue 2, Yellow 1, and Yellow 2 (Burke 1944a:2; King 2024b). UDT 7 was divided into 4 units responsible for each beach respectively. Each unit was transported to the reef's edge onboard an LCPR that also towed a rubber boat equipped with an outboard engine. This boat was to be used to recover swimmers. All units were subjected to "heavy enemy gunfire" beginning some 800 m from the beach. The unit responsible for Yellow 1 had to abandon reconnaissance efforts after several attempts due to

this fire, and two swimmers were wounded. Swimmers successfully conducted reconnaissance on the other three beaches and determined that there were no obstacles to impede the invasion and that conditions were “ideal for the passage of LVTs and DUCKs [sic], and that tanks could easily cross Yellow beaches” (Burke 1944a:3). UDT 7 sustained 2 team members killed and another 8 wounded during this action (Burke 1944a:3).

A description of some of the UDT swimmers in this engagement is worth noting:

The swimmers crouched down in the open cockpits. They looked fantastic, clad in blue sneakers, kneepads for crawling on coral, swim trunks, canvas work gloves to protect their hands from poisonous coral scratches, glass-fronted face masks, and helmets. They dangled balsa wood floats to mark mines, oblong plastic slates to record the water depth, and spare pencils for writing under water.

Adding a final surrealistic touch, each man was camouflaged blue and was painted from toe to chin, and down each arm, with horizontal stripes of ordinary black paint a foot apart, with shorter lines between. This war paint was not in imitation of the Indian naked warriors; it was Kauffman’s idea for quick measurement of lagoon and reef depths. The swimmers could touch their feet or hands to the bottom in shallow water to check its depth against their bodies (Fane and Moore 1996:95).

In the post assault phase of the battle for Saipan, UDT 7 deployed 8 buoys at Chalan Kanoa Channel, blasted a channel through the reef at Blue 2 to create a ramp for LSTs, and destroyed coral obstructions on the reef at the Blue Beaches. The official report of these operations notes that “all blasting operations were exceedingly difficult, due to the peculiar coral formation,” and further that it was fortunate “the reef form was such that no blasting was necessary for the unloading of LVTs, DUCKs [sic], and LCMs” (Burke 1944a:8).

Following activities on Saipan, UDT 7 participated in the invasion of Tinian. The team was divided into three units that conducted reconnaissance on Red, Green, and Blue Beaches near Tinian Town. This was a feint to trick the Japanese into believing that the beaches in

question would be used for an invasion. Swimmers did not approach the beach any closer than “the inner edge of the reef” (Burke 1944b:10; Fane and Moore 1996:129). The feint was judged a success, and the Commander of UDT 7, Richard Burke, found that “... all phases of this operation was extremely gratifying” (Burke 1944b:10).

Post-assault work done by UDT 7 at Tinian included searching for anti-boat mines off White Beaches 1 and 2 and removing unexploded ordnance from the reef. They also placed pontoons on White Beach 1 and 2 and used a minimal amount of blasting to accomplish this (Burke 1944b:13).

The next action for UDT 7 was Peleliu. In the pre-assault phase of the battle, Team 7 reconnoitered the reefs off White Beaches 1 and 2 simultaneously with UDT 6 Orange Beach reconnaissance activities on the morning of 12 September. The team, while subjected to machine gun and sniper fire from Japanese forces, found human-made obstacles on the reefs but no natural obstacles. UDT Seven returned to the White Beach reefs on the night of 14 September to blast obstacles, and no resistance from Japanese forces was encountered (Hutson 1944:2).

Post-assault operations conducted by UDT 7 included laying anchorage buoys for barges, reconnaissance of Orange Beach 3 for mines, blasting coral obstructions on Orange Beach 3 for pontoon causeways, reconnaissance and demolition of obstacles and mines on Scarlet Beach 3, reconnaissance and demolition on Scarlet Beaches 1 and 2, and reconnaissance and removal of obstacles on Purple Beach (Burke 1944c:5).

UDT 7 returned to the training base in Maui after Peleliu. Some members of the team worked as base training staff until their next action, which was the invasion of Okinawa. The team conducted reconnaissance activities on Yellow Beach 2 on 29 March 1945 using two LCPRs for deployment. Swimmers found three rows of wooden posts embedded in the reef.

They returned the next day and removed them with explosives. The water at Okinawa was cold relative to other sites UDT 7 had operated at and the swimmers found the work exhausting due to this cold and the extensive amount of time spent working in it (Burke 1945:2-4).

Post-assault activities included reconnaissance of some 10 different beaches. No demolition was reported, and there were no casualties suffered. However, on 9 April the vessel carrying UDT 7, USS *Hopping*, was hit by shore battery fire which killed one team member and wounded another eight (Burke 1945:7-15). Okinawa was the final action for UDT 7 before the war ended, and the unit was decommissioned in October 1945 (King 2024b).

KOCSA and UDTs at Peleliu

Carrell et al. (2020:14) used KOCSA to analyze the shorelines and invasion beaches of Peleliu in an effort to “understand the activities that influenced the invasion and the decisions and limitations imposed by the natural terrain and built environment”. The researchers restricted the scope of their investigation to areas of the island involved in the initial amphibious assault extending from the edge of the drying reef, some 600 m from the invasion beaches to an area roughly 300 m inland of the beaches (Carrell et al. 2020:54).

The KOCSA attributes identified by Carrell et al. (2020) directly influenced the activities of UDTs during the Peleliu invasion. The White Beaches and Orange Beaches themselves were both Key Terrain and Decisive Terrain for the initial assault. The initial waves of invading Marines had to gain control of the beaches to establish a beachhead where supplies could be offloaded and from which U.S. forces could push inland. A beachhead is defined as “a zone contiguous to the beach the possession of which permits the continuous landing of troops, equipment and supplies without serious interference from the enemy, and ensures the maneuver

space and the terrain features requisite for a further advance” (U.S. Marine Corps 1934:68). The immediate objective of an amphibious assault then is to establish a beachhead and ultimately “shift from amphibious to land warfare in order to bring defeat to the enemy” (Isley and Crowl 1951:8).

The Avenues of Approach necessary to reach the Key Terrain and Decisive Terrain of the landing beaches were the waters of the lagoon, through which Marines would transit onboard LVTs. The specific responsibility of UDT Teams 6 and 7 was to ensure that these Avenues of Approach were free of Obstacles. Twelve swimmers from UDT 7 reconnoitered White Beach 1 and 2 on the morning of 12 September. They deployed from the seaward side of an LCP(R) then swam across the reef and approached to within 100 yds of the beach (Burke 1944c:2; Carney 1944:85). Cover and Concealment for the action included both the LCP(R) from which the swimmers deployed, and the water itself (the same Cover and Concealment applies to the activities of UDT 6 described below). This Cover and Concealment shielded the swimmers from Observation by Japanese forces and subsequent fire as they entered the water and conducted reconnaissance. The UDT discovered that “the reef was smooth and flat, with a gentle slope to the beach” (Burke 1944c:2). They also found various Obstacles including range markers, wooden posts, and steel tripods. The swimmers returned on the night of 14 September and demolished “as many of the obstacles as practicable” with explosives (Burke 1944c:2) (FIGURE 5.4).

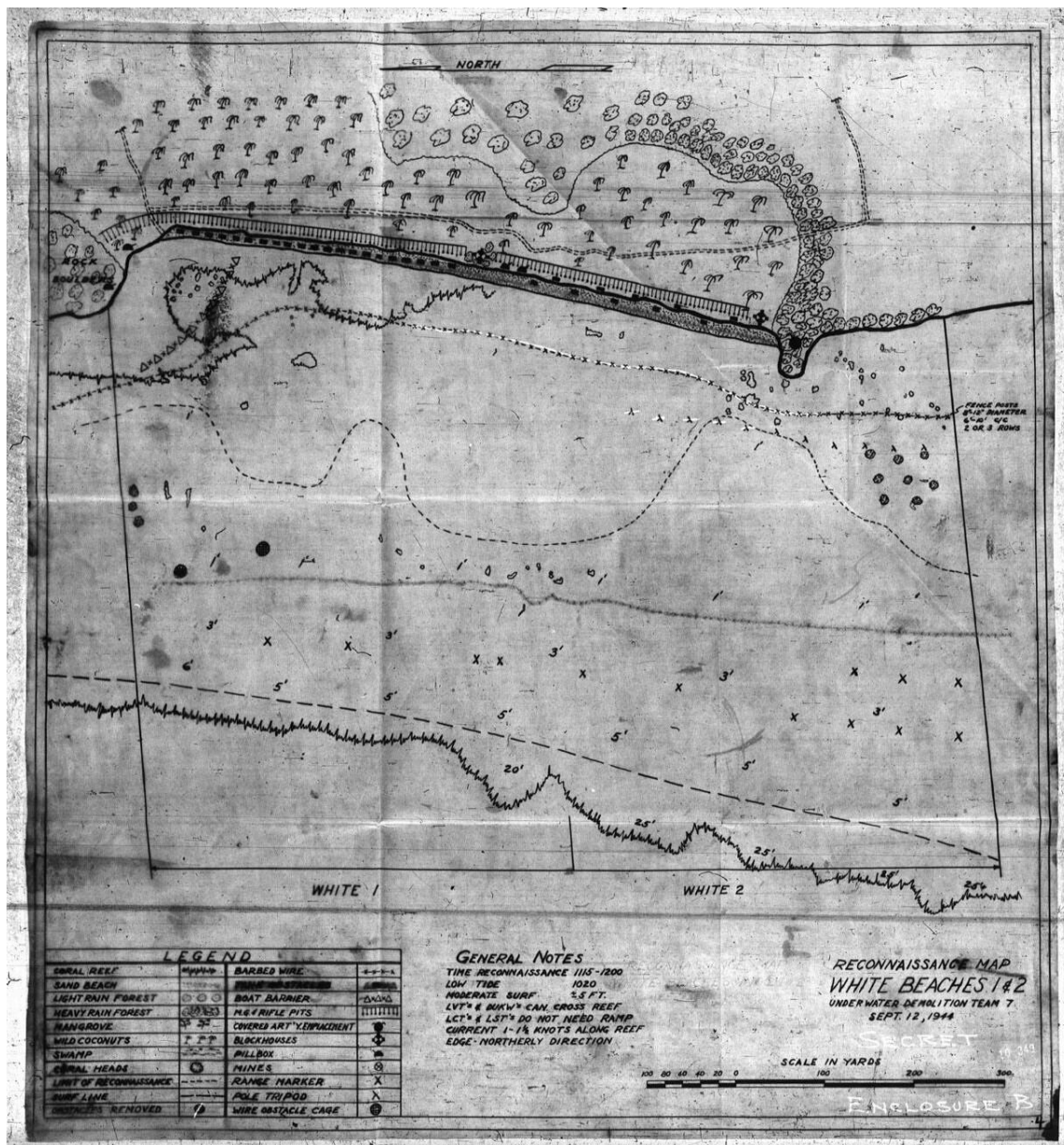


FIGURE 5.4. Reconnaissance map of White Beaches 1 and 2 drawn by UDT 7 (Burke 1944c:4).

Avenues of Approach to the Orange Beaches proved to be more difficult for UDT 6 to clear of Obstacles. UDT 6 performed a daylight reconnaissance (simultaneously with the reconnaissance activities of UDT 7 on White Beaches) of Orange Beaches on 12 September and found “numerous large boulders on Orange Beaches and on the drying shoal, which would require a great deal of demolition work to clear for vehicular roads over the reefs, as well as

many obstacles to be cleared” (Hutson 1944:3; Logsdon 1944:1). The “drying shoal” (referred to by Hutson 1944), or “drying reef” (referred to by Logsdon 1944), was a particularly rock-laden area of reef located south of Orange Beach 3. Carrell et al. (2020) however, refer to the entirety of the reef offshore of the Orange Beaches as a “drying reef,” and as an Obstacle in and of itself, as the depth of water over the reef was typically too shallow for any amphibious craft to pass other than LVTs and DUKWs (Carrell et al. 2020:111). Other Obstacles on Orange Beaches included large boulders, and human-made obstacles such as poles, wooden posts, barbed wire, mines, and bombs (Logsdon 1944:15, 16; Gailey 1983:70). The shallow nature of the reef and the ubiquitous Obstacles required UDT 6 to blast several lanes clear for the passage of amphibious vehicles (FIGURES 5.5 and 5.6). The blast sites examined in this study resulted from explosions at the lip of the reef off the Orange Beaches. The explosions were used to clear passages denoted on Figures 5.5 and 5.6 as “100’ LVT and DUKW passage” (designated Orange 3 Blast), “L.V.T. & DUKW” (designated Orange 2 Blast), and “Clear Passage for LVT & DUKW” (designated Orange 1 Blast).

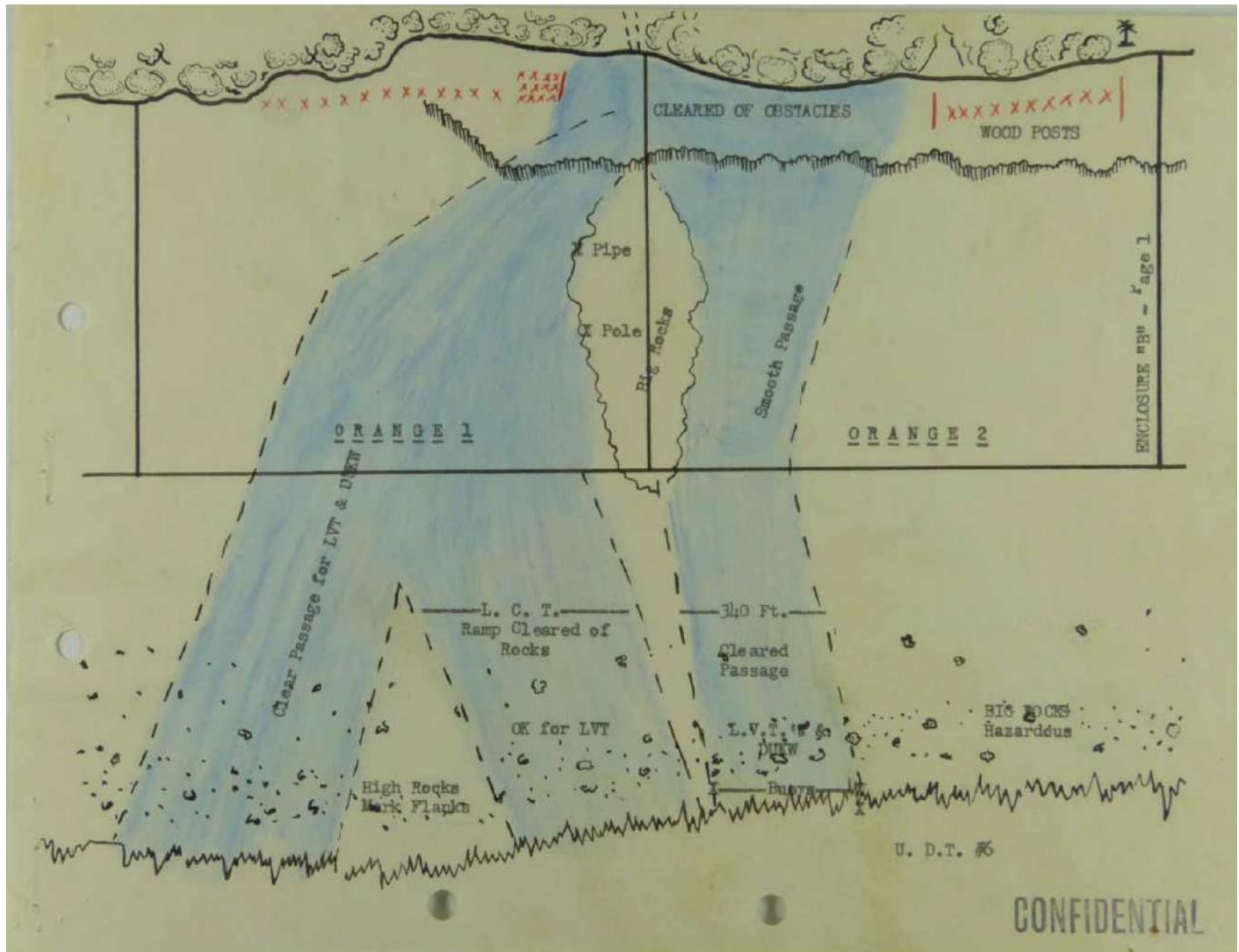


FIGURE 5.5. Reconnaissance map of Orange Beaches 1 and 2 drawn by UDT 6 (Logsdon 1944:10).

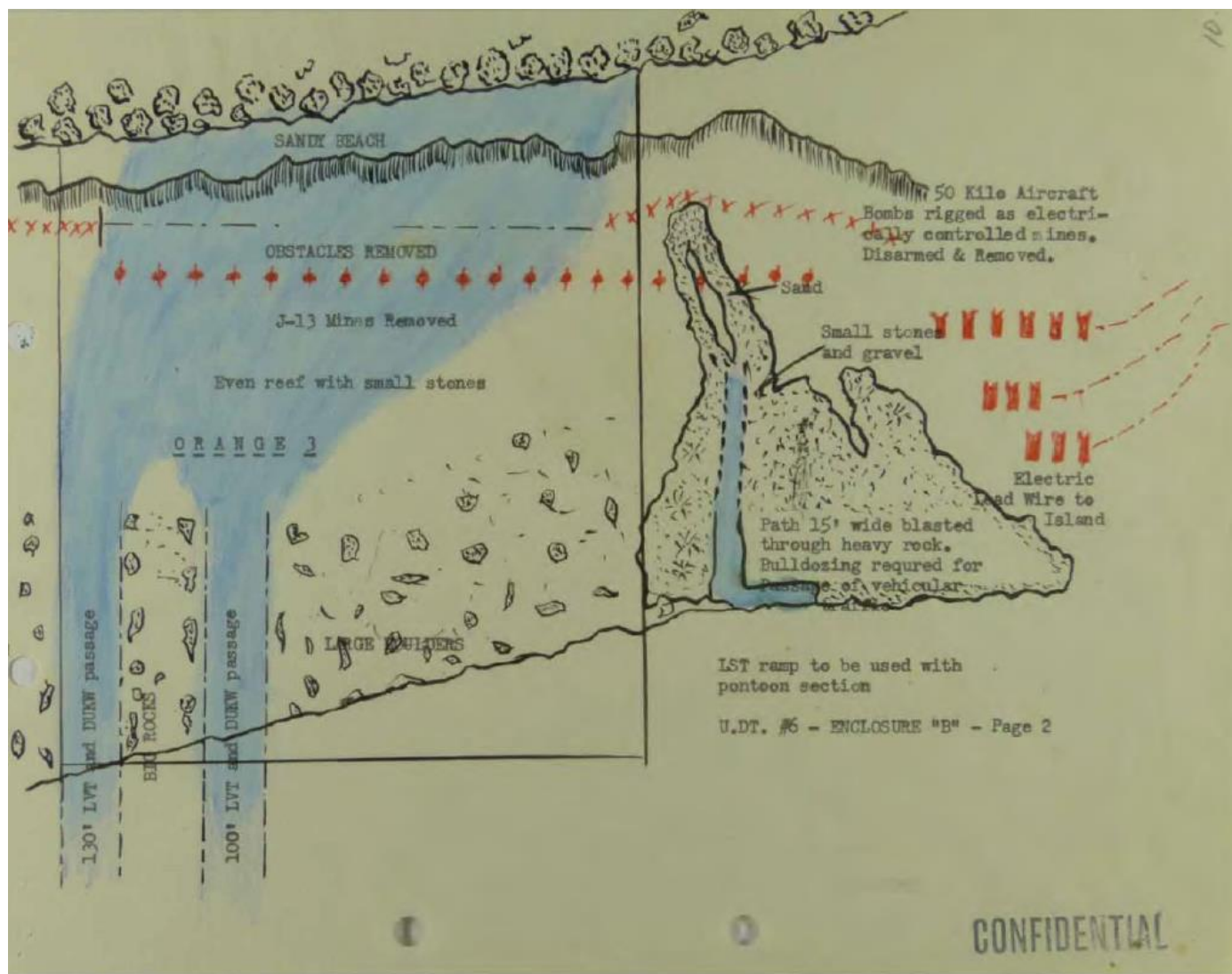


FIGURE 5.6. Reconnaissance map of Orange Beach 3 drawn by UDT 6 (Logsdon 1944:9).

UDT 6 conducted demolition operations on Orange Beach 3 and the drying shoal from 1:00-3:30 A.M in the morning of September 14. They blasted two passages for DUKWs on Orange Beach 3 and blasted a ramp wide enough for two LSTs on the drying shoal. The team continued demolition on September 14, again during daylight hours. They cleared a Landing Craft, Tank (LCT) landing area “and roadways for tanks and DUKWs across Orange 1, two roadways for DUKWs across Orange 2 and checked and spot blasted Orange 3 and the drying reef” (Hutson 1944:2; Logsdon 1944:1).

All these daylight activities occurred under “constant sniper and machine gun fire” from Japanese shore-based forces. The maps drawn by UDT 6 (Figures 5.5 and 5.6) were given to the Commander of the Peleliu Transport Group and to the Orange Beach Control officers on the morning of September 15 (Logsdon 1944:1).

Note that UDT 6 did not remove all Obstacles on the Orange Beaches. As a result, LVTs were “often obliged to pick their way shoreward in column,” presumably through the passages blasted by UDT (Hough 1950:46). Some amphibious vehicles had difficulty negotiating the remaining Obstacles. As recounted for instance in this passage quoting General Oliver Smith, the 1st Marine Division Assistant Commander, describing his approach to Orange Beach 2:

I had planned to go ashore in a DUKW but I got on this control vessel (USS *Hazelwood*) and saw all the burning amphibian tractors and all the mortar fire coming down inside the reef, and I decided I’d rather go in in an LVT that wouldn’t waste any time going across the reef. Eventually they were able to hail an LVT and it came alongside the control vessel and picked me up. I asked the boy who was driving it if he knew the way into the beach and he said yes, he had been in two times, so I said, ‘Okay, we want to go into...’ I think I told him Orange 2 which was the middle beach. He started toward shore and there was mortar fire falling in the water. When he got halfway from the reef to the beach, there was a barbed wire fence that went along parallel to the beach, and he turned north – he could have gone right through that fence but he didn’t – and paralleled the wire. Finally, I told him, ‘Look, you are going to run out of beach here pretty quickly, and we’ve got to move in.’ So he then turned in, and we landed on the north end of Orange... (Gailey 1983:70).

In another example, R. V. Burgin of the 3rd Battalion, 5th Marines described the movements of his LVT, Number 13, as it approached Orange Beach 2:

About seven hundred yards out, Number 13 lurched and halted, pitching us into one another. Treads flailed and something went grinding and scraping beneath our hull. We’d struck a reef. Now the Jap (sic) shells were landing closer — left, right and behind us. We sat there churning the water, and minutes seemed to drag by, though I’m sure only seconds were passing. Our sergeant, Johnny Marmet, leaned forward and stuck his .45 in the driver’s face. “If you don’t get this son of a bitch moving, I’m going to by God shoot you in the head!” he shouted. “We’re sitting ducks out here!” The driver was pushing and pulling controls like a madman, trying to rock a car out of the mud. Treads were

spinning, kicking up spray. Then something gently lifted us and we were moving again (Burgin and Marvel 2010:6-7).

Despite these remaining obstacles however, UDT actions cleared sufficient routes to the beach for a successful invasion.

The results of the KOCOA analysis provide an answer then to one of the primary questions asked in this thesis:

1. How did the activities of UDTs at Peleliu relate to a KOCOA terrain analysis of the Peleliu invasion?

A KOCOA analysis suggests that UDT actions functioned to identify and remove Obstacles to Avenues of Approach for amphibious vehicles transiting across the reef toward the landing beaches, which were both Key Terrain and Decisive Terrain. The tasks assigned to UDTs at Peleliu, as reflected in review documents for the invasion, were explicit in this regard:

- (a) Execute reconnaissance of the reef and approaches to the White and Orange Beaches.
- (b) Remove underwater obstacles and boat mines.
- (c) Blast the lip of the reef to facilitate passage of DUKWs onto the reef.
- (d) Remove coral heads that would interfere with landing troops and equipment by means of LCTs, LVTs, and DUKWs – two, 100 foot channels per beach to be cleared.
- (e) Blast a ramp for LCTs at a suitable place in the reef abreast White Beaches 1 or 2 and Orange Beaches 1 or 2 for unloading tanks.
- (f) Blast ramps for LSTs in the drying reef just south of Orange Beach 3 or on the reefs abreast the Scarlet Beaches (Nimitz 1945:63).

These actions of UDTs at Peleliu occurred within the context of U.S. strategy centered on the seizure of the Peleliu airfield, which was to be used to support the coming invasion of the Philippines. The geomorphology of the island and its associated fringing reef necessitated the tactical use of UDTs for the identification and removal of natural and human-made obstacles to clear access for invading amphibious vehicles.

Biological and Geomorphological Characterization

Structural Complexity

The blast zones Orange 1 Blast (Orange 1 LVT North), Orange 2 Blast (Orange 2 340 ft LVT South), and Orange 3 Blast (Orange 3 100 ft LVT) were documented in their entirety using photogrammetry to produce 3-dimensional (3D) orthophotos and DEMs (Carrell et al. 2020:101) (FIGURES 5.7-5.9).

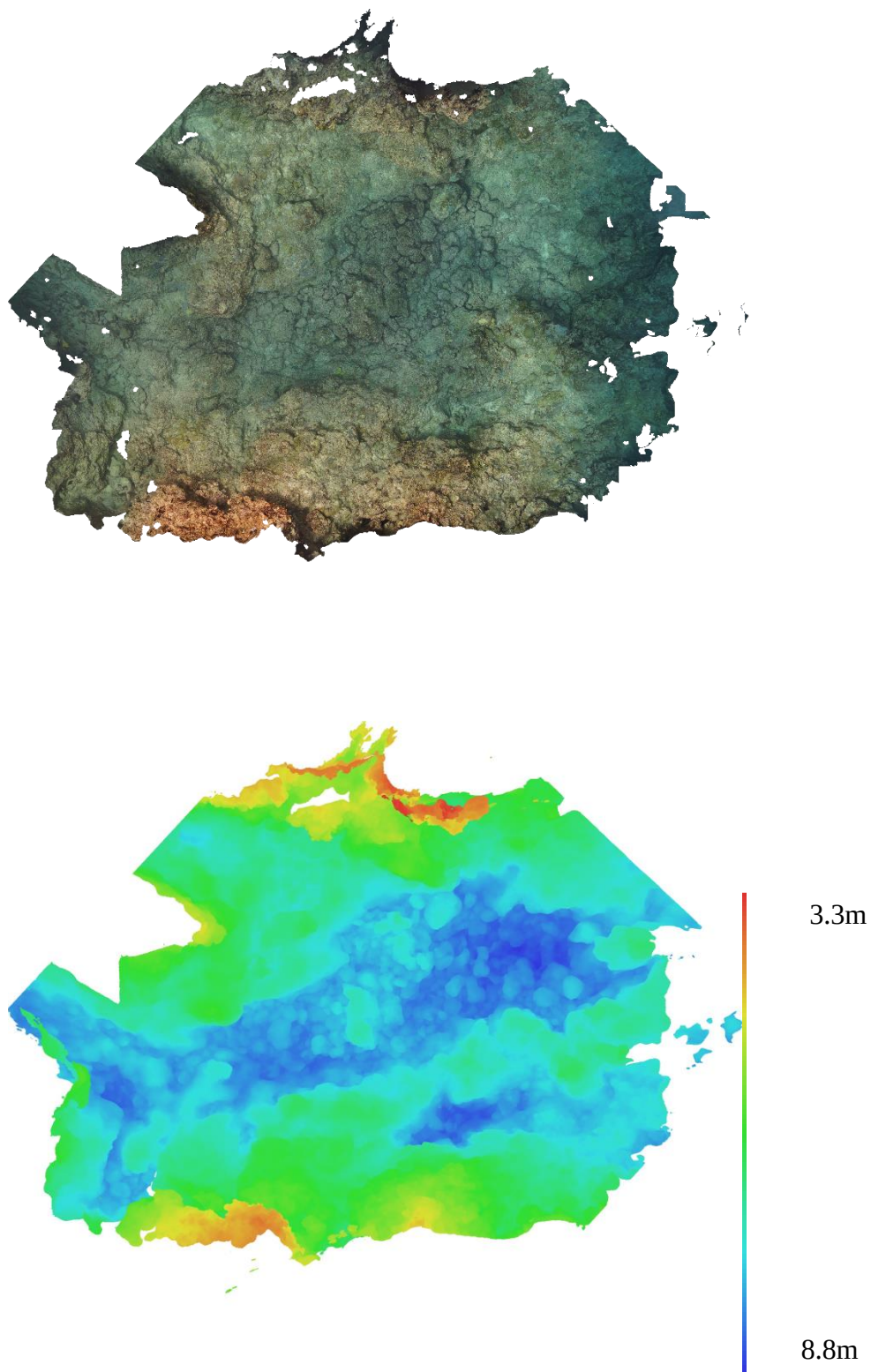


FIGURE 5.7. Orthomosaic and DEM of Orange 1 Blast zone. The zone covers an area of approximately 267 m² and ranges in depth from 3.3m to 8.8 m (Pascoe and Burns, UHH).

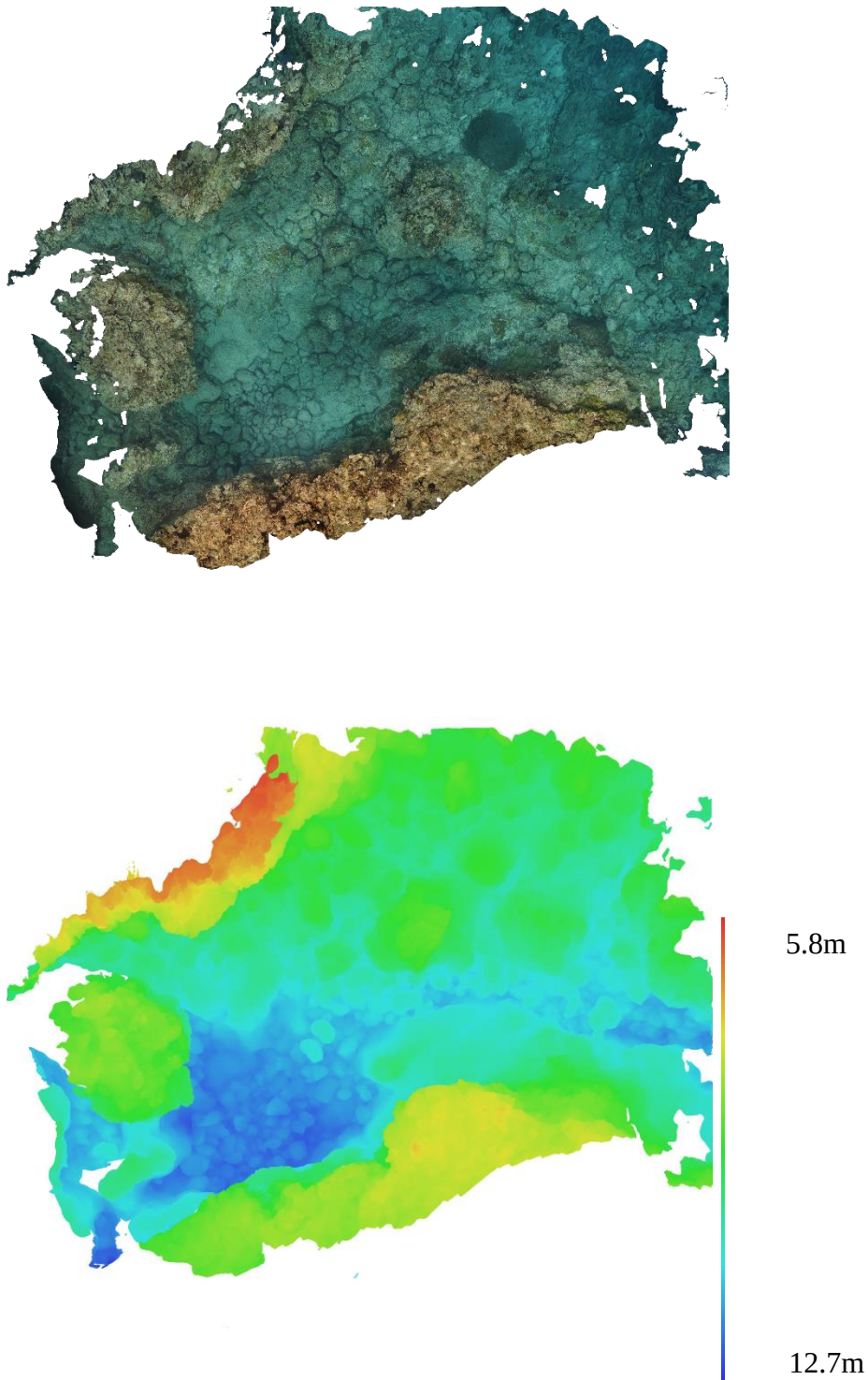


FIGURE 5.8. Orthomosaic and DEM of Orange 2 Blast zone. The zone covers an area of approximately 220 m² and ranges in depth from 5.8m to 12.7 m (Pascoe and Burns, UHH).

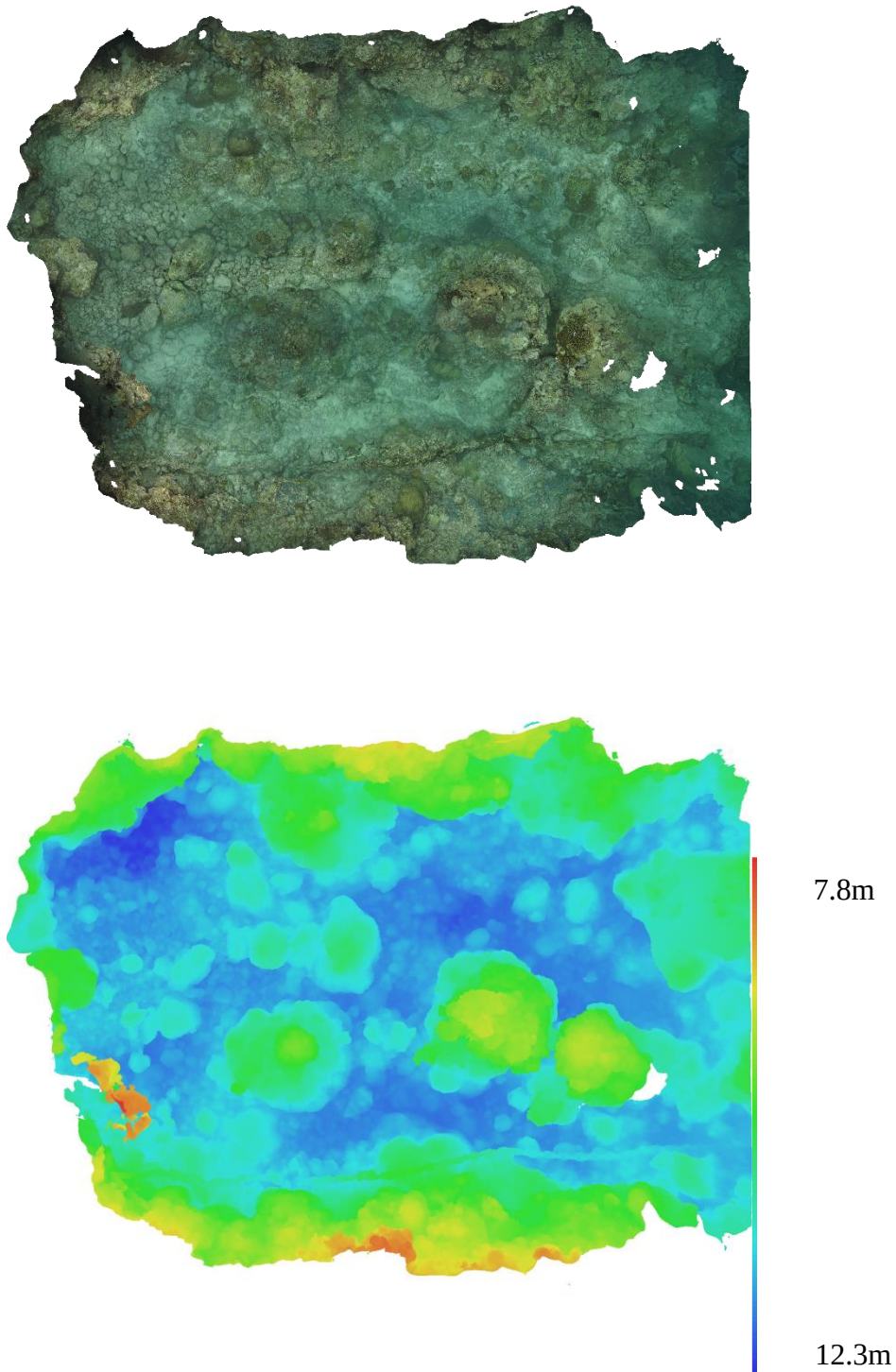


FIGURE 5.9. Orthomosaic and DEM of Orange 3 Blast zone. The zone covers an area of approximately 220 m² and ranges in depth from 7.8m to 12.3 m (Pascoe and Burns, UHH).

The combined area of Orange 1, 2, and 3 Blast zones is roughly 750 m². Blast zones were characterized as depressions, or craters, relative to surrounding geomorphology. The deepest portions of these depressions ranged in depth from approximately 5.5-6.9 m below surrounding areas. Scaled DEMs for these zones were mapped using ArcGIS Pro (FIGURE 5.10).

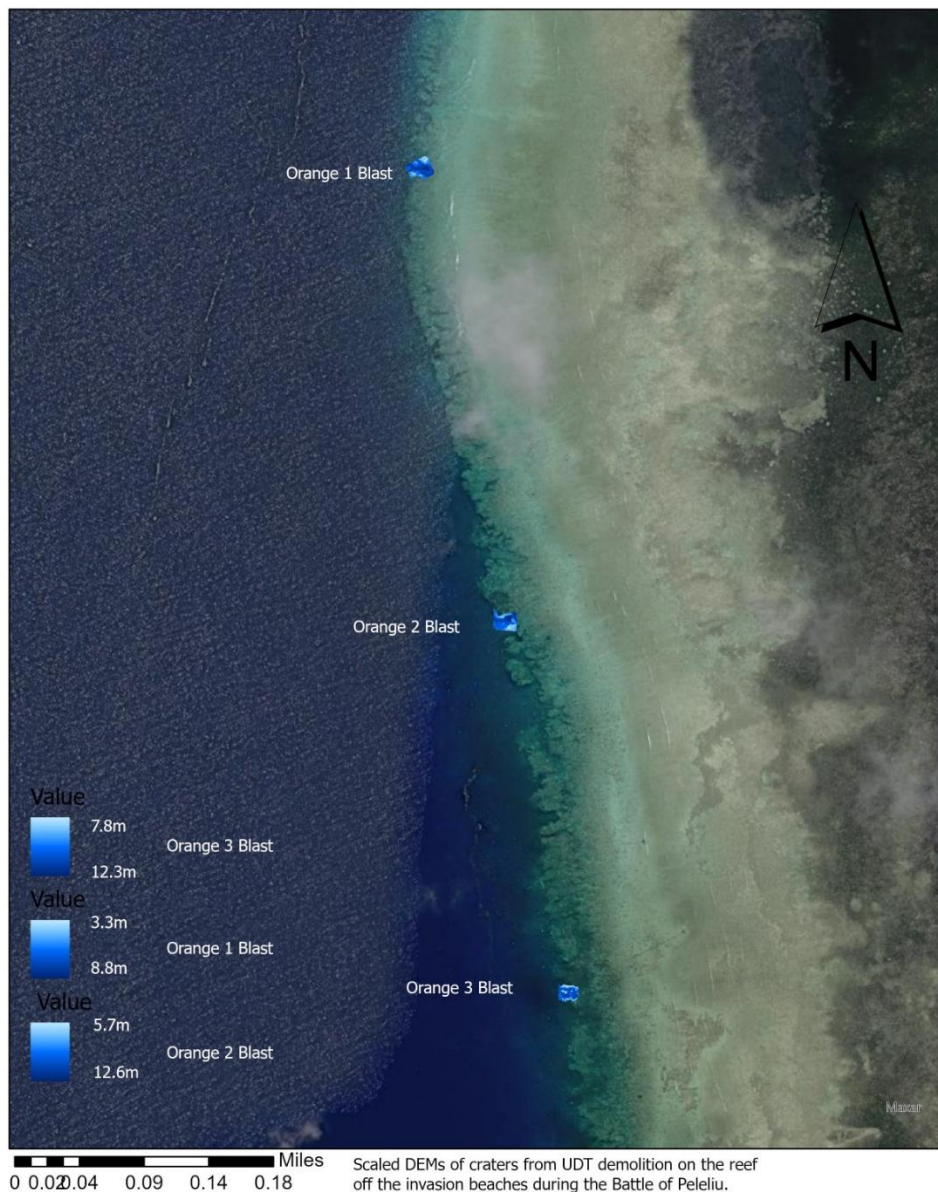


FIGURE 5.10. Scaled, georectified map of Orange Beach blast zone DEMs.

Additionally, characteristic spur and groove (SaG) geomorphology typically present on fore reef slopes was altered at blast sites (John Burn 2018, pers. comm.), and the reef edge in these areas “suddenly drops off to a rock and rubble filled channel” (Carrell 2023). The “spurs” of SaG are carbonate ridges composed of coral and algae, and “grooves” are regularly spaced channels between spurs (Duce et al. 2016:68) (FIGURE 5.11). These are the features reduced to rubble by UDT detonations (FIGURE 5.12).



FIGURE 5.11. Typical SaG geomorphology photographed on the western side of Peleliu. Note the sand-filled channel, or groove, between two ridges, or spurs (Colin 2009:65)



FIGURE 5.12. Detonation site at Peleliu. Note the rubble present below the reef shelf and absence of spurs. <https://oceanexplorer.noaa.gov/explorations/18peleliu/welcome.html>. Accessed 26 November 2023.

Orange Beach blast zones were more complex structurally than undisturbed White Beach areas. 3D surface area complexity is a measure of overall benthic complexity and was calculated by dividing 3D surface area by 2-dimensional planar for each DEM (Burns et al. 2015:10; Carrell et al. 2020:105; Pascoe et al. 2021:3). Orange Beach sites had significantly higher average 3D surface area complexity (mean= 1.806 ± 0.431) than White Beach sites (mean= 1.444 ± 0.334) (Two-sample t-test: $t = 4.4647$, d.f.= 51.334, $p \leq 0.01$) (Carrell et al. 2020:105).

3D surface area complexity increased with depth for both Orange Beach and White Beach zones (TABLE 5.1, FIGURE 5.13). Mean surface area complexity was higher at Orange Beach zones than corresponding White Beach zones (Carrell et al. 2020:105).

Zone	Mean
Orange Beach Shallow (0-15ft)	1.702 ± 0.379
Orange Beach Mid (16-35ft)	1.751 ± 0.194
Orange Beach Deep (36-50ft)	1.941 ± 0.373
White Beach Shallow (0-15ft)	1.464 ± 0.341
White Beach Mid (16-35ft)	1.696 ± 0.070

TABLE 5.1. Mean 3D surface area complexity for various Orange and White Beach depth zones (Carrell et al. 2020:105).

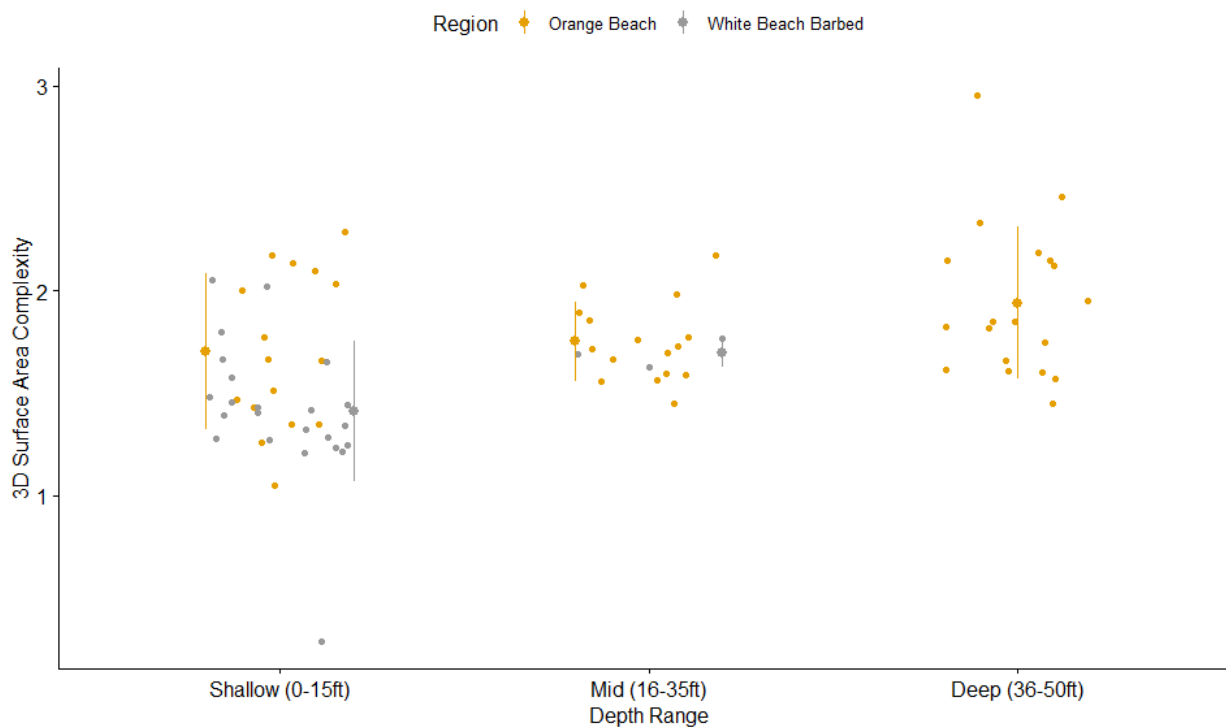


FIGURE 5.13. Average 3D surface area complexity increased with depth at both Orange Beach and White Beach zones (Carrell et al. 2020:105).

Benthic Characterization

Benthos at both Orange and White Beach zones consisted primarily of coral, turf algae, and crustose coralline algae. However, coral percent coverage was approximately 35% in Orange Beach zones, but only about 12% in White Beach zones. Turf algae composed about 50% coverage in White Beach zones, but only 30% in Orange Beach zones. Microalga and invertebrates were considerably less prevalent than the aforementioned benthos in both zones. Rock and rubble were roughly 8% coverage in both Orange and White Beach zones, but more sand was present in the Orange Beach zones. Percent cover of sand in Orange zones was roughly 12%, but only 6% in the White Zones (FIGURE 5.14) (Carrell et al. 2020:102).

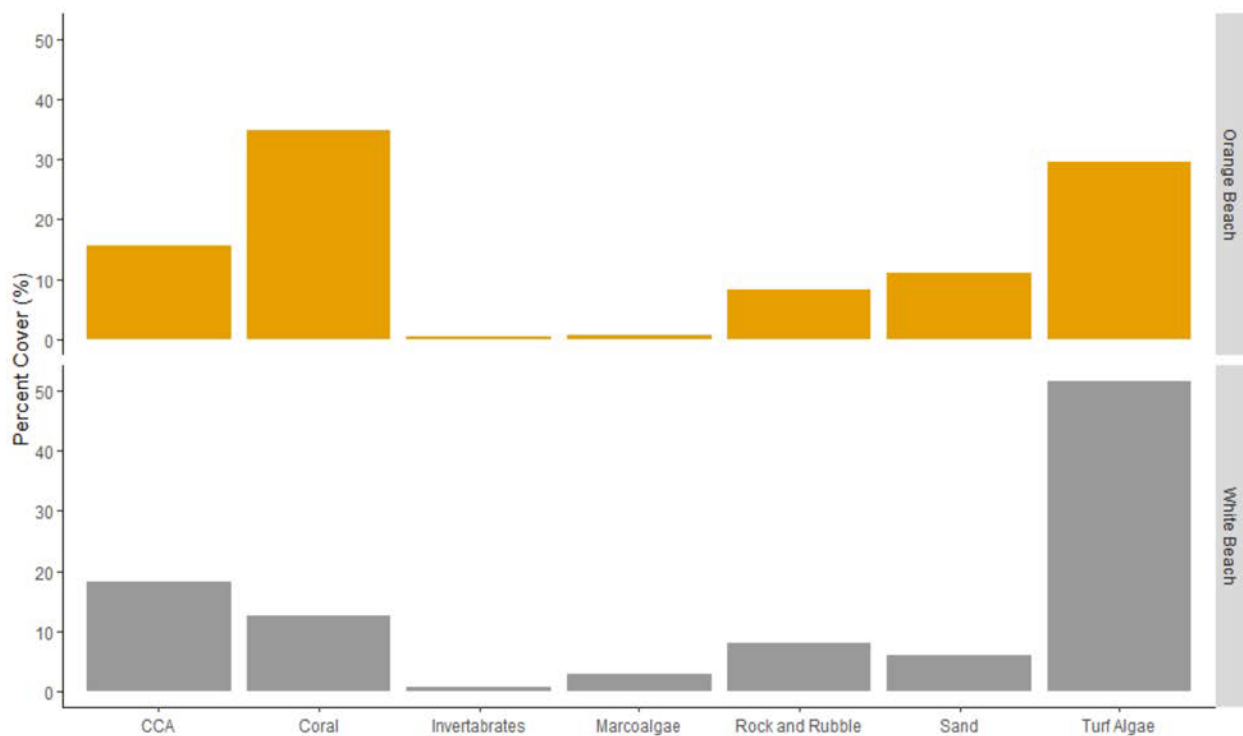


FIGURE 5.14. Benthic types present in Orange Beach and White Beach zones characterized by percent cover of surface area (Carrell et al. 2020:102).

Orange beach coral percent cover was significantly higher than that of White beach zones (Two-sample t-test: White Beach mean percent cover = 12.46 ± 14.90 ; Orange Beach mean percent cover = $34.9\% \pm 26.0$; $t=0.4832$, $df=73.204$, $p \leq 0.01$) (FIGURE 5.15). Additionally, coral percent cover generally increased with depth at both Orange and White beach zones (FIGURE 5.16 and FIGURE 5.17). Shallow (0-15 ft 0-5 m and mid depth categories (16-35 ft, 5-11 m) were created and compared for both White and Orange Beach zones. A deep depth range category (36-50 ft, 11-15 m) was also examined at Orange Beach, but there was no corresponding deep depth range at White Beach because depths beyond the mid-range exceeded this category. Coral percent cover was significantly higher at the deep depth range relative to the shallow depth range at Orange Beach. Coral percent cover was higher for both the shallow and mid depth ranges at Orange Beach zones relative to corresponding depth ranges at White Beach zones (Carrell et al. 2020:103).

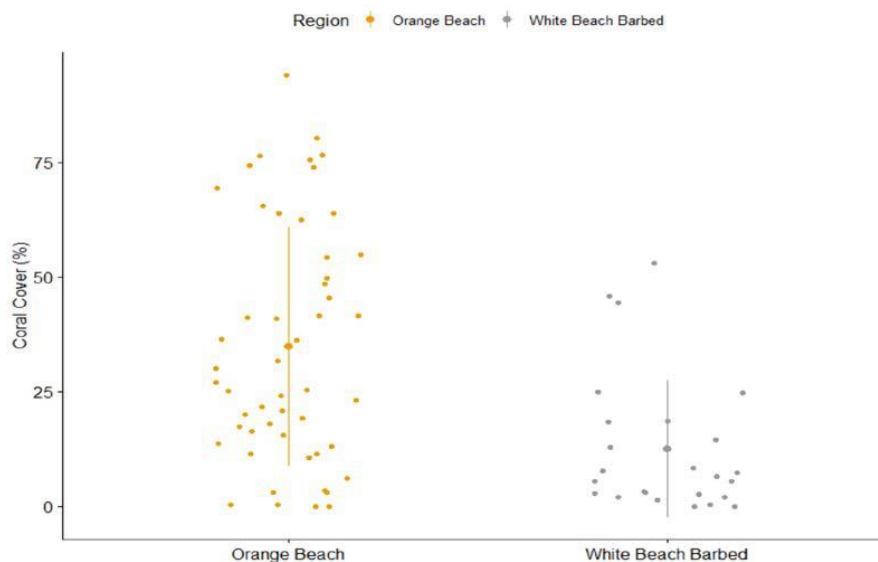


FIGURE 5.15. Percent coral coverage at Orange Beach and White Beach zones. Each scatter plot point represents average percent coverage for each surveyed plot. Average percent cover for each zone in its entirety is represented by a large point along with its respective standard deviation (White Beach zone (mean= 12.46 ± 14.90), Orange Beach zone (mean= $34.9\% \pm 26.0$) (Carrell et al. 2020:104).

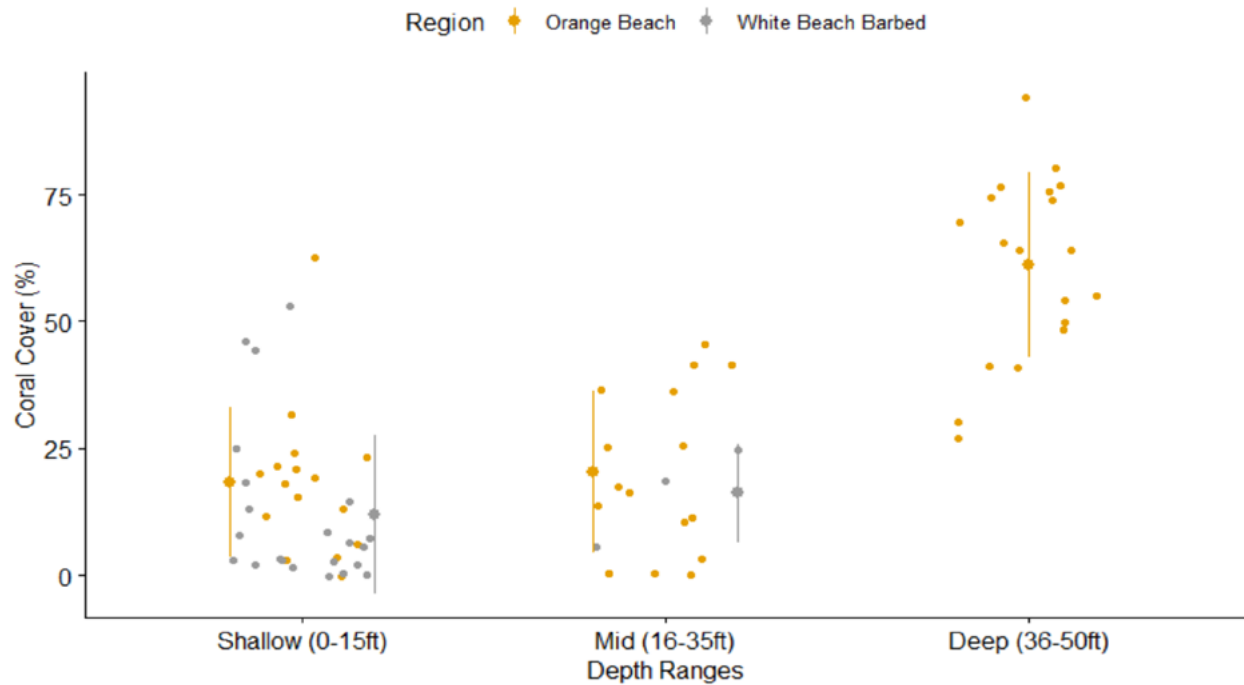


FIGURE 5.16. Average percent coral cover for each plot in shallow, mid, and deep depth ranges at Orange and White Beach zones. Note: there was no depth range between 36-50 ft at White Beach sites because depths exceeded this range. Average percent cover for each depth range for each zone is represented by a large point along with its respective standard deviation (Carrell et al. 2020:104).

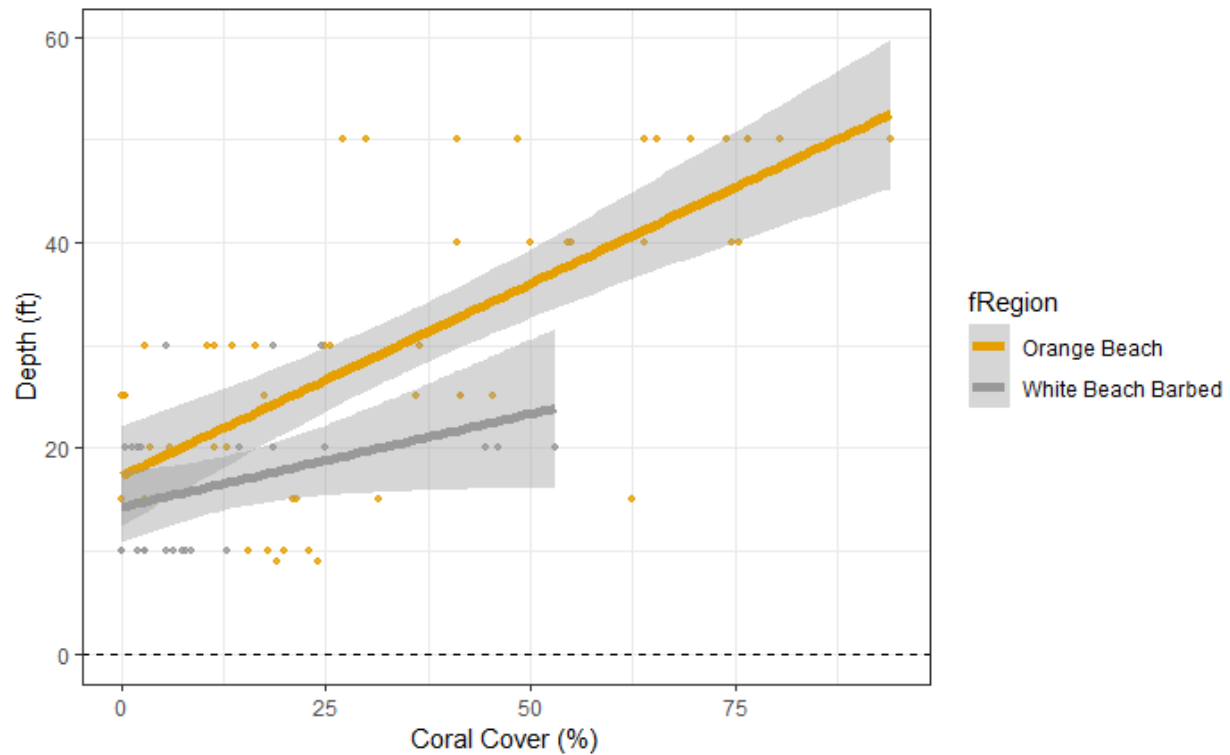


FIGURE 5.17. Percent coral cover increased with depth at both Orange and White Beach zones (Carrell et al. 2020:107)

Genus richness is the number of genera present in a defined area. Coral genus richness did not differ significantly between Orange Beach and White Beach zones. Orange Beach plots averaged six genera present each and White Beach plots averaged five genera present each (Two-sample t-test: $t = 0.77288$, $d.f. = 47.204$, $p = 0.44$). Orange Beach plots exhibited the highest genus richness at the deep depth range (36-50 ft, 11-15 m). The most prevalent genera in the Orange Beach zone by percent cover were *Montipora* and *Porites* at approximately 12% and 19% respectively. *Diploastrea*, *Montipora*, and *Porites* were the most prevalent genera at the White Beach zone. These three genera ranged between five to six percent cover. Both *Porites* and *Montipora* had significantly higher percent coral cover at Orange Beach than at White Beach (Carrell et al. 2020:103, 108) (FIGURE 5.18).

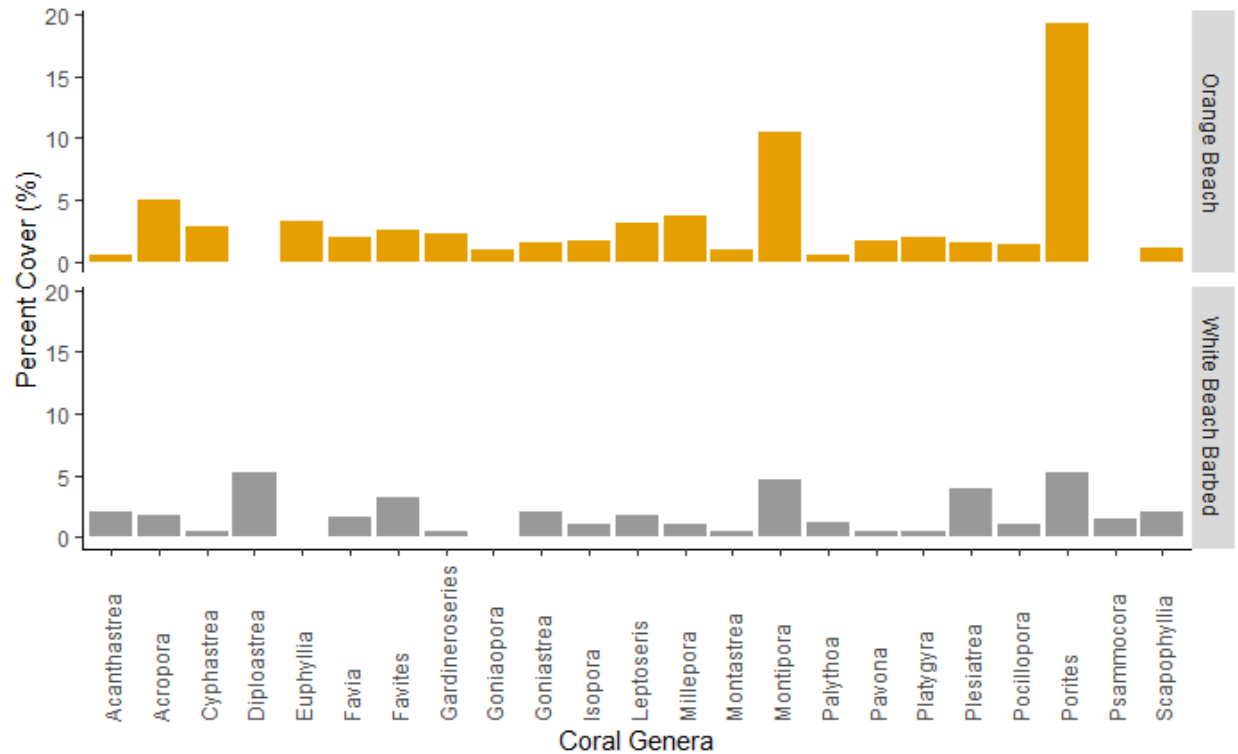


FIGURE 5.18. Percent cover of coral genera found in Orange Beach and White Beach zones (Carrell et al. 2020:103).

The Shannon-Weiner Index indicated that coral diversity was higher in Orange Beach zones than White Beach zones (FIGURE 5.19) (Carrell et al. 2020:105). Diversity is an ecological attribute that can be characterized by considering both richness and evenness. As noted above, richness is the number of genera present in a designated area. Evenness is a measure of the relative abundance of genera within a designated area. The Shannon-Wiener Index (H) is a proportional abundance metric that considers both richness and evenness to estimate diversity (Stirling and Wilsey 2001:286). Additionally, there was a positive linear relationship between genus diversity in both White and Orange Beach zones and 3D surface area complexity in each area – as 3D surface area complexity increased, coral diversity increased (FIGURE 5.19) (Carrell et al. 2020: 106-107).

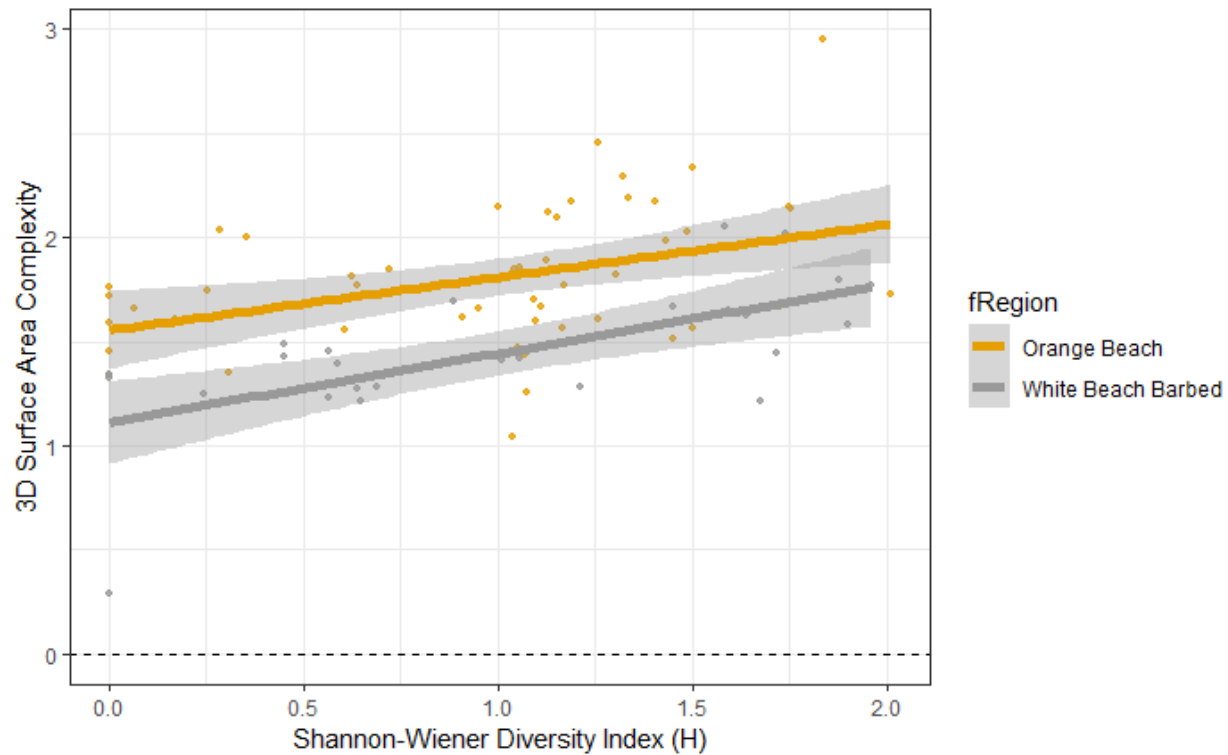


FIGURE 5.19. Coral genus diversity was positively correlated with 3D surface area complexity at both White and Orange Beach zones. (Carrell et al. 2020:106-107). Higher relative diversity is indicated by a higher H value.

Biological and Geomorphological Characterization Discussion

Orange Beach blast zones were found to have higher percent coral cover, surface area complexity, and diversity than undisturbed White Beach blast zones (Carrell et al. 2020:107-108). This finding, of coral recovery after a significant disturbance, stands in marked contrast to other analyses of coral reef habitat and composition following disturbance — many of which found little or no post-disturbance recovery (Fox and Caldwell 2006; Rogers and Miller 2006; Hernandez-Delgado et al. 2014).

Several factors may have contributed to coral recovery from disturbance off Orange Beach. Recovery from disturbance seems to be a function of the spatial and temporal scale of

disturbance. For instance, Fox and Caldwell found that coral cover within craters from single blast fishing events did not differ from undisturbed areas after five years, but that “extensively bombed” sites showed no recovery relative to undisturbed areas after six years (Fox and Caldwell 2006:1631). It is the case that UDT detonations in the Orange Beach blast zones were relatively discreet both spatially and temporally, so repeated disturbance from blasts did not occur, which may have allowed coral to recover.

Time since disturbance may also be a factor in recovery. Data from Peleliu was collected 74 years after UDT detonations occurred. Common coral genera, such as *Porites* and *Montastraea*, average one to ten centimeters in growth annually. This rate of growth over the extended period since the detonations occurred appears to have led to substantial coral recovery (Carrell et al. 2020:107).

Additionally, the significantly greater 3D habitat complexity observed at Orange Beach zones relative to undisturbed White Beach zones may have resulted from geomorphological changes brought about by UDT blasts. The creation of rubble from the blast may have led to increased habitat complexity, which is positively correlated with higher diversity of marine organisms. This was observed at the sites in question, where Orange Beach zones were characterized by greater diversity and significantly higher coral cover relative to undisturbed White Beach zones. This is in keeping with the intermediate disturbance hypothesis (IDH) (Carrell et al. 2020). The IDH predicts that species diversity peaks at moderate levels of disturbance intensity. Systems where disturbances are too frequent tend to have lower diversity, because there is only limited time for colonization to occur, and only those species that can reach maturity quickly can reproduce. Systems where disturbance is very infrequent are also typically characterized by low diversity. The most efficient competitors at exploiting resources will tend to

displace other species in such environments through the process of competitive exclusion (Connell 1978:1303). Disturbance from Orange Beach UDT blasts may have stimulated 3D habitat complexity and provided an intermediate level of disturbance relative to White Beach zones, thus leading to greater coral diversity (Carrell 2020:107).

As previously noted, *Porites* and *Montipora* composed a significantly higher percentage of coral cover at Orange Beach zones compared to White Beach zones. Higher 3D complexity at Orange Beach zones arising from UDT detonations may have created conditions that *Porites* and *Montipora*, both dominant coral genera, were able to exploit (Carrell et al. 2020:108).

These results then, provide answers to several of the questions this thesis seeks to answer:

2. Are areas where UDT blasts occurred on the reef discernable from undisturbed areas not subject to blasts?

Yes, UDT blast zones were characterized by the presence of rubble, depressions, and the obliteration of typical reef spur and groove geomorphology.

3. Do the geomorphological characteristics of disturbed areas differ from those of undisturbed areas?

Yes, surface complexity was significantly higher in the disturbed areas of blast zones relative to undisturbed areas where blasts did not occur. This may be attributed to the presence of greater quantities of rubble in disturbed areas relative to undisturbed areas.

4. Does coral reef genus diversity and percentage cover differ between disturbed areas and undisturbed areas?

Yes, coral reef genus diversity and percentage cover were higher in disturbed areas than undisturbed areas. Diversity is an ecological attribute that encompasses both richness, the relative number of genera in a given area, and evenness, the relative abundance of genera in a designated area. Although genera richness did not differ significantly between disturbed and undisturbed areas, A Shannon-Wiener Diversity Index, which takes both richness and evenness into account, did indicate that disturbed areas in blast zone had more diversity than undisturbed areas. Furthermore, coral diversity showed a positive relationship with higher 3D surface area complexity, which was found in disturbed areas relative to undisturbed areas.

The coral reefs subjected to UDT blasts appear to have recovered then, as far as diversity and higher coral coverage relative to undisturbed areas are concerned. Nonetheless, these areas have been altered geomorphologically, as exemplified by the presence of the aforementioned craters, rubble, and the obliteration of typical spur and groove geomorphology.

Peleliu and Warfare Ecology

Peleliu, and the effects of UDT explosions on its reef, may be placed within the warfare ecology framework. The preparation phase of warfare on Peleliu entailed the building of the airfield on the southern end of the island, and the fortification of the island by Japanese forces. Both processes changed land use patterns and altered the ecology of Peleliu.

Construction of the airfield began in 1938 and was completed by 1940. All residents from two (Teliu and Ngerkeyukl) of the five Palauan villages on Peleliu were removed, and farmland was taken from a third (Ngesias) to make way for the airfield. The villagers who moved cleared land for houses and new gardens both on “public land” and on a small island located near the

village of Ngerdelolk. Workers constructing the airfield “cleared forests and plantations and leveled or filled terrain that extended from Ngesias all the way to the southwest coast” (Murray 2016:70). All the land used for the airfield “was valuable as a source of wild plant food, wood, materials, crabs, or medicine plants” (Murray 2006:159-167). The final airfield installation was substantial in area covered and consisted of several buildings and radios towers as well as two runways, the longest of which extended over 1000 ft (300 m) (Gailey 1983:43).

The construction of fortifications began in earnest in early 1944, following a bombing raid on the airfield carried out by U.S. Navy carrier-based airplanes (Murray 2006:177; Browne 2016:55). Some 500 caves were used by Japanese forces on Peleliu, 200 of which were wholly artificial, while the other 300 were natural. The majority of these natural caves were “improved” to one degree or another. Improvement typically consisted of leveling the floor, removing hanging rocks, controlling seepage, and enlarging them. Sometimes multiple entrances or tunnels used to join caves were constructed (Phelan 1945:2, 25).

Cave ecosystems are known to be incredibly fragile and vulnerable to disturbance (Wynn and Pleytex 2005:148). Little is known however about the effects of World War II perturbations on these environments in Peleliu. Caves in Peleliu are used extensively by the critically endangered Pacific Sheath-tailed bat (*Emballonura semicaudata*). The current population status of the species is unknown, as there have been no recent surveys conducted (Waldien and Scanlon 2021:1). The species was present in the “Thousand Man Cave” on Peleliu in 2018 (personal observation), and archaeologists Price and Knecht (2012:40) noted bat colonies in caves as well.

In addition to fortifying caves, Japanese forces built large numbers of pill boxes to defend against invasion. They also dug anti-tank trenches off potential invasion beaches. In particular,

these stretched intermittently behind White and Orange Beaches, and were 8 ft (2 m) deep and 10 ft (3 m) wide (Isely and Crowl 1951: 404).

Machlis and Hanson (2008:730) state that war is “largely distinguished by immense and concentrated energy flows... severe disturbances” and “habitat destruction”. This certainly characterizes crucial aspects of the Battle for Peleliu. During the second stage of the warfare ecology taxonomy on Peleliu — war — some 6,000 tons of shells were fired by ships, 800 tons of bombs were dropped by aircraft, 16 million rounds of ammunition were fired, and 116,000 hand grenades were used (Weiss 2019:43). Note that this incredible volume of weaponry does not include that expended by U.S. Army or Japanese forces (Murray 2006:216). Incendiary weapons, including flamethrowers and bombs containing napalm, were also used by U.S. forces (FIGURE 5.20 and 5.21). The use of this weaponry destroyed nearly all the vegetation on Peleliu (Baker 1946:206, Defilipps 1987:48).

This was particularly the case in the highlands of the Umurbrogol, where some of the fiercest fighting occurred (FIGURE 5.22). One Marine wrote movingly of the forbidding aspect of this landscape during the battle:

Old Marines talk of Bloody Nose Ridge as though it were one, but I remember it as a series of crags, ripped bare of all standing vegetation, peeled down to the rotted coral, rolling in smoke, crackling with heat and stinking of wounds and death. In my memory it was always dark up there, even though it must have blazed under the afternoon sun, because the temperature went up over 115°, and men cracked wide open from the heat. It must have been the color of the ridge that made me remember it as always dark — the coral was stained and black, like bad teeth (Davis 1961:90).



FIGURE 5.20. Flamethrower mounted on an LVT firing at enemy strongpoints on Peleliu (Naval History and Heritage Command).



FIGURE 5.21. Napalm strike by U.S. Marine corsair on Japanese emplacements (Hough 1950:178).



FIGURE 5.22. U.S. Marines approach Peleliu highlands. Note the lack of living vegetation (Hough1950:141).

U.S. forces altered the geomorphology of the terrestrial landscape during the battle as well. For instance, they purposely demolished cliffs with artillery, then used the resulting rubble to build ramps for tanks to climb into better assault positions (Gale 1996:38). One such ramp constructed in the Omleblochel Mountains was over 70 m in length (Price and Knecht 2012:9).

UDT detonations off the Orange and White invasion beaches altered reef geomorphology, as noted previously in this thesis. Additionally, UDTs 6 and 7 conducted demolition projects off other beaches during the week immediately following D-day (September 15). UDT 6 blasted a channel for LSTs off Scarlet 1 beach, and UDT 7 removed obstacles off

Scarlet 1, 2, and 3 Beaches. UDT 7 also created a channel off Purple Beach for LST landings (Burke 1944c:5; Logsdon 1944:2). Detonation sites off Purple and Scarlet Beaches were not examined in this study, so their effects on the reef are unknown.

Organized resistance by Japanese forces on Peleliu ended in late November 1944. This marks the end of the second stage of warfare on Peleliu, although small numbers of surviving Japanese soldiers continued fighting well into 1945. Additionally, planes launched from the Peleliu airfield conducted sorties against targets in Palau until nearly the end of the war (Hough 1950:178; Ross 1991:348; Hallas 1994:278).

So, fighting continued, but without associated ecological ramifications on a large scale. In a sense then, the second stage overlapped with the third and final stage of warfare — postwar activities. This is in keeping with Machlis and Hanson's (2008) concept of the taxonomy of war. They note that stages often overlap, such as when war preparations overlap with reconstruction activities (Machlis and Hanson 2008:730).

The stage of postwar activities was initially characterized by the development of Peleliu by American forces into a base that housed thousands of personnel (Murray 2006:265). This process entailed lengthening and expanding the airfield and building roads. It also involved constructing numerous buildings including two hospitals, two chapels, and housing for the various personnel stationed at Peleliu (FIGURE 5.23 and FIGURE 5.24). Additionally, construction battalion personnel dredged a harbor on the southern end of Orange Beach (Murray 2006:222).

The people of Peleliu were not allowed to return to their island until June 1946. What they found was shocking — near total deforestation and the destruction of “almost every structure that had existed before the battle” (Murray 2006:266). All five villages had been obliterated (Murray

2006:266-267, 271). Peleliu was unrecognizable — “the war meant ecological and social destruction, really the abrupt loss of an entire way of life” to the native residents of Peleliu (Murray 2006:267,224).



FIGURE 5.23. Aerial photographs depicting Peleliu before the U.S. invasion, and after the expansion of the airfield. Note the deforestation on the southern end of the island evident in the post-battle photo relative to the conditions present in the pre-invasion photo (Fein and Hulteen 1946:32).



FIGURE 5.24. Orange Beach with view to the North. Photo taken in July 1945. Note the total absence of vegetation in this formerly heavily forested area. Indeed “many features relating to the beach landings had been destroyed by the American reconstruction and expansion of the airfield” (Knecht et al. 2012:50).

The effects of the second stage of warfare remain evident on Peleliu. The U.S. Navy closed their base and left Peleliu in May 1948 (Murray 2016:129). Most of the base buildings are no longer present on the island, but some foundations remain (Denfield 1988:57-59). The harbor remains as well. These sites are surrounded by second growth forests which dominate much of the landscape and have grown to generally replace the forests present before the battle (Baker 1946:209; Kluge 1969:22; Government of Palau and the National Park Service 1991). Several invasive plant species likely brought to Peleliu during the war and are now present on the landscape. These include the small tree *Timonius timon*, which is now a dominant species on the island, and the shrubs *Pluchea carolinensis* and *Maesa tetrandra*, both of which are found

growing alongside the airfield (Fosberg and Sachet 1987:164; Space et al. 2008:15; Costion 2011:48, 2013:27).

Approximately 6% of ordinance used in World War II failed (Price and Knecht 2012:15). Given the vast amount of ammunition used during the Battle for Peleliu then, a significant amount of UXO remains on the landscape. Further, this aged UXO is “unstable and subject to spontaneous detonation” (Price and Knecht 2012:15). This UXO is “present everywhere by the thousand” and so makes travel through the island landscape hazardous and limits the ability of Palauan’s to utilize the land as they may wish (Price and Knecht 2012:20). Additionally, islanders used UXO for blast fishing. Fishing in this manner occurred through the 1960s in Palau, with potentially devastating consequences for reefs (Naughton 1985:16).

This thesis addresses elsewhere how the reefs of Peleliu developed after UDT detonations occurred. However, UDT explosions were not the only source of reef disturbance. Deforestation resulting from the battle may have led to erosion and the subsequent accumulation of sediment on reefs. Reef flats prior to the battle were characterized by the presence of white sand. But Palauans reported that, post-battle, the “bottom changed to a dark, muddy silt, and a type of seaweed began to grow thickly” (Murray 2016:126). This was a fundamental change to the shoreward reefs off Peleliu that altered species composition. Additionally, the people reported that fish stocks were reduced, and their species composition changed. These stocks never returned to prewar levels. Furthermore, fish caught off the invasion beaches themselves “made people nauseated, but we didn’t know why” (Murray 2016:126).

Chapter 6. Conclusion

This thesis has sought to provide a historical analysis of the development and actions of UDTs on Peleliu, and to characterize the geomorphological and ecological effects of the invasion on the coral reefs of the landing beaches. The actions of UDTs were part of an evolution in tactical response to the challenges presented by the unique environments of Pacific Islands. UDTs were integral to successful amphibious invasions by identifying and clearing avenues of approach for landing craft through reefs to successfully access invasion beaches. Detonations triggered by UDTs left lasting and identifiable alterations to the geomorphology of the coral reefs of Peleliu. These disturbed reefs, however, have recovered coral diversity and coral coverage.

The areas disturbed by UDT blasts may have meaning beyond that of ecology, however. One member of UDT 7, Edwin R. Ashby, characterized the emotional toll of participating in UDT actions as such:

Each time we went in on an operation, it was a little harder than the time before to get yourself up for the mission. The first time was the easiest. You hadn't been through it before and you didn't really know what to expect, even though you had heard all the stories from the other guys who had already been there. You always had to get yourself in the right state of mind so you were sure you would have the strength and not fall apart when you had to do your job.

As soon as the stuff started flying, the whole situation started to seem a little like a dream. It was happening all around you, but it didn't seem real. You would psych yourself up and even the sound of the shells and rifle fire seemed to get less. They were kind of muffled, though you could still hear everything.

But you just kept going, did your job, and turned back out to sea for pickup. It wasn't until you got back aboard ship and everything was over that maybe your hand would start to shake a bit, or you got the funny feelings in your stomach (Ashby in Dockery 2001:115).

These archaeogeomorphological features on the reef may, in some sense, embody the violence associated with the invasion, and the courage and fear of those caught in the whirlwind of war, as exemplified in the passage above. They are tangible manifestations of the battle for Peleliu and are cultural heritage. They are difficult for people to access, and perhaps difficult to recognize for those unfamiliar with coral reefs, but nonetheless carry meaning similarly to other World War II underwater cultural heritage sites such as airplanes and shipwrecks.

The recovery of coral reefs at the sites of UDT detonations is an encouraging development for an island that was changed so much ecologically by the fighting during the battle for Peleliu. This is positive too for the people of Peleliu, whose very lifeways were altered so much by a war that was not theirs. And yet the scars of war remain on the reef, and are evident in the remaining rubble and craters. These remnants evoke those swimmers of the UDTs, clad only in shorts and facemasks, and laden with explosives as they swam from boats toward certain danger. This cultural heritage remains, and lies under the waves that continue to lap at the shores of an island that witnessed so much death and destruction, but is healing.

Future Research

UDTs were active in every major Pacific amphibious assault after their formation in 1943. These operations included Saipan, Tinian, Guam, Iwo Jima, Okinawa, and many others. Certainly not every beach reconnoitered by UDTs underwent demolition, but many did. These are potential sites for future research to determine how the coral reefs in these locations were affected by the war and to gauge their potential recovery. In particular, it would be valuable to examine the reefs of Purple and Scarlet Beaches at Peleliu, where UDTs undertook demolition in

the post-assault phase of the battle. Did those reefs recover in a manner similarly to those examined in this thesis?

Another location of interest to examine would be Saipan, where demolition was done by UDTs on the reefs off the Blue Beaches. Researchers from a variety of institutions have been working in Saipan for more than a decade focusing on World War II-related cultural heritage projects (McKinnon 2023:239). Their research has been multidisciplinary in nature, but underwater cultural heritage has featured prominently. They have worked closely with local community members in their research, and it would be valuable to have local engagement in the analysis of Saipan's reefs.

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