

Article

Locating War Beneath the Waves: Archival-Guided Multidisciplinary Documentation of World War II Blast Features in Guam

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Abstract

The National Park Service conducted an amphibious battlefield survey in 2023 of the Agat and Asan Beach Units of War in the Pacific National Historical Park, Guam. This exploratory project used a multidisciplinary approach to further understanding of the 1944 Battle of Guam, one of the most significant invasions of the Pacific Theater during World War II. As part of the project, the team located and documented blast features created by U.S. Navy Underwater Demolition Teams during the removal of obstacles placed on and near the landing beaches by the Japanese as deterrents. The discovery of these blast features was guided by archival research and documented through photogrammetry, bathymetry, and RTK GNSS surveys. The blast features represent intentional modification to the seafloor and were examined in archaeological and ecological contexts. This article discusses the discovery and documentation of the blast features, the long-lasting impact of World War II on the island, the value of integrating cultural and natural resource studies, and implications for maritime heritage research and management. This article concludes with considerations for future directions for archaeological and multidisciplinary research focused on seafloor modification.

Keywords: World War II; archival research; photogrammetry; bathymetry; RTK GNSS surveys; amphibious battlefields; seafloor modification

1. Introduction

Recent underwater archaeological work in the Pacific [1–3] demonstrates that submerged blast features associated with World War II amphibious operations, particularly those created by U.S. Navy Underwater Demolition Teams (UDTs), constitute an important and increasingly acknowledged type of underwater cultural feature. Research such as Carrell et al. [1] and Keusenkothen's [2] study of the amphibious battle at Peleliu shows that these features can be identified and interpreted archaeologically, despite their often subtle appearance, especially as they integrate into reef environments over time. The documentation of blast features is part of an emerging area of research within Pacific conflict archaeology that expands archaeological focus beyond typically considered World War II sites, such as shipwrecks, to encompass broader submerged amphibious conflict landscapes [4,5].



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Amphibious warfare in World War II was an environmental process. Amphibious operations required the deliberate modification of coastal and submerged nearshore environments to enable beach landings, the movement of personnel, and the neutralization of natural and man-made obstacles intended to restrict the transfer of troops and equipment from the water to shore. In the Pacific Theater, these operations frequently took place in shallow-water reef settings, where underwater demolition and pre-invasion bombardment directly altered the seafloor and associated habitats [2,6–10]. The resulting blast features represent intentional, material interventions in marine environments and offer a valuable lens for examining the interaction between military activity and coastal ecosystems in the context of war.

This article presents results from an amphibious archaeological investigation conducted by the National Park Service (NPS) in 2023 as part of a NOAA Ocean Exploration-supported expedition. The project was conducted at two units of War in the Pacific National Historical Park on the western coast of Guam: the Asan Beach Unit and the Agat Unit (Figure 1).

The park was established in 1978 with the mission “to commemorate the bravery and sacrifice of those participating in the Pacific Theater of World War II and to conserve and interpret outstanding natural, scenic, and historic values and objects on the island of Guam for the benefit and enjoyment of present and future generations” [11]. In support of the park mission, the primary goals of the project were to: identify and document coastal and submerged archaeological features related to the World War II 1944 Battle of Guam, including blast features created by UDTs; reconstruct the battlescapes of the Agat and Asan Beach Units; and investigate changes to the coastal and offshore environments that may be due to World War II activities and modern-day impacts. Due to its exploratory nature, this project was intentionally broad in scope and employed a wide range of complementary remote sensing technologies (side-scan sonar, multibeam bathymetry, magnetometer, photogrammetry, and terrestrial LiDAR), diver-based documentation methods, and community engagement. The work discussed in this article is a subset of the wider project goals and findings (detailed in Wright Nunn et al. [3]), focused on the blast features identified inside the reef flat at the Asan Beach Unit and on the reef crest at the Agat Unit. The reef crest is the highest, most seaward edge of a coral reef, acting as the primary barrier that breaks incoming ocean waves.

Using a combination of archival research, georectified historical maps, and diver investigation supported by in-water navigation tools, the team located the blast features and documented them using photogrammetry, multibeam bathymetry, and RTK (real-time kinematic) GNSS (Global Navigation Satellite Systems) surveys. Guam provided an especially suitable setting for this work. The island was the site of extensive amphibious operations prior to and during the 1944 Battle of Guam, and its shallow reef environment closely links submerged and terrestrial wartime actions. The project combined archival records of amphibious operations with underwater investigation, which allowed the blast features to be examined not as isolated archaeological anomalies, but as components of a coherent amphibious conflict landscape and in the context of the broader natural environment. This research demonstrates the value of multi-disciplinary exploratory projects that integrate terrestrial and submerged lands, documented by a variety of technology and methods.

By building off prior research in the Pacific and applying a systematic methodology, this study contributes to a growing recognition of submerged blast features and amphibious operations-related materiel as archaeologically significant features. More broadly, it demonstrates how the study of underwater conflict landscapes can demonstrate the lasting environmental impacts of World War II-era amphibious operations. The methods and interpretations presented here are intended to be applicable to other Pacific battlefields

and to shallow-water conflict zones elsewhere, where similar forms of wartime seafloor modification took place and may still exist.

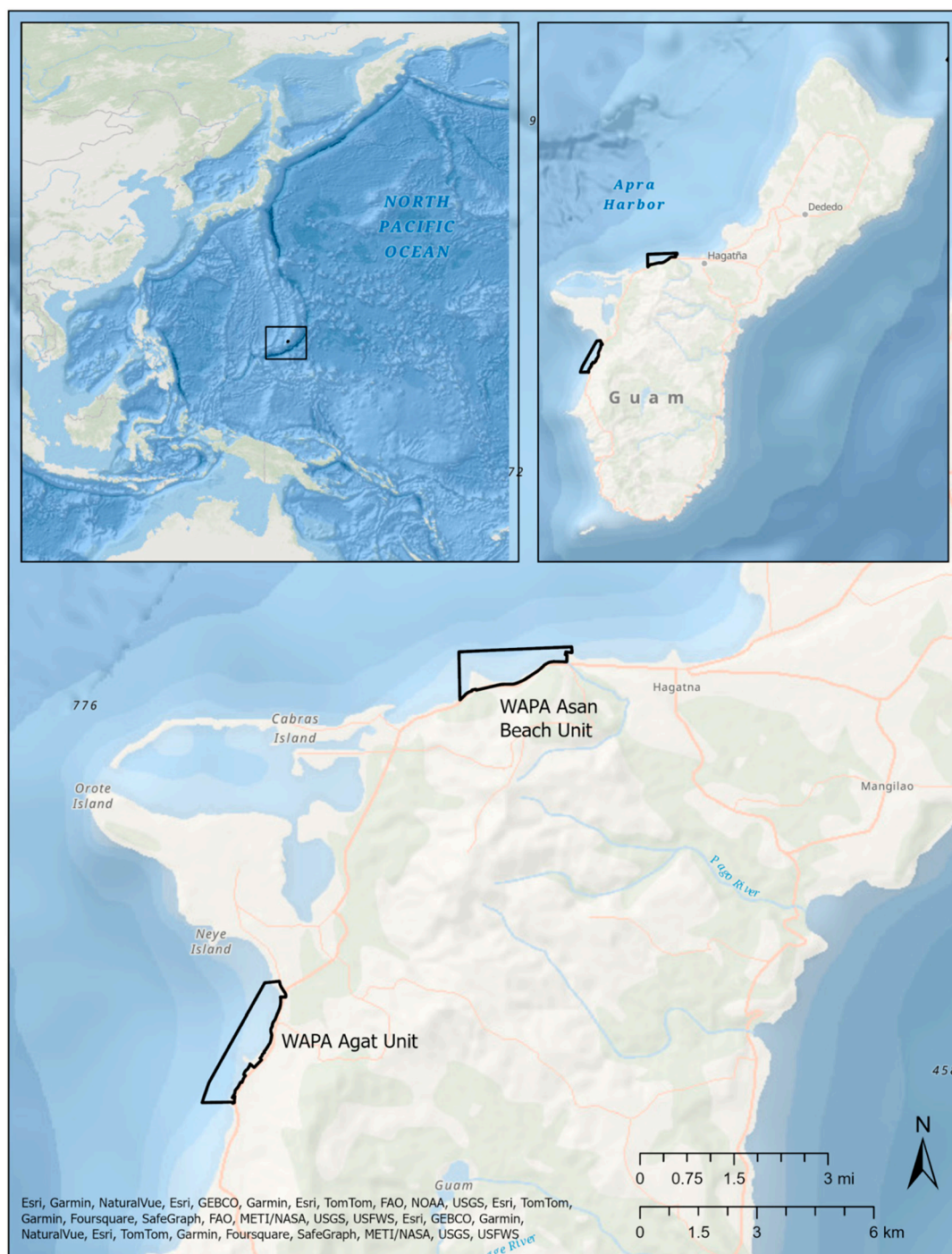


Figure 1. Location of Asan Beach Unit and Agat Unit, War in the Pacific National Historical Park, Guam. Image: Monique LaFrance Bartley, NPS.

This project is part of a wider set of multidisciplinary projects with a World War II archaeological focus supported by NOAA Ocean Exploration, led by Carrell [1], McKinnon [12], and Raupp and Bush [13] in recent years. These projects demonstrate the benefits of creative, multidisciplinary approaches to archaeological study, which provide collaborative opportunities between archaeologists and natural resource scientists.

Additionally, archival sources provided context and geospatial information for each project, critical for informing field methods, areas of operation, and interpretation.

2. Locating Blast Features from the Historical Record

The U.S. Navy developed specialized underwater demolition capabilities during World War II. Prior to 1943, the U.S. military did not have such specialized units, but rapidly adapted following early and disastrous amphibious operations in the Pacific. The most notable of these operations was at Tarawa, where inadequate understanding of the reef environment, tidal variation, and man-made obstacles contributed to catastrophic loss of U.S. forces [10]. In response, the U.S. Navy established formal UDTs trained in hydrographic survey, coastal reconnaissance, and the systematic removal of man-made obstacles and reef features, such as natural coral pinnacles [8,10].

Underwater Demolition Teams 3, 4, and 6 participated in the landings at Guam [6–9]. After each of these teams completed training, they were held in reserve for the landings on Saipan, but were ultimately not needed or deployed. The landings on Guam were the first time UDTs 3, 4, and 6 saw combat as a unit. After the invasion of Saipan, UDT 4 experimented with replicas of Japanese obstacles made from coral rubble-filled coconut log cribs to determine the most efficient way of demolishing them [8,14]. The team found that the best method was to place two packs of tetrytol explosives (Figure 2) on the seaward side of each crib [14]. This method, with slight variation, is further expanded upon in UDT 3's War History [7], which describes a double line of primacord that was run between obstacles. One pack of tetrytol was placed on each obstacle and tied into the primacord, with two caps. Four-minute fuses were tied together, resulting in continuous explosions along an entire row of obstacles. The average time to remove 30 obstacles by a UDT was 16 min [7].

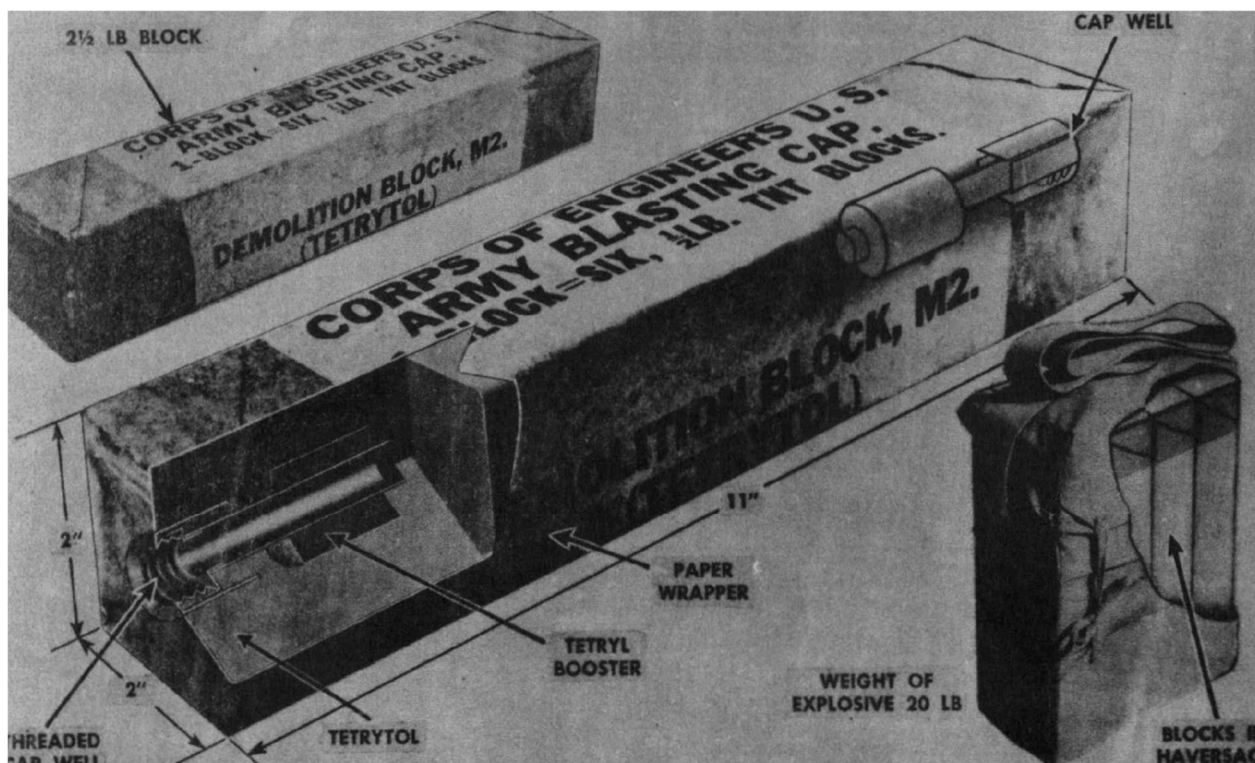


Figure 2. A wartime illustration of a tetrytol pack. Image via Department of the Navy.

Collectively, UDTs 3, 4, and 6 conducted pre-assault reconnaissance and demolition, served as landing craft pilots during the invasion, and conducted post-assault demolition

once the beachheads at Asan and Agat were secure. Pre-assault reconnaissance allowed the teams to collect information on water depth and conditions, to determine and mark the extent of coral reef boundaries, and to assess the number, size, and composition of man-made obstacles. During these reconnaissance missions, UDTs were protected by fire support from nearby vessels including high-speed transport ships, destroyers, and landing craft, who fired over the heads of the men working on the reef [6,8]. UDTs removed 623 obstacles at Asan [15]. The number of obstacles removed at Agat is not specified in historical documentation.

On 21 July 1944, the day of the invasion, UDTs served as pilots to guide the landing force ashore, and maintained buoys marking undemolished coral pinnacles and obstructions identified during reconnaissance [6,14,15].

After the initial assault on the beaches, UDTs continued survey and demolition to improve the efficiency and safety of the landings, piloted landing crafts ferrying reinforcements and supplies ashore, and located and destroyed anti-vehicle mines [15]. It was also at this time that UDT 4 blasted a 200-foot wide channel in the reef at Agat to accommodate the beaching of three Landing Ship Tanks (LSTs) side-by-side [8].

As part of these operations, UDTs produced a documentary record that included hand-drawn reconnaissance maps, after-action maps, and unit histories. The survival of these records makes World War II amphibious battlefields archaeologically distinctive, as few, if any, earlier conflicts produced comparable documentation. These documents enabled precise archaeological correlation between archival sources and underwater features that still exist within the landscape.

The location and documentation of the blast features began with archival research at the National Archives at College Park, Maryland, which houses the vast majority of U.S. military records related to World War II. Documents collected included historic photographs of wartime Guam, maps detailing the invasion planning, UDT reports and unit histories, and reconnaissance maps hand-drawn by UDT members. Most of these records were found in Record Group 80: General Records of the Department of the Navy, and were scanned and analyzed to support both historical interpretation and fieldwork planning.

One of the most valuable of these documents proved to be a hand-drawn reconnaissance map produced by a member of UDT 3 (Figure 3). This map documented the location of man-made obstacles and pre-invasion placement of explosives on the reef flat within what is now the Asan Beach Unit of War in the Pacific National Historical Park. UDT War Histories informed the location of the blast channel at Agat. Additional archival records provided broader contextual support for battlefield interpretation, including maps that detailed the invasion beaches with annotations related to pre-invasion bombardment and fire support, reports from U.S. Navy ships supporting bombardment efforts, and UDT War Histories. Historic photographs documented the man-made obstacles and shoreline defenses prior to their removal by UDTs (Figure 4).

The hand-drawn reconnaissance map from UDT 3 was georectified to a modern map using Esri ArcGIS prior to fieldwork. This map was loaded onto a tablet encased in a waterproof housing and equipped with an Underwater Information Systems (UWIS) navigation system that uses GPS and trilateration between the tablet and three buoys to pinpoint the diver location. Once in the water, the team used the georectified historic map to navigate directly to the hypothesized locations of the blast craters. Once a first crater was found, the team was able to follow the line of craters visible on the seafloor and represented in the historic map. While the blast craters were initially located based on their spatial correspondence with the georectified historic map, they were readily identifiable as small depressions that were morphologically distinct from the surrounding reef flat. Individual craters showed variation in size and shape, and some contained metal debris.

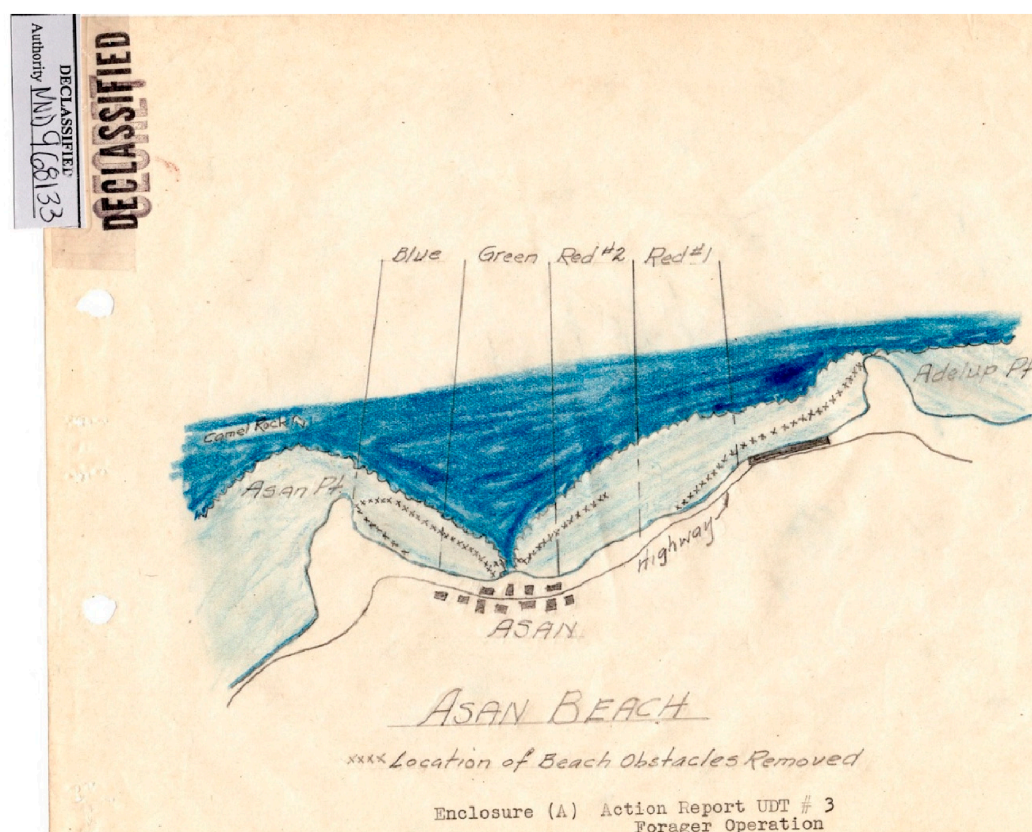


Figure 3. A hand-drawn historic map by UDT 3 illustrating the location of obstacles removed from Asan Beach prior to the invasion. Light blue color represents the area inside of the reef crest; dark blue represents outside of reef crest. The black “x” symbols show obstacle locations as estimated by UDT members. Image: Department of the Navy via National Archives at College Park, Record Group 38.

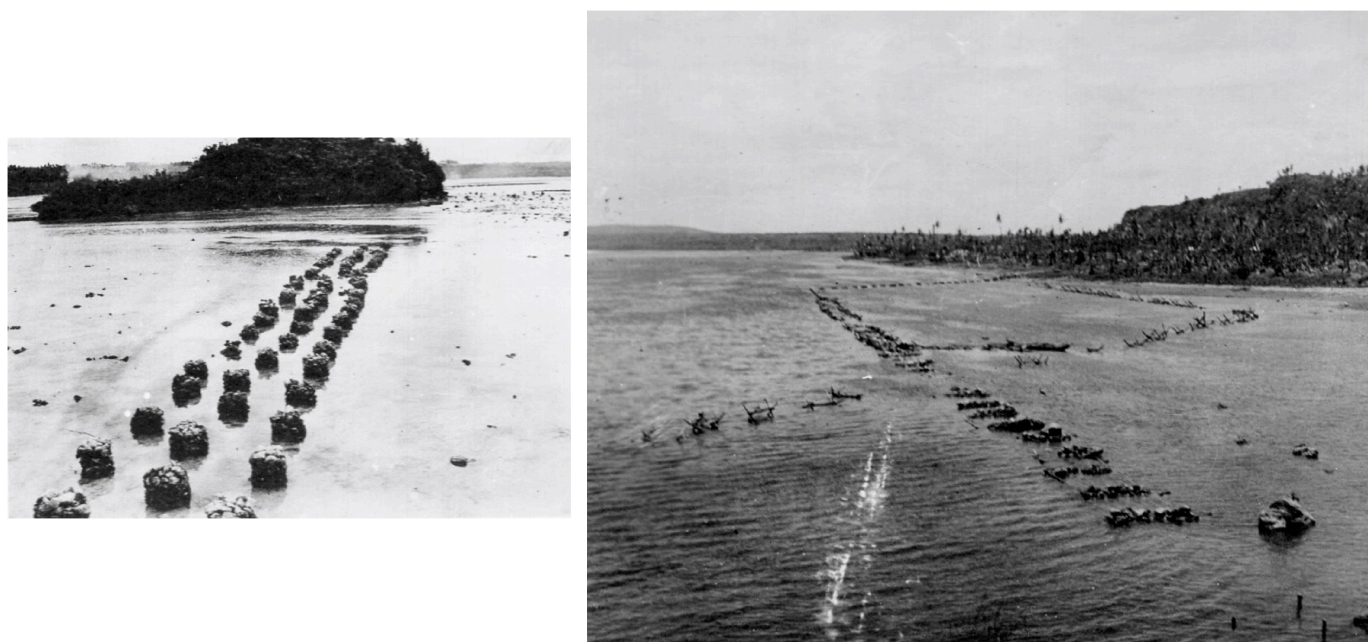


Figure 4. Historic photographs documenting the man-made obstacles and shoreline defenses on Guam placed by the Japanese to impede the amphibious invasion. Image: Department of the Navy via National Archives at College Park, Record Group 38.

No comparable UDT reconnaissance map was found for the area that is now the Agat Unit of War in the Pacific National Historical Park. However, reference was made in the historic documentation to post-invasion large-scale demolition of the reef crest to create a channel large enough to accommodate three LSTs to land side-by-side [14]. Archival research indicates that this channel was 200 ft across and blasted directly offshore of the former location of Agat village (Figure 5) [8,14]. The village was moved after the war and is presently south of its original location [16]. The blast channel location was preliminarily determined from modern aerial imagery and confirmed during diver-based reconnaissance surveys. The channel was confidently identified based on its correspondence with the location and size indicated in historical documentation, as well as the unique abundance of small coral boulders in this area, interpreted as rubble produced by the blasting. A second man-made channel located north of the Namo River mouth was determined not to be the specific blast channel of interest because it is significantly larger (405 ft across) and characterized by a sandy seafloor.

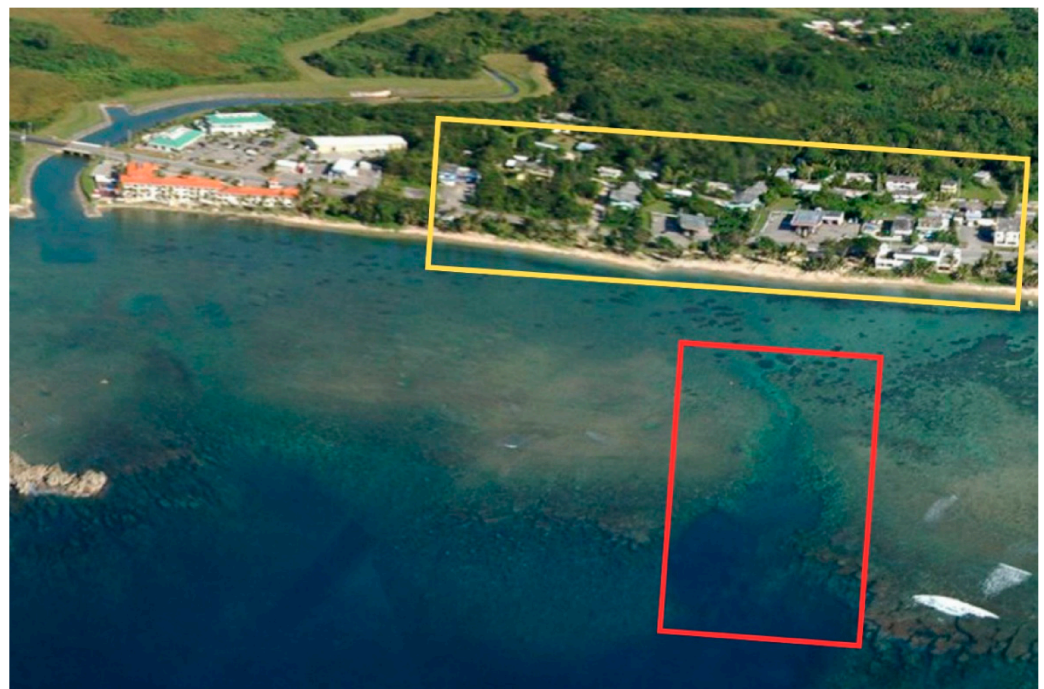


Figure 5. Map indicating the location of the old Agat village (in yellow) and of the blast channel (in red). Image: Anne Wright Nunn, NPS. Background image via Guam Aerial Imagery Project.

3. Survey Methodology and Results

A subset of blast craters along the western portion of the reef flat within the Asan Beach Unit was documented using a combination of photogrammetry, multibeam bathymetry, and RTK GNSS surveys. Due to project time constraints, the team was unable to document every crater on the western side and focused on those most accessible. Environmental conditions during the survey impeded documentation on the eastern side of the reef. Mapping of the remaining craters is a goal for future research.

The blast channel through the Agat Unit was documented using multibeam bathymetry and photogrammetry. This combination of survey approaches supported documentation of individual features such as single craters, as well as large-scale landscape modifications.

3.1. RTK GNSS

Trimble R12i (Trimble, Westminster, CO, USA) GNSS equipment was used to collect the coordinates and elevation of blast craters within the reef crest at the Asan Beach

Unit (Figure 6). The R12i was interfaced with Trimble Access software (v.2023, Trimble, Westminster, CO, USA), and data collection and quality were monitored in real time. Existing benchmarks were used as reference points, and the use of the park's NTRIP base station enabled RTK corrections, improving the positional accuracy of the measurements. The raw data were imported into Trimble Business Center (v.2024.12, Trimble, Westminster, CO, USA) and exported as an x, y, z dataset, where x and y represent coordinates (e.g., latitude and longitude, or easting and northing), and z represents elevation. The data were imported into Google Earth (Mountain View, CA, USA) and Esri ArcGIS Pro (v. 3.6, Redlands, CA, USA) for visualization and map creation (Figure 7).



Figure 6. Project team members documenting the location of a blast crater within the Asan Beach Unit using GNSS equipment. Image: Brett Seymour, NPS.

3.2. Photogrammetry

Photogrammetry data were collected using the NPS SeaArray system to document the reef blast channel at the Agat Unit [17]. SeaArray is a diver-operated three-camera photogrammetry system capable of centimeter-level accuracy over areas of hectares [18]. SeaArray used the UWIS system, which allows the operator to track and record location in real time. Maps generated in ArcGIS were displayed on a waterproof tablet connected to UWIS and ensured full data coverage of the survey areas.



Figure 7. Map showing location of blast craters (yellow circles) in reef flat within the Asan Beach Unit, documented using GNSS RTK as part of this project, overlaid onto a hand-drawn historic map by UDT 3. Image: Nicole LaRoche, NPS.

For the blast craters within the reef flat of the Asan Beach Unit, photogrammetry data were collected using a single-DSLR camera because the water was too shallow (1–3 feet in depth) for SeaArray [19]. The georectified historic map was loaded onto a UWIS Tablet equipped with Allure Data Collection (v.2023, UWIS Oy, Littoinen, Finland), and the team snorkeled to the overlaid location to find and document these shallow craters.

For both survey areas, still digital images were captured with approximately 80% overlap between each photo. These photos were processed into 3D models and high-resolution orthomosaics using Agisoft Metashape Professional (v. 2.0.1, Agisoft, Saint Petersburg, Russia) and 3DF Zephyr (v. 7.0, 3Dflow, Verona, Italy) software (Figure 8). The resulting models were georectified, uploaded to Construkt Reality (v.4.13.0.3, Construkt, Toronto, ON, Canada) for visualization and archiving, and are available to park resource managers, researchers, and the public.

3.3. Multibeam Bathymetry

Multibeam sonar data were collected at the Asan Beach and Agat blast sites using an EchoBoat 160 (Seafloor Systems, Inc., El Dorado Hills, CA, USA) autonomous surface vessel (ASV) equipped with a iWBMSe multibeam sonar system (NORBIT, Trondheim, Norway) and a SurfMaster inertial navigation system (INS) (Applanix, Richmond Hill, ON, Canada). Survey tracks were planned in HYPACK software (v.2022 Q3, Xylem, Middletown, CT, USA) and designed to achieve full-area coverage. Data were collected using the HYSWEEP module in HYPACK. Incoming data were monitored in real time via a remote connection to the ASV in HYPACK to ensure coverage and quality.

Data inside the reef crest at Asan Beach were collected with the ASV via autonomous surveys that were preprogrammed and run from a command station onshore (Figure 9a). These surveys targeted 100% coverage with 5–10% swath overlap and were conducted during the high-tide cycle for increased survey efficiency and coverage in very shallow water depths. The Agat survey was conducted by towing the ASV, enabling more efficient use of the battery system and real-time control over survey lines (Figure 9b). This deeper water survey targeted 100% coverage with 20–30% swath overlap.

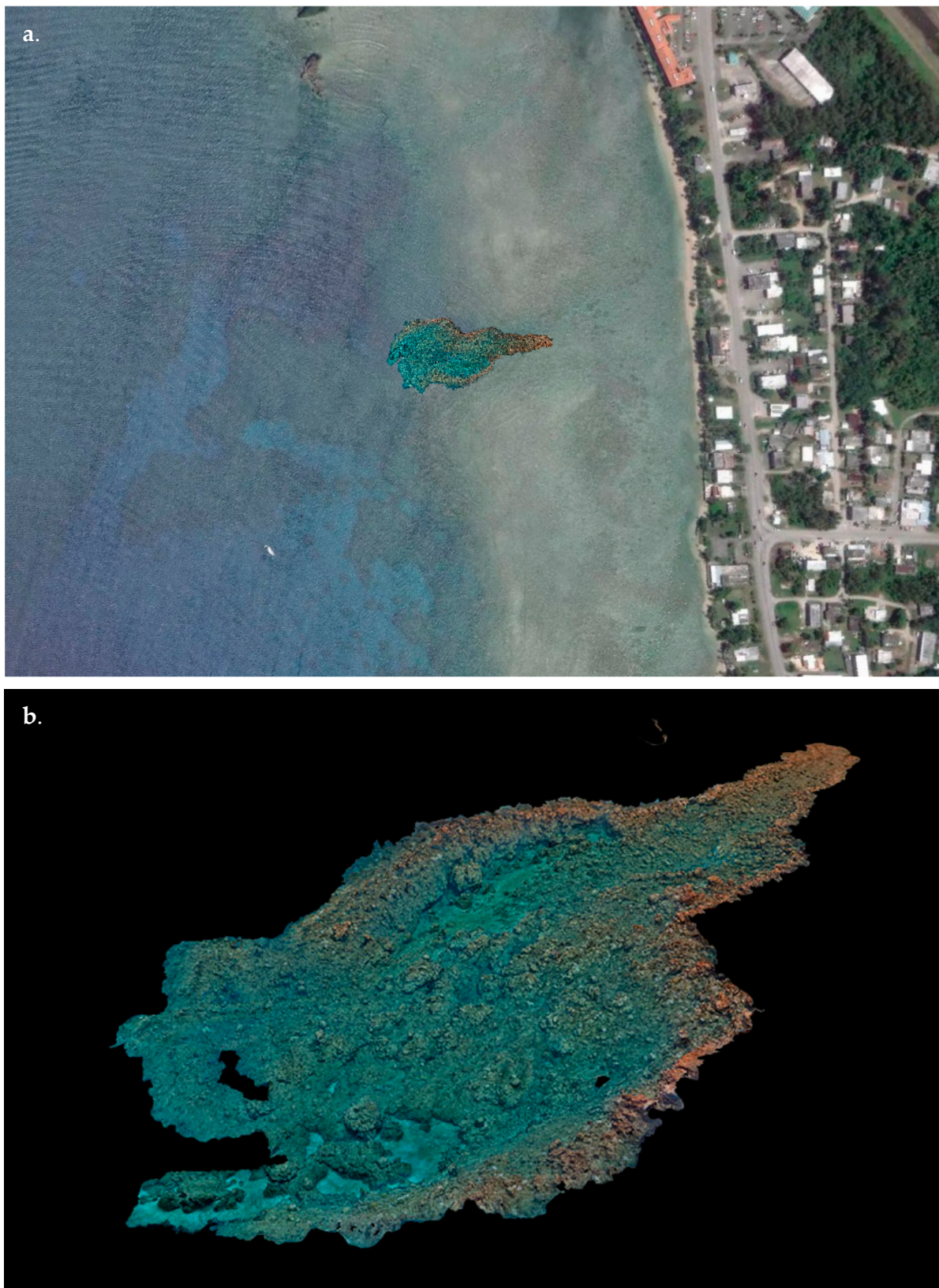


Figure 8. Cont.

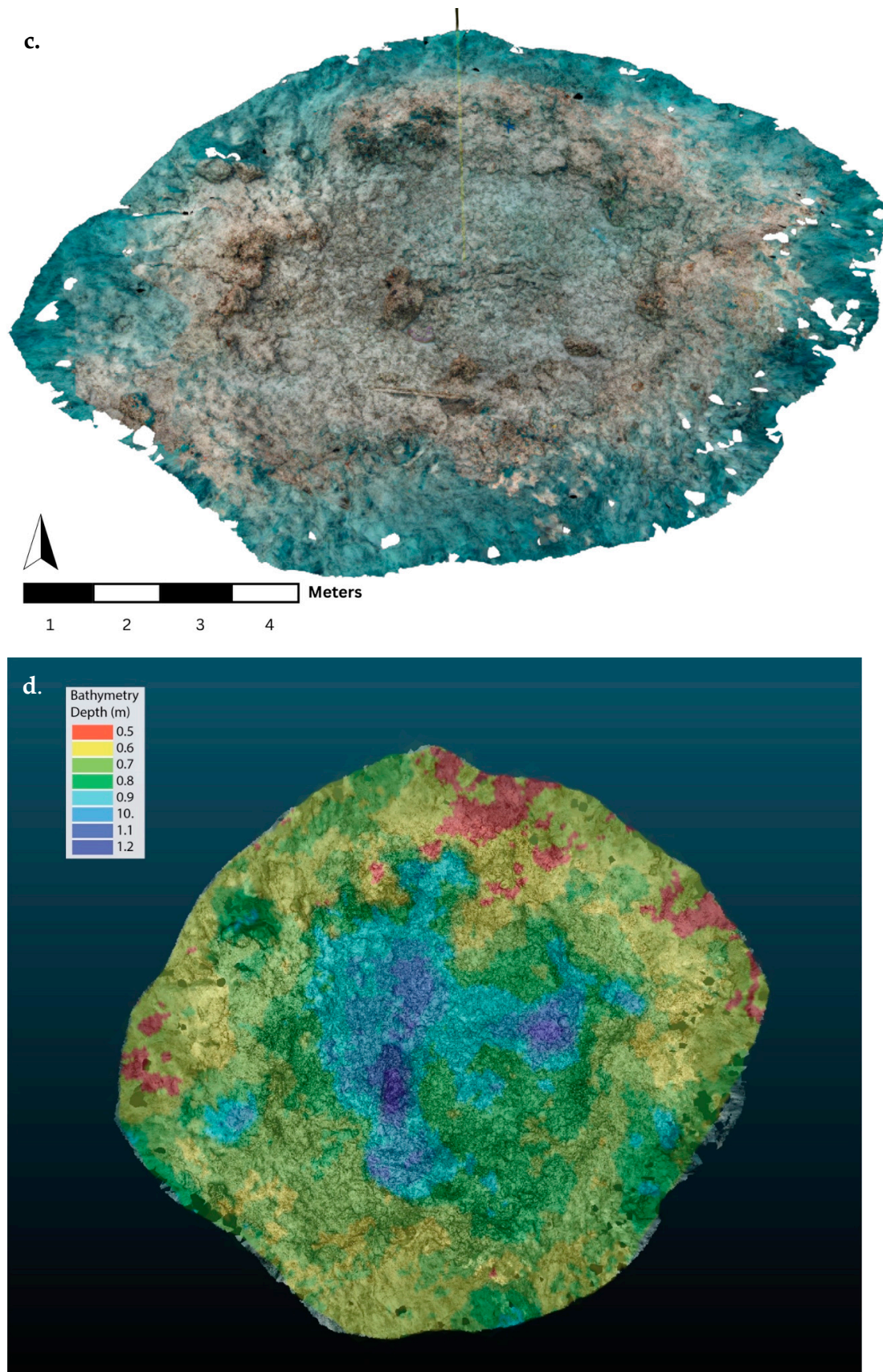


Figure 8. Photogrammetry model outputs of blast channel through the reef at Agat (a,b) and a blast crater in the reef flat at Asan Beach (c). Asan blast crater photogrammetry with bathymetry overlaid to show depth and structure (d). Water depths referenced to Mean Low Low Water and shown in meters. Image: Brett Seymour, Anne Wright Nunn, and Nicole LaRoche, NPS.

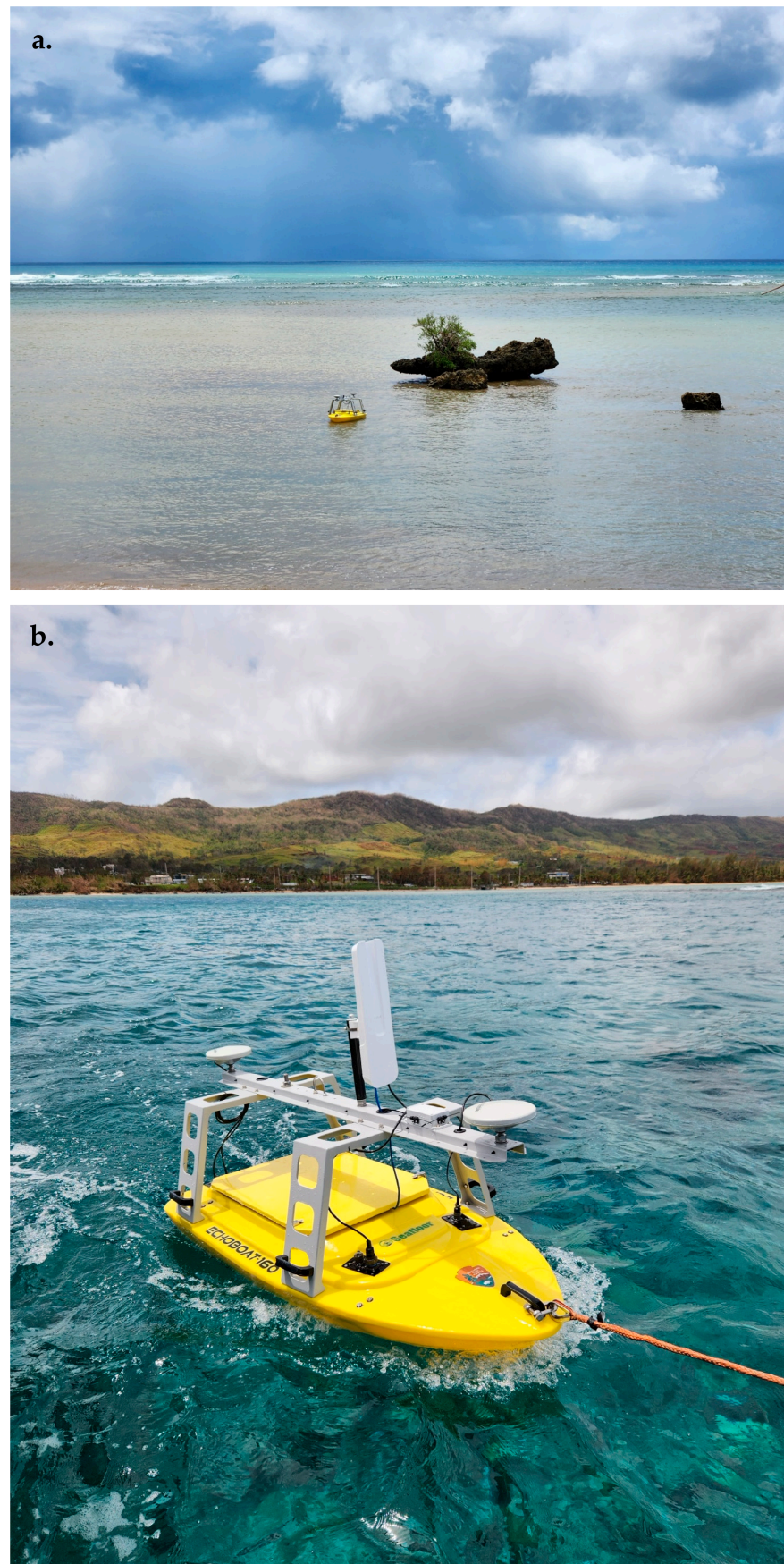


Figure 9. ASV collecting bathymetry data within the Asan Beach Unit in autonomous mode (a) and within the Agat Unit using a towed configuration (b). Image: Monique LaFrance Bartley and Tahzay Jones, NPS.

Multibeam data were processed using HYSWEEP (v.2024) and POSPac Mobile Mapping System (MMS) software (v.9.0, Applanix, Richmond Hill, ON, Canada). The Post-Processed Trimble CenterPoint Real Time Extended (PP-RTX) option within POSPac MMS was used to apply cloud-based global GNSS corrections to improve the horizontal and vertical positioning accuracy of the bathymetry data and adjust the data to Mean Low Low Water (MLLW). The post-processed positioning information was then applied to the soundings data in HYSWEEP, followed by corrections for sound velocity and motion (pitch, roll, and yaw). Outlier soundings were also removed to clean up erroneous data for the final product.

For the Asan Beach Unit, surveys focused on mapping the more accessible western line of blast craters. The resulting bathymetry data confirm that the shallow water blast craters indicated on the historic UDT map are still present in the seascape (Figures 10 and 11). The blast craters exhibit a depth range of 0.04 m to 0.46 m (measured from the reef flat surface to the bottom of the depression) and an approximate diameter range of 0.32 m to 8.19 m, yielding an approximate volume range of 0.1 m³ to 9.4 m³. For the Agat Unit, full-coverage bathymetry data were collected from the reef crest out to the 60 m isobath, including the area of the blast channel (Figure 12). The final bathymetry mosaics were exported as 50 cm resolution GeoTIFF files and imported into Esri ArcGIS Pro (v.3.6, Redlands, CA, USA) for visualization and map creation.

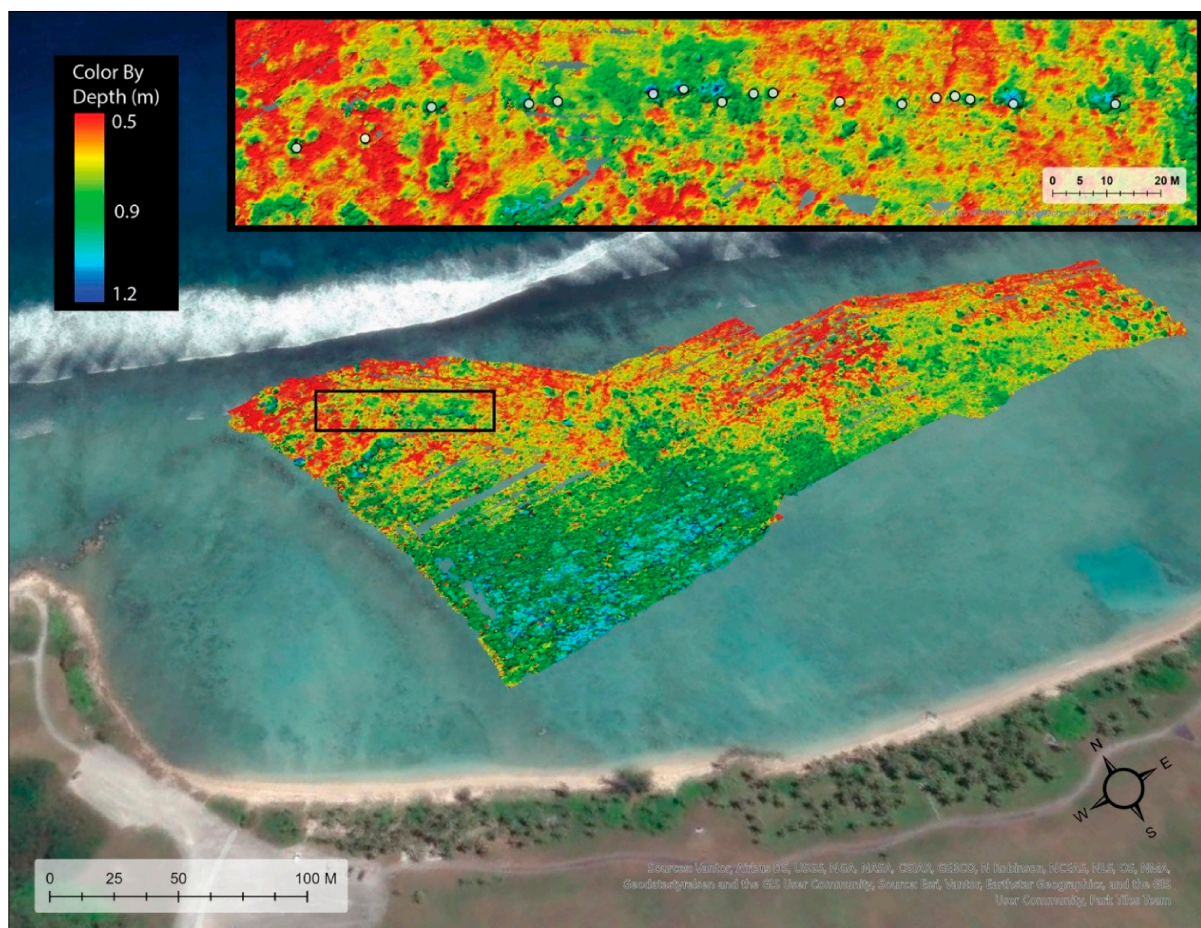


Figure 10. Manually collected GNSS RTK points overlaid on bathymetry data showing location of blast craters within the reef flat of the Asan Beach Unit. Water depths referenced to Mean Low Low Water and shown in meters. Image: Nicole LaRoche, NPS.

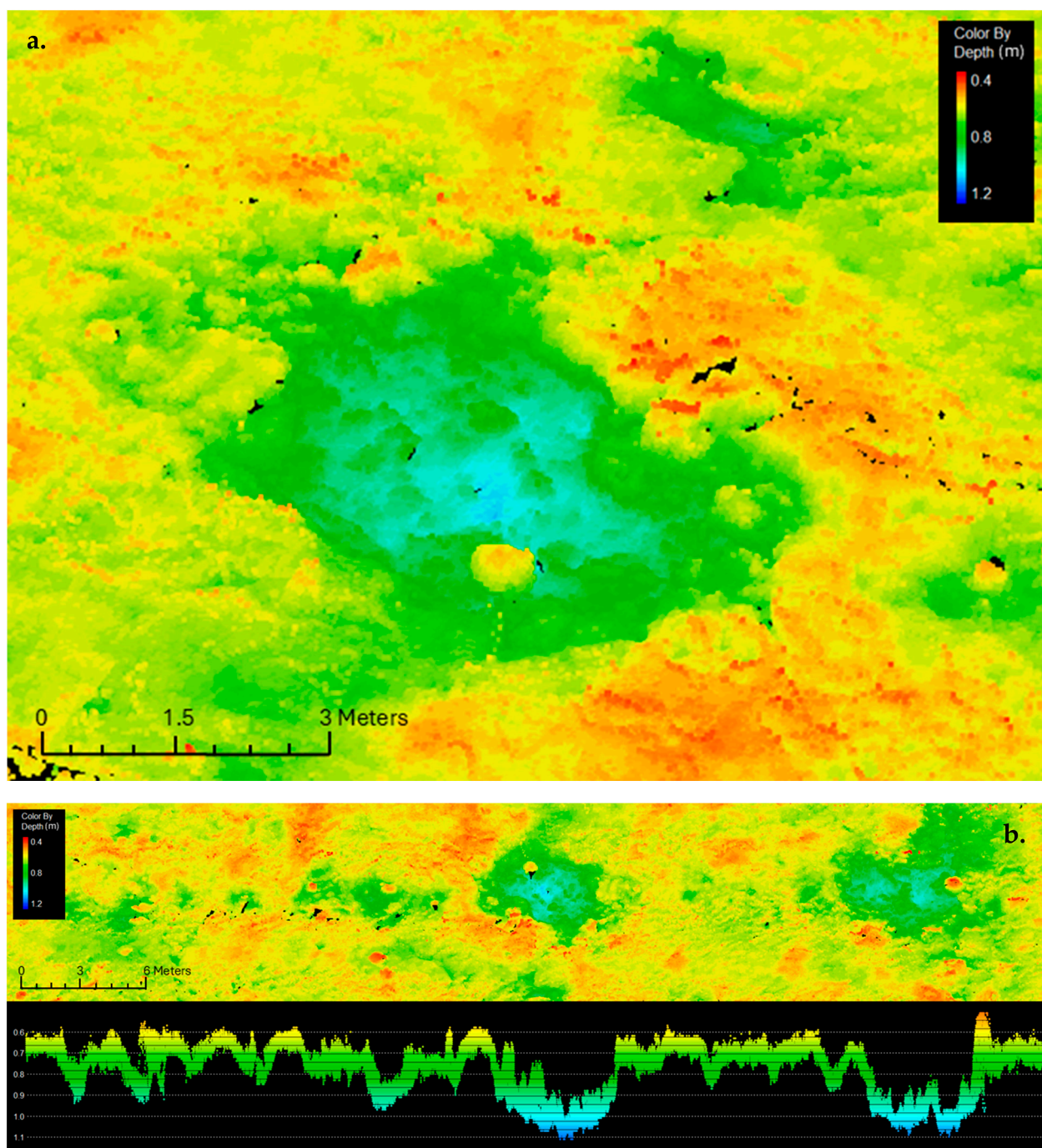


Figure 11. Bathymetry data collected within the Asan Beach Unit zoomed in on one blast crater (a) and showing a distinct line of craters in planar and profile views (b). Water depths referenced to Mean Low Low Water and shown in meters. Image: Nicole LaRoche, NPS.

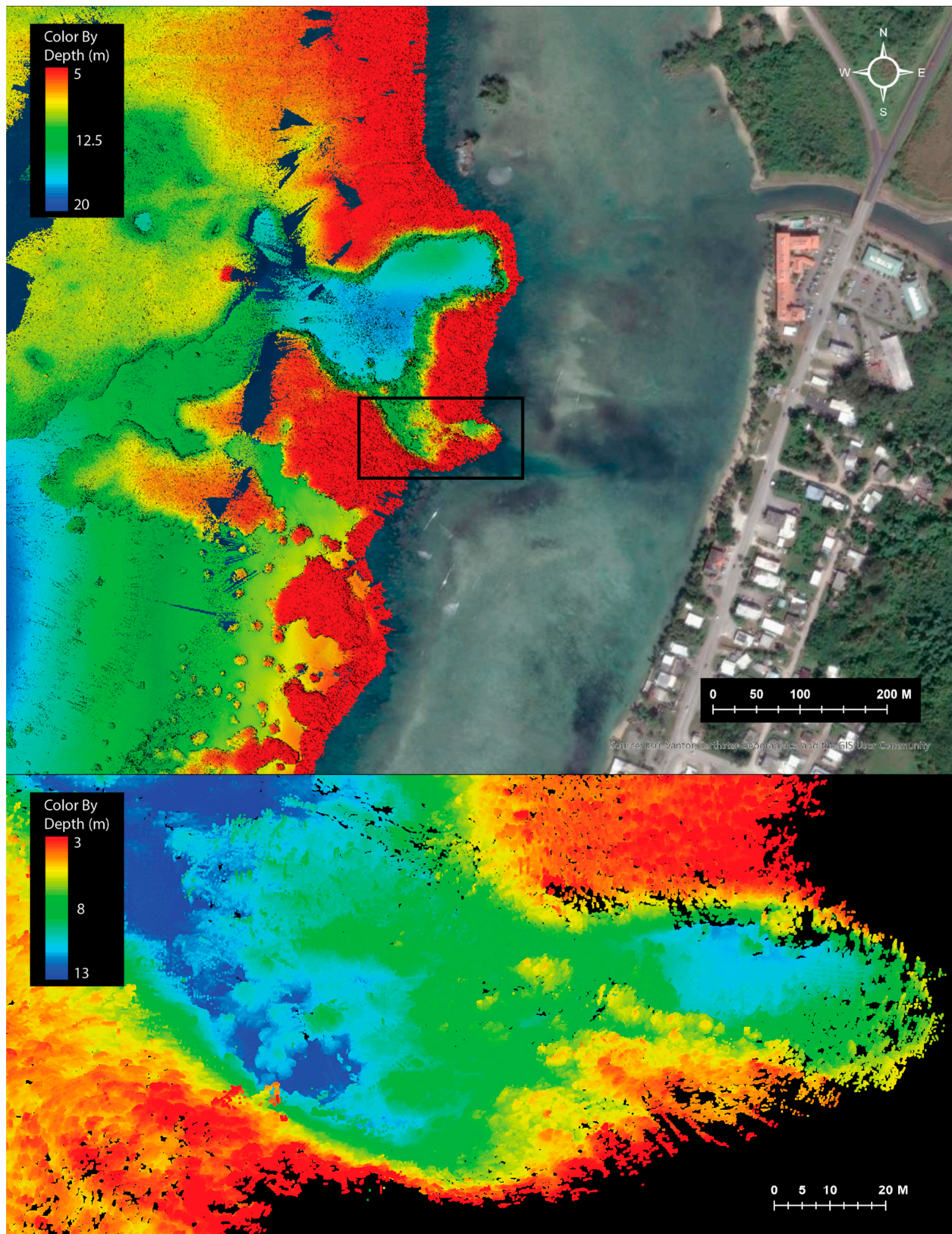


Figure 12. Bathymetry showing the blast channel created in the reef crest within the Agat Unit. Water depths referenced to Mean Low Low Water and shown in meters. Black rectangle in top portion of image indicates zoomed extents in bottom portion of image. Image: Nicole LaRoche, NPS.

4. Discussion

4.1. Value of Archival Research and Multidisciplinary Approaches

The integration of archival research with geospatial analysis shows the value of historical records not only as contextual sources but as predictive tools for locating submerged features associated with amphibious warfare. This approach was only possible due to the availability of operational records associated with the Battle of Guam, which may not be available in other conflict contexts. While geospatial positioning was limited by the resolution and hand-drawn nature of the historic UDT 3 map and the inherent uncertainty of manual georectification, the spatial correspondence between the georectified map and the physical depressions observed at Asan Beach was sufficient to support their identification as blast craters created by UDT 3 prior to the invasion. The presence of numerous craters aligned with the mapped obstacle and demolition locations decreases the probability of coincidental identification.

The use of archival materials to guide site-specific fieldwork facilitated this targeted investigation, as opposed to what otherwise could have been a large-scale reconnaissance effort. This methodology could serve as a model for use in other Pacific battlefield environments and elsewhere, should similar archival documentation exist. This method can be particularly helpful in complex environments, such as coral reefs, where natural and man-made features (e.g., blast features) may appear similar. These situations encourage closer collaboration across disciplines, such as archaeology, history, geoinformatics, ecology, biology, and geomorphology, to confidently examine and interpret data and provide context.

The use of a variety of complementary survey methods is another aspect of implementing a multidisciplinary approach. A thoughtful survey design can facilitate data collection and analysis that inform research questions across disciplines (e.g., bathymetry and photogrammetry can inform archaeological questions, as well as those focused on ecology, the environment, coastal processes, and related topics). The utility of such environmental survey data is maximized when they are considered collectively. This approach also better aligns with practical management and planning applications that require holistic site-level understanding, such as marine spatial planning efforts, establishment and management of marine heritage sites, management of marine assets, and anticipated impacts of proposed development actions.

In recent years, several NOAA Ocean Exploration-supported projects have demonstrated the value of multidisciplinary approaches to documenting and interpreting World War II maritime heritage sites in the Pacific [1,12,13,20,21]. In 2018, Ships of Discovery completed a systematic investigation of the U.S. amphibious invasion landscape at Peleliu by conducting towed side-scan sonar and magnetometer surveys to identify targets prior to documentation with diver-based photogrammetry [1]. Forty previously unrecorded archaeological sites were located offshore of the invasion beaches and inshore in the lagoon. Throughout the project, biologists worked alongside the archaeological team to conduct and interpret 425 photogrammetric reef plots around UDT blast features and other archaeological sites to provide baseline information on geomorphology, coral species recovery, and potential impacts to the sites, including damage from ecological disasters and blast fishing.

Similarly, East Carolina University [12] investigated the underwater archaeology of the World War II 1944 Battle of Saipan. LiDAR collected by NOAA's Office for Coastal Management [22] helped inform a predictive underwater cultural heritage model that guided ground-truthing conducted by divers and remotely operated vehicles (ROVs). The team collected photogrammetric data, eDNA samples, and site conservation data (temperature, salinity, conductivity, dissolved oxygen, pH, oxygen redox potential, corrosion potential, and visual observations). This study recommended combining archaeological

and biological surveys to better understand the archaeological significance, site stability, and in situ management requirements [12].

Another East Carolina University study, led by Raupp and Bush [13], used towed synthetic aperture sonar to document Holtz and Massacre Bays of Attu, Alaska. The survey design was informed by extensive archival research. The project integrated indigenous Unangan perspectives and collaborated with a Japanese photogrammetry and marine technology research consortium to bring multiple cultural and disciplinary perspectives to the battlefield interpretation. This approach led to the rediscovery of several World War II invasion-related features, including a U.S. Navy anti-submarine net, two Japanese shipwrecks (*Kotohira Maru* and *Cheribon Maru*), and a U.S. Army-contracted cable layer (SS *Dellwood*) [13,23].

The project discussed in this paper also employed a multidisciplinary approach. The blast features were documented using a variety of technologies that, collectively, provided information beyond what a single dataset alone offers. Photogrammetry and bathymetry both provided high-resolution visual representations of the blast features, were used to determine feature dimensions, and can support future analysis. For example, both datasets can be used to investigate rugosity of the reef systems to better understand habitat quality. The colorized photogrammetry data can be used to assess coral composition and cover. Bathymetry data were acquired over a greater spatial extent, allowing features to be placed in the context of the larger seascape. The RTK GNSS data provide precise locations for each blast crater and readily facilitate their relocation for assessment and monitoring.

While this project used a combination of documentation techniques, employing a subset could also be sufficient to achieve project goals. The use of RTK-based mapping offers a practical and effective means for documenting and relocating features in shallow water, particularly for projects with limited resources that require rapid elevation and spatial measurements. Bathymetry and photogrammetry methodologies are more data-rich and visual, providing greater exploratory opportunities, though they tend to be more costly and technical to implement. When combined with terrestrial data, such as the LiDAR collected as part of this broader project, the blast features can be placed in a more comprehensive historical context and guide modern-day management of the battlescape, extending from land to sea. Collectively, this project illustrates the value of a scalable, multi-method approach.

4.2. Unexpected Discovery of the Blast Features and Their Long-Lasting Impacts

The presence of the blast features after 80 years serves as confirmation of the long-lasting impacts of the events that took place during World War II. The blast craters within the Asan reef flat exist in a very shallow, dynamic, high-energy environment, which, prior to fieldwork, suggested the possibility that the craters may have filled in with sediment and coral fragments through natural coastal processes and storm events. The historic diameter and depth of the blast craters are unknown. While it is possible that the initial craters were more expansive and have partially filled in over time, there is evidence to suggest otherwise. The existing blast craters show distinct boundaries, limited sedimentation and rubble fill, and a lack of coral growth along the crater margins, suggesting they continue to retain their original dimensions (Figures 8, 11 and 13). Furthermore, some craters were found to contain fragments of embedded metal, which could be interpreted as remnants of the obstacles that were destroyed by UDTs. Similarly, the abundance of small coral boulders in the blast channel at Agat is interpreted as rubble produced by blasting, indicating that the impacts of the demolition remain present today.

The detonation of explosives by UDTs resulted in the removal of natural reef material. These blast features are now interpreted as both historical and cultural features and have

modern significance to the local community. For example, during the collection of oral histories with the local diving community as part of this broader project, divers noted that the base of the blast channel at Agat is a known hotspot for marine debris collection; however, the community was unaware of the channel's wartime origin. The project team also observed substantially more marine debris in this area than in adjacent undemolished reef. Community members also reported using the "shallow depressions" (blast craters) in the Asan reef flat to aid in fishing. One community member noted that he was moved to learn of the wartime origins of the depressions and their connection to his own history. These observations point to the continuing wartime impacts of the amphibious operations that remain visible underwater and continue to shape both environmental processes and community interactions with the seascape. The information can be used to communicate the events and impacts of World War II in a way that can meaningfully garner appreciation and resonate broadly with local community members and the public.



Figure 13. Photograph of a blast crater depression in the reef flat of the Asan Beach Unit at low tide. Image: Monique LaFrance Bartley, NPS.

Public awareness of the World War II origins of the blast craters may be limited because they resemble the surrounding environment. Visual observations (Figure 13) suggest that the blast craters and the surrounding reef flat exhibit similar physical and biological characteristics. The reef flat is primarily composed of coral rubble and sandy sediment interspersed with live coral, aquatic vegetation, and macroalgae. In this respect, the blast craters themselves appear to have limited influence on reef-flat ecology, as indicated by visual observations of habitat quality and associated species. While not empirically evaluated, information from historical accounts and photographs (Figure 14) suggests extensive wartime alterations to the entire reef flat from invasion operations and the subsequent military occupation of the adjacent land. This extensive military use led to impacts across the entire reef flat, effectively making ecological impacts from creation of the blast craters indistinguishable from those due to other wartime activities. Furthermore, similar environmental conditions across the reef flat, such as shallow water depths, rugosity and structure, temperature, nutrient availability, water quality, etc., lend to the expectation of ecological similarity of the blast craters and the surrounding area.



Figure 14. Historic photographs on the beach in Guam that show the vast amount of military resources brought onto the island directly on top of the shallow reef, including LSTs and other amphibious vehicles. Images: National Archives at College Park, Record Group 127GW.

Carrell et al. [1] also examined World War II blast impacts at Peleliu (Palau) in the western Pacific by comparing coral characteristics for segments of reef blasted by UDTs and segments that were not disturbed. The study found that while the same coral species (*Porites* and *Montipora*) dominated both areas, the blasted area had statistically significant results showing higher percent coral cover and 3D habitat complexity (rugosity). The authors explain the higher coral cover through the intermediate disturbance hypothesis; that increased habitat complexity in the altered reef supports coral growth and diversity. While quantitative coral assessments were not conducted as part of the project on Guam, visual observations did not indicate higher coral cover in the blast craters relative to the rest of the Asan reef flat. It appears the blast craters themselves do not increase rugosity to the reef flat, rather they present as shallow empty depressions with comparable rugosity. Additionally, the Peleliu assessments were conducted on the outer reef slope at greater water depths (~3.5, 6.5, and 13.5 m), whereas the Asan blast craters are located in the back reef flat at shallower depths (~1 m). These environmental differences in rugosity, depth, and study site locations relative to the reef crest are likely dominant factors in the blast features having overall ecological similarity at Asan versus higher coral cover in Peleliu, though past and present human activity and use of the sites may also be substantial contributing factors. Assessment of the Agat blast channel was not conducted due to time constraints, though it remains a topic for future work, especially since this site is more comparable to the sites assessed at Peleliu [1]. Nonetheless, it is clear that the blast features at these locations have become integrated into the seascape, emphasizing their value as both a cultural and ecological resource that warrants additional consideration and future assessment, a perspective similar to how the disciplines of shipwreck archaeology and marine ecology have converged to assess the unique study of shipwreck ecology [24–26].

4.3. Implications for Maritime Heritage Research and Management

War in the Pacific National Historical Park is an evolving cultural and natural resource landscape that has been and will continue to be shaped by pre-war, wartime, and current human activity, as well as spatio-temporal environmental and geologic processes.

The transition from the marine environment to the terrestrial environment was a critical juncture for the U.S. to carry out operational objectives successfully during the battle. To document this connection, high-resolution LiDAR data were collected as part of this broader project targeting the coastal environment, archaeological resources and monuments, and park infrastructure. The LiDAR data, together with the bathymetry data, were used to place elements of the battle in a geospatial context, including the location of the submerged blast craters in relation to the coastal pill boxes and gun emplacements, and provide a more complete understanding of the land-to-sea battlescape. These data can also be used to visualize the invasion beaches to better understand how Japanese defensive positions relate to subsurface remnants of the war, provide context for other submerged cultural resources, and more fully develop interpretative narratives of the battle.

Recognizing the link between the marine and terrestrial environments is also important in the modern day for guiding management of the battlescape and associated resources. Physical reminders of World War II throughout the park, including artifacts from the battle and monuments honoring those who served and lost their lives, play a significant role in acknowledging and communicating the events of World War II on Guam and are fundamental to the park's mission. However, these resources are located in a dynamic coastal system and are increasingly vulnerable to impacts from changing environmental conditions, including coastal erosion, storm-related flooding, and sea level rise. Additionally, changes to the landscape itself alter the visual representation of the battlescape for the modern-day visitor. Documenting coastal change over time provides valuable insights into

past, present, and future conditions that can guide management decisions related to park cultural resources, as well as facilities and infrastructure that support visitor use.

For example, LiDAR data collected as part of this project were opportunistically used to document coastal conditions pre- and post-Typhoon Mawar, a category 4 storm that made landfall in May 2023. Comparison of the geomorphology of the Asan River showed that the area was substantially altered by Typhoon Mawar. The riverbank sustained erosion from storm surge, while the mouth experienced sedimentation following the heavy rains and flooding. Sediment transported by the river outflow formed an expansive sediment delta at the river mouth that extended onto the reef flat, creating exposed land, even at high tide, over an area previously fully submerged (Figure 15). This delta has since been completely eroded and demonstrates the highly dynamic nature of the coastal margin in the reef flat. The sediment dynamics captured in the pre- and post-Typhoon Mawar surveys highlight why the presence of the blast craters was uncertain after 80 years and also indicate the potential for blast craters located nearest the river mouth to be filled in by sedimentation with future storms. Typhoon Mawar is a single example of an extreme rainfall event commonly associated with tropical storms and typhoons on Guam which lead to slope instability and nearshore sedimentation [27,28], events that are projected to increase in the future [29]. Given this potential for future sediment transport, it is recommended that further surveys be conducted to fully document each remaining blast crater on the reef flat.

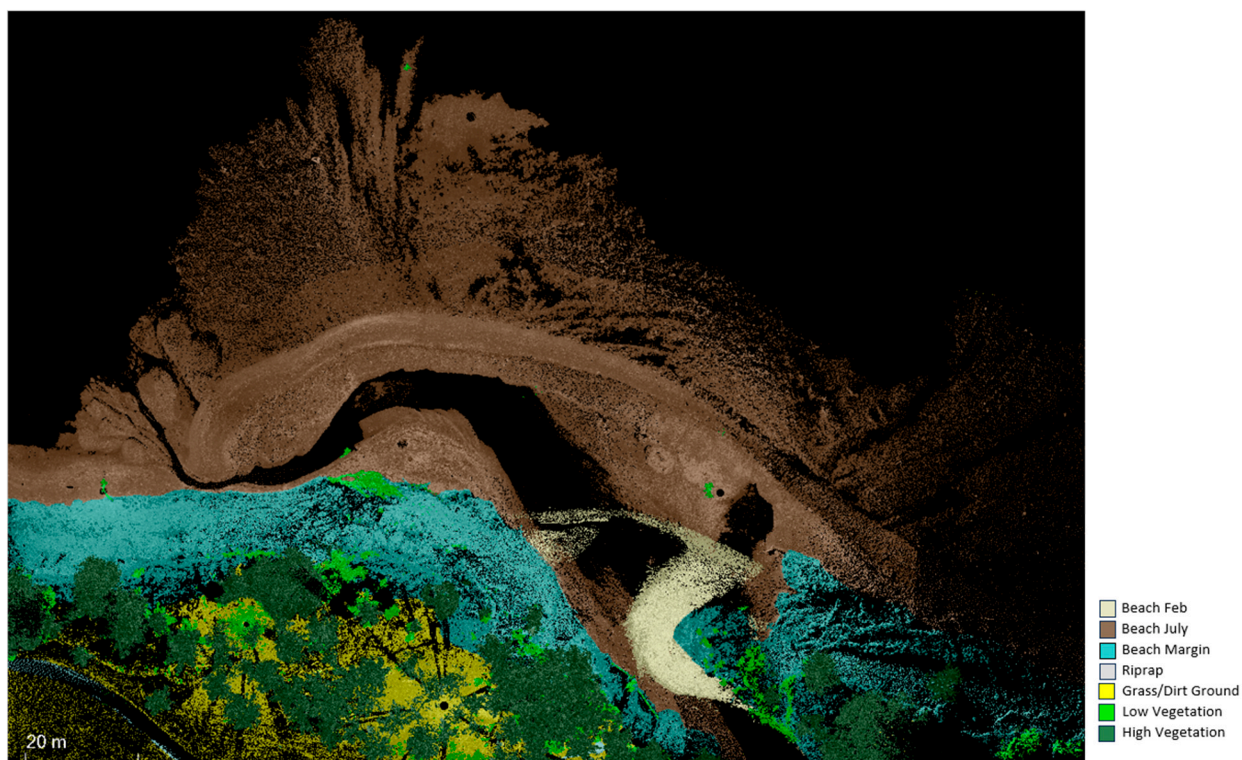


Figure 15. LiDAR data collected pre- and post-Typhoon Mawar (May 2023) showing substantial alteration of the Asan River mouth and sediment deposition. Pre-Mawar data (light tan) were collected in February 2023; post-Mawar data (dark brown) were collected in July 2023. Image: Audrey Brown, NPS.

Beyond physical assessment of coastal dynamics, the utility of LiDAR data for park management includes assessing cultural and natural resources, monuments, and facilities threatened by sea level rise. Sea level rise scenarios [30] were superimposed on the LiDAR data to assess the elevation of coastal resources relative to projected sea level at various

points in time. This information places the blast craters and other cultural resources, such as pill boxes and gun emplacements, in the broader coastal hazard context and can guide the park in prioritizing management actions.

Documenting and understanding coastal processes and associated implications of these dynamics at the landscape and feature-level allows scientists and decision makers to develop effective management and interpretation strategies. At the park level, this information supports the Asan and Agat Units Management Plan [31] that addresses visitor use and the preservation of natural and cultural resources in order to protect and interpret the significance of the sites. The methods and results of this project will be made available through open-access publications and data, with the potential for these to serve as a reference model for an integrated, multidisciplinary strategy for studying complex marine and coastal systems.

More broadly, this work aligns with national-level research, programmatic objectives, and administrative priorities within the United States. Multidisciplinary projects that synergistically integrate natural and cultural resource assessments enhance research impact and advance broader maritime heritage objectives and priorities, including U.S. federal programs and initiatives. U.S. federal coordination of ocean science and technology takes place at the interagency level where priorities are identified. Collaboration in recent years by subcommittees, councils, and working groups have resulted in several publications. For example, the National Ocean Mapping, Exploration and Characterization (NOME) Council, which includes members from 15 U.S. federal agencies and departments, coordinates ocean mapping, exploration, and characterization for the United States. Both multidisciplinary and collaborative approaches are emphasized to achieve the goals outlined in the 2020 NOME Strategy and the 2024 Implementation Plan [32,33]. Priorities of the Interagency Working Group on Ocean Exploration and Characterization subgroup on Cultural Heritage include the exploration and characterization of major naval and military battlefields and the “need and flexibility of incorporating studies on the inter-relationship between natural and cultural resources in mapping and characterization efforts” [34]. Similarly, the U.S. Strategy for Ocean Exploration that laid the groundwork for the establishment of NOAA Ocean Exploration recommended multidisciplinary exploration approaches [35]. The mission of NOAA Ocean Exploration is to explore the unknown ocean and “conduct interdisciplinary. . . and scientific voyages to locate, define, and document historic shipwrecks, submerged sites, and other ocean exploration activities that combine archaeology and oceanographic sciences” [36,37]. NOAA Ocean Exploration encourages the use of innovative technology and novel methods for the assessment of maritime heritage to improve archaeological site identification and documentation.

These and other efforts provide opportunities for exploratory projects that inform our understanding of maritime heritage and allow for open-ended findings that facilitate further research opportunities and monitoring. Information learned can also be used to guide management and preservation decisions and enhance communication and outreach efforts. The value of exploration-focused projects is increased when they are cross-disciplinary, employ a range of technologies and methods, and consider terrestrial to submerged lands as an uninterrupted setting.

4.4. Future Directions of Seafloor Modification Archaeological Sites

The recognition of seafloor modification archaeological sites presents the opportunity to highlight and focus on feature-based large-scale seascape analysis. Battlefield-related landscape modifications are often treated as archaeological features in terrestrial contexts, but their underwater counterparts remain understudied and have rarely been identified as archaeological resources. Recent projects have begun to create awareness and demon-

strate the importance of archaeology focused on seafloor modification. The World War II blast features documented in this project on Guam [3] and by Ships of Discovery at Peleliu [1] highlight intentional seafloor modification to support military operations. Brennan et al. [38] and Mayer et al. [39] provide examples of unintentional seafloor modification resulting from wartime activity. Brennan et al. [38] documented the Baker Crater and other craters formed by nuclear testing at Bikini Atoll as an archaeologically meaningful part of the modified seascape. Mayer et al. [39] used multibeam sonar to map shipwreck remains associated with the D-Day landings at Normandy and leveraged the resulting data to assess sediment movement in the area.

Terrestrial archaeology provides a clear model for documenting these types of features as part of larger-scale battlefield documentation. Everett et al. [40] conducted a multi-method remote sensing survey to map buried structures, including ordnance remnants inside bomb craters, on the cliffs at Pointe du Hoc, Normandy, using ground-penetrating radar, electromagnetic induction, and magnetic gradiometry. Tunwell et al. [41] documented a 136-crater World War II “bombscape” in the forests of central Normandy, connecting individual craters to specific air raids, bomb types, and, in one instance, a specific aircraft and crew, using historical documentation. Passmore et al. [42] conducted a similar project, documenting a “craterscape” in Normandy using multiple methods, including LiDAR, GIS, and archival records and photographs, to illustrate the connection between tactical events (such as the creation of a crater) and their broader operational context. Wiesenewski et al. [43] applied a large suite of methods, including drone-based multispectral imagery, terrestrial laser scanning, LiDAR, gradiometry, and others, to document the World War I Hawthorn Mine Crater from the Battle of the Somme, noting the important role of historical aerial imagery, maps, and other archival documents in identifying these types of features. Waga et al. [44] used LiDAR and laser scanning to document bomb craters in Poland, emphasizing the value of these tools as an effective means for placing individual craters into the broader context of the entire battlescape; this approach and use of point cloud data is a terrestrial complement to this submerged battlescape study at the Asan Beach and Agat Units.

These terrestrial studies illustrate that blast features are not insignificant byproducts of war, but are primary archaeological evidence of military operations and intentional modification of the landscape that inform our understanding of past events. Underwater archaeologists should continue to apply similar landscape-oriented perspectives when documenting and interpreting submerged and amphibious battlefields if they are to be fully understood and managed.

There are other examples of undocumented and unanalyzed World War II blast features in the Pacific that warrant archaeological documentation, such as a possible bomb crater associated with the sinking of *Sankisan Maru* at Chuuk Lagoon, as reported by sport divers [45]. Examples of underwater blast features exist beyond the Pacific as well. At the site of HMS *Triumph*, sunk during the World War I Gallipoli Campaign, Brennan et al. [46] identified possible craters formed by submarine depth charges dropped to protect the battleship against submarine *U-21*. While these craters are in context with a known wreck site, the implications that depth charges also leave behind blast features extend beyond site or wreck-specific analysis. Depth charges that failed to sink their intended targets may have produced similar craters elsewhere, leaving crater “fields” on the seabed. There are likely many other examples of these types of craters that, if located and documented, could provide insight into the spatial extent of naval engagements and possibly patterns of pursuit and evasion. In turn, these crater fields may represent an underutilized source of archaeological evidence for reconstructing underwater and naval battlescapes, and could be particularly useful at sites of engagement where no wrecks are present to anchor inter-

pretation. Unknown blast features may already be present in previously collected mapping data, but have yet to be recognized as archaeological features. Future collaboration could facilitate access to these datasets and enable the identification of such features, thereby strengthening our understanding of submerged and amphibious battlescapes.

Exploratory archaeology projects, particularly those focused on underwater battlefield archaeology, can build on foundational questions about the locations of archaeological sites and artifacts by also examining whether and why the seascape was intentionally modified. Asking these questions will encourage more complete documentation of submerged and amphibious battlefields and promote collaboration between underwater archaeologists and researchers across other disciplines. The use of multidisciplinary methods and expertise, as presented here, can complement archaeological research by helping to identify and contextualize the implications of historical findings, with seafloor modification serving as an example of how such an approach can highlight complex interactions between human activity and the coastal environment.

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References

1. Carrell, T.; Burns, J.; Mckinnon, J.; Krivor, M.; Enright, J.; Roth, M.; Pascoe, K.; Raupp, J.; Arnold, S.; Keusenkothen, M. *Peleliu's Forgotten WWII Battlefield*; NOAA Ocean Exploration: Silver Spring, MD, USA, 2020. [CrossRef]
2. Keusenkothen, M.A. Underwater Demolition Teams and the Geomorphological and Ecological Effects of a World War II Amphibious Landing on a Coral Reef in the Pacific. Master's Thesis, East Carolina University, Greenville, NC, USA, May 2024. Available online: <http://hdl.handle.net/10342/13427> (accessed on 20 April 2026).
3. Wright Nunn, A.; LaFrance Bartley, M.; Jones, T.; Moore, D.B.; LaRoche, N.; Hintenlang, L.; Brown, A.; Kilgo, J. *Guam: A Biogeographic and Maritime Cultural Landscape Exploration of a WWII Amphibious Battlefield*; NOAA Ocean Exploration: Silver Spring, MD, USA, 2025. [CrossRef]
4. Jeffery, B.; Mckinnon, J.; Van Tilburg, H. Underwater Cultural Heritage in the Pacific: Themes and Future Directions. *Int. J. Asia Pac. Stud.* **2021**, *17*, 135–168. [CrossRef]
5. Mckinnon, J.; Carrell, T. *Underwater Archaeology of a Pacific Battlefield: The WWII Battle of Saipan*; Springer International Publishing: New York, NY, USA, 2015. [CrossRef]
6. Department of the Navy. *Naval Combat Demolition in the Central Pacific*; Department of the Navy, Office of the Chief of Naval Operations, Intelligence Division, Office of Naval Records and Library; National Archives and Records Administration: College Park, MD, USA, 1945.
7. Department of the Navy. *UDT-3—War History*; Department of the Navy, Office of the Chief of Naval Operations, Intelligence Division, Office of Naval Records and Library; National Archives and Records Administration: College Park, MD, USA, 1945.
8. Department of the Navy. *History of Underwater Demolition Team Four*; Department of the Navy, Office of the Chief of Naval Operations, Intelligence Division, Office of Naval Records and Library; National Archives and Records Administration: College Park, MD, USA, 1945.
9. Department of the Navy. *History of Underwater Demolition Team Six*; Department of the Navy, Office of the Chief of Naval Operations, Intelligence Division, Office of Naval Records and Library; National Archives and Records Administration: College Park, MD, USA, 1945.
10. Dubbins, A. *Into Enemy Waters: A World War II Story of the Demolition Divers Who Became the Navy SEALs*; Diversion Books: New York, NY, USA, 2022.
11. National Park Service. Foundation Document Overview War in the Pacific National Historical Park Guam, National Park Service. 2017. Available online: <https://npshistory.com/publications/foundation-documents/wapa-fd-overview.pdf> (accessed on 17 March 2026).
12. McKinnon, J.F.; Carrell, T.L.; Field, E.; Richards, V.; Scott-Ireton, D.; Tan, A.; Yamafune, K.; Anthony, G. *Final Report: NOAA Ocean Exploration NOFO NA22OAR0110662-T1-01, Exploring Deep-Water WWII Battlefields in the Pacific Using Emerging Technologies*; NOAA Ocean Exploration: Silver Spring, MD, USA, 2024. [CrossRef]
13. NOAA Ocean Exploration. Exploring Attu's Underwater Battlefield and Offshore Environment. Available online: <https://oceanexplorer.noaa.gov/expedition/24attu-battlefield/> (accessed on 1 April 2026).
14. Carberry, W.G. *Report of Underwater Demolition Team 4—Its Activities During the Guam Operation and Recommendations for Future Demolition Operations*; Department of the Navy, Office of the Chief of Naval Operations, Intelligence Division, Office of Naval Records and Library; National Archives and Records Administration: College Park, MD, USA, 1944.
15. Crist, T.C. *Action Report Underwater Demolition Team #3 Forager Operation*; Department of the Navy, Office of the Chief of Naval Operations, Intelligence Division, Office of Naval Records and Library; National Archives and Records Administration: College Park, MD, USA, 1944.
16. Nelson, P.; Duwall, L.; Tamimi, L. Asan and Agat Invasion Beaches: Cultural Landscape Inventory, War in the Pacific National Historical Park, National Park Service, Pacific West Regional Office, Cultural Land-Scapes Inventory Report 975116. 2003. Available online: <https://www.npshistory.com/publications/wapa/crl/part1.htm> (accessed on 1 April 2026).
17. National Park Service. Agat Reef, Guam. Constructed Reality. Available online: <https://constructed.com/asset/aoulyjec3p1> (accessed on 20 April 2026).
18. Wright, A.E.; Conlin, D.L.; Shope, S.M. Assessing the Accuracy of Underwater Photogrammetry for Archaeology: A Comparison of Structure from Motion Photogrammetry and Real Time Kinematic Survey at the East Key Construction Wreck. *J. Mar. Sci. Eng.* **2020**, *8*, 849. [CrossRef]
19. National Park Service. WAPA ASAN Blast Crater. Constructed Reality. Available online: <https://constructed.com/asset/a4u95-ft8mzb> (accessed on 20 April 2026).
20. Terrill, E.; Pietruszka, A.T.; Moline, M.; Kraft, R. *Surveys of WWII U.S. Cultural Assets in the Saipan Channel*; NOAA Ocean Exploration FY20 FFO Grantee Final Report; NOAA Ocean Exploration: Silver Spring, MD, USA, 2024.
21. Pietruszka, A.; Batchelor, H.; Breece, M.; Colbourn, C.; Hess, B.; Gallimore, E.; Moline, M.; Nager, A.; White, E.; Terrill, E. Kiska Alaska's Underwater Battlefield: An Exploration of World War II-era Submerged Archaeological Sites. *Int. J. Naut. Archaeol.* **2024**, *54*, 504–519. [CrossRef]

22. NOAA Office for Coastal Management. 2019–2020 USGS/NOAA Topobathy Lidar: CNMI (Aguijan, Rota, Saipan, Tinian) | InPort. 2022. Available online: <https://www.fisheries.noaa.gov/inport/item/66790> (accessed on 1 April 2026).
23. Bush, D.; Raupp, J.T.; Unrein, A. Exploration of Alaska’s World War II Submerged Heritage: The Kotahira Maru and SS Dellwood Wreck Sites Off Attu Island. *Heritage* **2026**, *9*, 166. [[CrossRef](#)]
24. Meyer-Kaiser, K.S.; Mires, C.H. Underwater cultural heritage is integral to marine ecosystems. *Trends Ecol. Evol.* **2022**, *37*, 815–818. [[CrossRef](#)] [[PubMed](#)]
25. Mires, C.H.; Meyer-Kaiser, K.S. A Case Study in Maritime Heritage Ecology: Understanding How Structural Changes to the 1898 Shipwreck Portland Affect Biological Diversity and Colonization. *J. Marit. Archaeol.* **2023**, *18*, 197–218. [[CrossRef](#)]
26. Paxton, A.B.; McGonigle, C.; Damour, M.; Holly, G.; Caporaso, A.; Campbell, P.B.; Meyer-Kaiser, K.S.; Hamdan, L.J.; Mires, C.H.; Taylor, J.C. Shipwreck ecology: Understanding the function and processes from microbes to megafauna. *BioScience* **2024**, *74*, 12–24. [[CrossRef](#)] [[PubMed](#)]
27. Storlazzi, C.D.; Presto, M.K.; Logan, J.B. Coastal Circulation and Sediment Dynamics in War-in-the-Pacific National Historical Park, Guam; Measurements of Waves, Currents, Temperature, Salinity, and Turbidity, June 2007–January 2008, U.S. Geological Survey, Open File Report 2009-1195. 2009. Available online: <https://pubs.usgs.gov/of/2009/1195/> (accessed on 1 April 2026).
28. Patil, U.; Yeo, M.-H.; Chakraborty, S.; Congress, S.S.C.; Higgs, B. Probabilistic Slope Stability Assessment of Tropical Hillslopes in Southern Guam Under Typhoon-Induced Infiltration. *Geosciences* **2025**, *15*, 453. [[CrossRef](#)]
29. Yeo, M.-H.; Pangelinan, J.; King, R. Identifying Characteristics of Guam’s Extreme Rainfalls Prior to Climate Change Assessment. *Water* **2022**, *14*, 1578. [[CrossRef](#)]
30. Sweet, W.; Hamlington, B.; Kopp, R.E.; Weaver, C.; Barnard, P.L.; Bekaert, D.; Brooks, W.; Craghan, M.; Dusek, G.; Frederikse, T.; et al. Global and Regional Sea Level Rise Scenarios for the United States, National Oceanic and Atmospheric Administration, NOS.01. 2022. Available online: <https://pubs.usgs.gov/publication/70229139> (accessed on 1 April 2026).
31. National Park Service. Asan and Agat Units Management Plan and Environmental Assessment, National Park Service. 2024. Available online: <https://parkplanning.nps.gov/document.cfm?documentID=134032> (accessed on 1 April 2026).
32. National Ocean Mapping, Exploration, and Characterization Council of the Ocean Science and Technology Subcommittee of the Ocean Policy Committee. 2024 Implementation Plan Update for the National Strategy for Ocean Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone. 2024. Available online: https://www.noaa.gov/sites/default/files/2025-01/2024%20NOMECS%20Implementation%20Plan_FINAL.pdf (accessed on 8 March 2026).
33. Ocean Science and Technology Subcommittee of the Ocean Policy Committee. National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone. 2020. Available online: <https://www.noaa.gov/ocean-science-and-technology-subcommittee/national-ocean-mapping-exploration-and-characterization-nomec-council/nomec-strategy-and-implementation-plan> (accessed on 2 April 2026).
34. Interagency Working Group on Ocean Exploration and Characterization for the National Ocean Mapping, Exploration, and Characterization Council and Ocean Science and Technology Subcommittee of the Ocean Policy Committee. Strategic Priorities for Ocean Exploration and Characterization of the United States Exclusive Economic Zone. 2022. Available online: https://oeab.noaa.gov/wp-content/uploads/2022/12/NOMECS_OEC_Priorities_Report.pdf (accessed on 8 March 2026).
35. President’s Panel on Ocean Exploration. *Discovering Earth’s Final Frontier: A U.S. Strategy for Ocean Exploration. The Report of the President’s Panel for Ocean Exploration*; National Oceanic and Atmospheric Administration: Silver Spring, MD, USA, 2000.
36. NOAA Ocean Exploration Our Mission. NOAA Ocean Exploration. Available online: <https://oceanexplorer.noaa.gov/> (accessed on 2 April 2026).
37. Rep. Holt, Rush [D-NJ-12]. H.R.146—111th Congress (2009–2010): Omnibus Public Land Management Act of 2009. Available online: <https://www.congress.gov/bill/111th-congress/house-bill/146> (accessed on 2 April 2026).
38. Brennan, M.L.; Trembanis, A.C.; Delgado, J.P.; DuVal, C.; Otto, G. The Maritime Cultural Landscape of the Simulated Nuclear Battlefield at Bikini Atoll. *J. Marit. Archaeol.* **2024**, *19*, 549–574. [[CrossRef](#)]
39. Mayer, L.; Calder, B.; Schmidt, J. High-Resolution Multibeam Sonar Survey and Interactive 3-D Exploration of the D-Day Wrecks off Normandy. *AGU Fall Meet. Abstr.* **2003**, *1*, 2.
40. Everett, M.; Pierce, C.; Save, N.; Warden, R.; Dickson, D.; Burt, R.; Bradford, J. Geophysical investigation of the June 6, 1944 D-Day invasion site at Pointe du Hoc, Normandy, France. *Surf. Geophys.* **2006**, *4*, 289–304. [[CrossRef](#)]
41. Tunwell, D.; Passmore, D.; Harrison, S. Second World War bomb craters and the archaeology of Allied air attacks in the forests of the Normandie-Maine National Park, NW France. *J. Field Archaeol.* **2016**, *41*, 312–330. [[CrossRef](#)]
42. Passmore, D.; Tunwell, D.; Harrison, S. Revisiting the US military ‘Levels of War’ model as a conceptual tool in conflict archaeology: A case study of WW2 landscapes in Normandy, France. *Methods Confl. Archaeol.* **2018**. Available online: https://www.researchgate.net/publication/340535714_Revisiting_the_US_military_‘Levels_of_War’_model_as_a_conceptual_tool_in_conflict_archaeology_a_case_study_of_WW2_landscapes_in_Normandy_France (accessed on 2 April 2026).

43. Wisniewski, K.; Doyle, P.; Hunter, R.J.S.; Pringle, J.; Stimpson, I.G.; Wright, D.; Squires, K.; Sutherland, Z.; Cassella, J.; Graham, F.C.; et al. A multidisciplinary scientific investigation of the 1916 Hawthorn Mine Crater, Beaumont Hamel, Somme, Northern France. *J. Confl. Archaeol.* **2024**, *18*, 125–156. [[CrossRef](#)]
44. Waga, J.M.; Szypuła, B.; Fajer, M. The Archaeology of Unexploded World War II Bomb Sites in the Koźle Basin, Southern Poland. *Int. J. Hist. Archaeol.* **2023**, *27*, 688–713. [[CrossRef](#)]
45. Higgs, C.L. Dive Diary: Sankisan Maru, SS Thorfinn. Available online: <https://thorfinn.net/dive-diary-sankisan-maru/> (accessed on 2 April 2026).
46. Brennan, M.; Coleman, D.; Roman, C.; Turanli, T.; Davis, D.; Catsambis, A.; Moore, J.; Merrigan, M.; Bajdek, B.; Whitesell, D.; et al. Maritime History of ANZAC Cove. *Oceanography* **2011**, *24*, 20–21.

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