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"Special Session: AUVs: Groundtruthing High-Resolution AUV Side Scan Sonar Contacts for Unexploded Ordnance in a Deepwater GeoHazard Assessment"

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Abstract

Two of the latest directives from the Minerals Management Service indicate a growing concern about Unexploded Ordnance (UXO) located in close proximity to deepwater exploration and development sites within the Gulf of Mexico (NTLs 2006-G12 and 2007-G01) [1, 2]. This paper describes a unique study that yielded project-specific, quantitative avoidance criteria and risk management analysis of UXO, identified during a routine geohazard survey. The ordnance was located with high-resolution Autonomous Underwater Vehicle (AUV) side scan sonar data outside one of seven known dumping zones, in approximately 3,000 feet of water.

Working with high-resolution (410 kHz) AUV side scan sonar data, as well as Remotely Operated Vehicle (ROV) gathered imagery and gradiometer data analysis, a team of global ordnance experts from AMTI (Applied Marine Technology, Inc.) conducted in-depth analytical research, researched historical records, and provided a conclusive analysis of the ordnance. From this, the team identified ordnance types, and assessed and quantified project specific risks. Although industry is increasing exploration and construction within and near to these designated dumpsites, this is the first known instance of such a precise analysis on UXO identified from AUV side scan sonar targets.

The process described in this case study can be applied to geohazard assessments of planned offshore construction sites within and near known ordnance disposal areas in the Gulf of Mexico, as well as globally. These include block studies, well site clearances, right-of-way and lease term pipeline route assessments, and umbilical and communications cable route assessments. The process included an assessment of damage potential to survey and construction equipment by accidental munitions detonation; thereby providing risk mitigation recommendations.

Field data include high-resolution AUV side-scan sonar, ROV imagery and pipe-tracker results, historical data and background on ordnance. AMTI provided detailed risk mitigation criteria in the event of an accidental detonation and the effect on infrastructure and/or other equipment it may have. The conclusions include a series of recommendations and precautionary measures.

Exploration and development is progressing into areas where the potential to encounter UXO is greater. If used systematically, technology now available – high-resolution side scan sonar, and deepwater ROV photography and gradiometry tools, coupled with the high navigational accuracy of AUVs – could greatly increase the value of a geohazard assessment. Additionally, utilization of Explosive Ordnance Disposal (EOD) experts during geohazard survey operations where unexploded ordnance is or could potentially be involved can reduce the timeline in which the survey and assessment is conducted.

Introduction

After WWII, and without regulations to adhere to, the world's oceans were the perfect dumping grounds for unused, unsafe and excess ordnance. From 1946 through 1970, military ordnance was dumped in the Gulf of Mexico by the U.S. armed forces, and it was the primary disposal site for the excess munitions originating from a number of large ordnance houses in the southeastern United States. That ordnance included, but was not limited to, projectiles, bombs, and chemical ordnance.

As industry continues to progress into deeper and deeper water, it will continue to encounter the world's munitions dumping grounds, charted and uncharted. Because records were poorly kept and navigation was not as precise as it is today, ordnance has and will be encountered outside known munitions dumping grounds. Many of these munitions may be either armed or in such an unstable condition that a minor influence could detonate them.

The MMS (Minerals Management Service), charged with the task to manage ocean energy resources, requires that all exploration and production activities be conducted in a safe, and environmentally responsible manner. As high-resolution surveys continue to venture further into deepwater we learn more and more about previously uncharted and little thought about seafloor regions and the environments they support. Experience has taught us that increased knowledge and understanding leads to a constantly changing set of requirements to fulfill in order to conduct ourselves in the safest and most responsible manner.

In June of 2006, the MMS released its Notice to Lessees NTL 2006-G12, which outlined regulations for conducting Ancillary Activities in the Gulf of Mexico OCS Region. Within this Notice, the MMS states a requirement to comply with protective measures when conducting activities within Ordnance Dumping Zones, as well as Military Warning Zones ("Water Test Areas") 1 through 5. Figure 1 displays the areas delineated by the MMS as Ordnance Disposal and Military Warning Areas in the Gulf of Mexico.

Additionally, during the writing of this paper, the MMS released NTL 2007-G01, which updated the Shallow Hazards Program requirements. This notice also recognizes ordnance as a manmade hazard that may have an adverse effect on proposed well operations. Although the standard Gulf of Mexico geohazard survey and assessment does not currently involve a specifically defined unexploded ordnance assessment, prudent owners, operators, and service vendors should consider it on top of the To-Do list when planning projects in those sensitive areas. This paper presents such an assessment as well as provides additional insights into the problem of unexploded ordnance encountered in deepwater.

Three fundamental problems exist that the standard geohazard assessor faces in dealing with the UXO problem. These are simply limitations in technology, awareness, and expertise. The solution lies in the utilization of innovative technology, well thought out and appropriately planned geohazard survey specifications, and most importantly the utilization of unconventional industry experts with the ability to perform adequate and thorough ordnance risk assessments.

Deepwater Geohazard Survey Technology

Deficiencies in Standard Technology

Deficiencies in survey technology include the inability to effectively identify and assess specific ordnance encountered during routine geohazard surveys utilizing 'standard' deepwater survey equipment. Factors that affect the ability to detect an object include resolution ability of the equipment, size and position of the object on the seafloor, acoustic properties of the surrounding sediment, burial status of the object, and component materials that make up the object. This means that an object's size may not allow adequate ensonification for object detection on conventional 120 kHz side scan sonar data. Acoustic records must also be clean and free of noise that could obscure the object. Additionally, ordnance may not be proud to the bottom, in other words, lying on the ocean floor and easily discernable. Complete or partial burial makes for very difficult object detection with side scan sonar, scanning sonar, photographic images and/or video footage. Additionally, magnetometer sensors are useless if the ordnance encountered completely lacks a ferrous content.

Other technological deficiencies include navigational accuracy. Navigational accuracy presents a two-fold problem that affects the effectiveness of a proper geohazard assessment where UXO may or could be involved. First, poor navigational accuracy of the past when vessels were dumping ordnance at sea; and second, the need for precision in locating these items today.

Navigational positioning systems utilized in past years during UXO dumping were not as precise as it is today. LORAN (LOng RAnge Navigation) for example, which is a land based RF system, was utilized by the U.S. Navy during WWII and the years following. With LORAN, as seafaring vessels traveled further from the coast, its signal strength, and accuracy degraded. It was also limited at times by weather and atmospheric conditions, which added to it being an imprecise positioning source for vessels dumping ordnance during those years. This means simply that ordnance intended for the designated bounds of a dumpsite, could in fact have been dumped outside of those bounds. The Global Positioning System (GPS), which provides a positioning solution by utilizing signals from a number of satellites orbiting the Earth, is more widely used today than LORAN, especially in marine applications.

In order to obtain the most efficient use of any type of survey data, a high level of positional accuracy is a must. Deeptow systems rely on USBL (Ultra Short Base Line) for system tracking. USBL accuracy degrades with increasing water depths as the towfish moves laterally further away from the towing vessel. Accuracy of these systems is also dependent upon the configuration of the survey. For example, a deeptow system, being tracked with USBL in a 'single-boat' configuration is not as accurate as an expensive 'two-boat' configuration. These towed systems also rely on the ability of the vessel operator to keep the fish 'on-line', as the system is dragged through the water. These standard systems can leave the assessor with a low degree of positional confidence.

AUV Technology

What sets Autonomous Underwater Vehicles (AUVs) apart from standard deeptow systems is their increased data quality, data detail, and navigational accuracy. C & C Technologies C-Surveyor I^tm AUV was utilized for the case study presented in this paper. The C-Surveyor I^tm is designed to collect deep-water, high-resolution geophysical data for site and route surveys in water depths up to 3,000 meters. It was the first AUV designed and operated for commercial survey applications, and has been working commercially since early 2001[3].

Primary survey sensors found on the C-Surveyor I^tm include a Simrad EM2000 Multibeam Bathymety System, and EdgeTech Chirp Side Scan Sonar and Subbottom Profiler. The EdgeTech side scan sonar is a dual frequency system that uses a calibrated wide band digital frequency modulated (FM) signal to provide high resolution, low-noise images. This sonar simultaneously transmits linearly swept FM pulses centered at two discrete frequencies: 120 kHz and 410 kHz [4,5].

Typically, on standard geohazard surveys, 120 kHz sonar data is acquired. At 120 KHz, the AUV operates at speeds of 4 knots and maintains an altitude of approximately 40 meters off-bottom. The resulting effective range per channel is 225 meters (450-meter swath), which should provide 1-meter object detection. At 410 kHz, the AUV operates closer to the seafloor, at an altitude of approximately 20 meters. The resulting effective range per channel is 50 to 75 meters[3], which should provide half-meter object detection.

The integrated subbottom profiler utilizes transmit pulses generated in the frequency band between 2 and 8 kHz, to create acoustic profiles of the subsurface[3]. Subsurface penetration in the Gulf of Mexico is typically on the order of 150 to 175 meters.

The C-Surveyor I[tm] AUV utilizes inertial navigation systems for primary positioning of the underwater vehicle. A mission plan is downloaded into the AUV system computers prior to vehicle deployment. During survey operations, the mother ship is positioned utilizing Differential GPS. The AUV's inertial navigation system is then continually updated from the mother ship via an Acoustic Command Link. The AUV position solution utilizes input from a HiPAP (High Precision Acoustic Positioning) system on the mother ship and a Doppler velocity log on the AUV, which provide input into the inertial navigation system for internal guidance system checks. Post-processing routines can be implemented to further refine the sub sea positions. The resulting navigational accuracy is +/- 15 m real time, and +/- 5 meters post processing[3].

With the high degree of repeatable positional accuracy of the AUV, coupled with the freedom from time consuming, tethered surveys, AUV systems are vastly becoming the system of choice when data integrity is important.

ROV Technology

Remotely Operated Vehicles (ROVs) are utilized en mass by the oil and gas industry. According to the Marine Technology Society's Remotely Operated Vehicle Committee, there are approximately 400 commercial work class and heavy work class ROV systems in operation worldwide[6]. The committee further estimates (estimates dated March 2004) that approximately 85 percent of these are utilized in support of the offshore oil and gas industry, with the remaining 15% in use for the installation and maintenance of sub sea cables[6].

The oil and gas industry utilizes ROVs to monitor and/or perform sub sea installation, construction, and maintenance activities, as well as to perform general inspections. Specific types of ROV videographic and photographic cameras, in conjunction with proper lighting and skilled maneuvering techniques, can yield valuable project focused information. These unmanned submersibles are an extremely crucial element in deepwater operations where saturation diving is not an option.

ROVs are typically positioned using USBL (Ultra Short Base Line) acoustic positioning for general inspections, route clearances, and installation touchdown monitoring. Additional sensors include gyrocompasses for heading determinations, inclinometers for pitch and roll determinations, and scanning or forward looking sonars for acoustic imaging. Camera pan and tilt sensors determine the specific orientation of the camera. This information aids the ROV pilot as well as data viewers in the determination of camera direction and orientation.

In addition to cameras, ROVs also utilize a large array of other tools, which include a variety of metal detectors. Marine magnetometers are used for the detection of objects with a ferrous content, while gravity gradiometers are more useful for the detection of objects of solid mass (non-compositional specific). These tools can assist with the assessment of existing buried objects not otherwise detected using sonar or photographic imagery. Utilizing a marine gradiometer during an ROV visual inspection as part of a geohazard site or route assessment, can greatly improve the confidence of the assessment, especially where manmade objects may exist.

Unexploded Ordnance Background

Unexploded Ordnance (UXO) throughout the world's oceans continues to be a hazard and will be for some time to come. The North and Caspian Seas are a perfect example of this. The North Sea is littered with live ordnance[7] (Figure 2) with numerous accounts of inadvertent detonations during evolutions at or near the oceans bottom, damaging or destroying equipment and infrastructure and placing humans in imminent danger. There are also accounts that the Caspian Sea has been used as a UXO dumping ground. These UXO, some of which are presumed to be fuzed, were likely dumped during the Russian – Iranian Naval battle, and from excess Russian inventory along with other Former Soviet Union countries[8]. Numerous companies that are producing oil and gas fields in the North Sea and exploring the Caspian Sea are also exploiting deepwater fields surrounding the United States.

Historically, incidents involving ordnance discovered off the coasts of the United States have been limited primarily to fishing boats dragging ordnance up in their nets. It is very rare that a detonation occurs during one of these events although it has happened. In the early 1980's off the coast of New Jersey, a fishing boat attempted to haul a WWII torpedo warhead in to harbor. While at anchor, outside the harbor, and awaiting Navy Explosive Ordnance Disposal (EOD) responders, a storm emerged. The increased wave and wind activity rattled the warhead against the fishing boat, accidentally detonating it and sinking the fishing boat. Due to instances like these, survey, transportation, and exploration companies venturing into deep waters are becoming more susceptible to encountering UXOs and the distinct possibility of an accidental detonation.

UXO dump zones also exist off the Atlantic and Pacific coasts. Although the Atlantic and Pacific oceans drop off very quickly and oil and gas exploration has been limited along those coasts, current technology for deepwater production is making the possibility of Atlantic and Pacific margin exploration more of a reality. This will only increase the need for UXO awareness and viable solutions to their existence in deepwater.

DoD Ocean Disposal

Ocean disposal evolutions were conducted from WWII until 1970 when at-sea disposal by the U.S. armed forces was halted. At the end of WWII, the United States had huge stockpiles of excess ordnance and lacked enough storage facilities to house it. The solution to depleting the inventory was to dump the ordnance at sea. Although, the U.S. Navy officially authorized the procedure from between 1952 through 1964, the practice continued for another six years. During this time, an estimated 31 million pounds of old bombs and rockets were destroyed through a combination of at-sea detonation and dumping[9].

The extent of military munitions dumped at sea was not limited to bombs, projectiles, and other general types of conventional ordnance. Chemical munitions not used overseas during the war were also dumped, sometimes while the vessels carrying it were transiting foreign waters returning home to the United States. Stockpiles of chemical munitions located in the United States that were beyond their lifespan or that were leaking were also disposed of at sea off all coastlines. In 2001, the Government published a report entitled *Offshore Disposal of Chemical Agents and Weapons Conducted by the United* States; however, bounding coordinates (i.e., longitude and latitude) were omitted from the final publication out of concern for public awareness and safety. The Department of Defense (DoD) is conducting research to determine the exact dumping locations and the types of hazards that these abandoned munitions may present. The DoD is releasing information on these locations on a need to know basis.

Historically, the standard practice had been to store and transport ordnance and fuzes separately. Ordnance, in particular, larger ordnance such as bombs and munitions, generally did not contain fuzing systems and were disposed of at sea in bulk. Standard operating procedures for flight deck operations required aircraft payloads to be fuzed prior to air operations. These procedures allowed aviation ordnance men to determine the time setting and target specific fuzing configurations prior to fuzing the ordnance.

Other Sources of Disposed UXO

Military munitions can also be found on the ocean floor for reasons other than the convenience of disposal. Emergency disposal of ordnance and live-fire practice rounds by both ships and airplanes are two examples. In the event of misfires, hung ordnance, or damaged ordnance, the standard procedure was to jettison the faulty items over the side of the ship immediately. In the event of an in-flight emergency, aircraft carrying live ordnance practiced the same emergency action procedure of jettisoning of ordnance payloads[10].

Seafaring vessels and aircraft have been conducting live-fire practice evolutions at sea since long before WWII. Conservatively, it is estimated that five percent of the ordnance expended during those evolutions can be found on the ocean floor. After WWII, DoD ordnance disposal operations, emergency disposal incidents, and live-fire training exercises from the 1940s through 1970 were generally documented; however, there was no overarching administrative guidance or reporting system to provide consistency in reporting nor to consolidate the data regarding the amount of ordnance dumped during this period[10].

Mines and Mine Planting

The depth of the water is an important aspect in the art of mine warfare. Generally, mine warfare occurs in shallow water within depths of 100 to 300 feet. Mines deployed in very deep water (depths greater than 300 feet) pose little hazard to shipping. The greatest threat in these water depths is to submarines and deep-sea submersibles, which are susceptible to the explosive effects due to proximity. Surface vessels may pass over bottom mines in very deep water without actuating the firing mechanisms or, if in the event of an actuation, without suffering any, if at all, substantial damage[11].

Accidental Detonation and Effect

Of primary concern during any evolution is safety. Evolutions involving operations on the sea floor where ordnance exists demands extra attention to safety. Inadvertently contacting a UXO in an unknown state could have catastrophic consequences to both humans and equipment. Accidental detonations can occur with just a minor disturbance of the UXO. The condition of the ordnance, and whether it is fuzed or not, will be a significant determining factor in how sensitive it is to outside influences. Pressure, as a function of water depth, and size of charge are all factors that must be considered when determining the expected effect of detonation to equipment and personnel.

Effect on Equipment/Infrastructure

The obvious destructive power of an explosion is seen on the news on a daily basis. An underwater detonation is no less destructive and can result in severe damage to equipment, infrastructure and support craft and could possibly result in injury or death to personnel. Of primary concern are the AUVs, ROVs, and the sub sea infrastructure itself. Water depth, explosive weight and the proximity of the equipment or structure to the UXO; factor significantly in the damage caused by a detonation.

Effect on Environment

The primary concern regarding munitions dumped in the underwater environment involves the sediments lying on the bottoms of rivers, lakes, ponds, wetlands, and other near-shore coastal environments. These sediments support biological communities and can become contaminated with hazardous constituents leaking from dumped munitions. The major concerns include the continued health of the biological community and its ability to support the ecosystem, and the potential uptake of chemicals by plants and sea life that ultimately form part of the food chain supporting human life. Additionally, hazardous munitions constituents may be suspended in water and available to humans through dermal contact during recreational activities, and ingestion by drinking contaminated water, or consuming contaminated marine life[12].

Object Identification

UXO sites include underwater firing ranges, mine fields and dump zones. Sub sea UXO can range in size from less than 20 millimeter projectiles to 2,000-pound bombs. They come in a myriad of shapes, and can be buried at depths of inches to tens of feet. UXO items can occur singly, in clusters or massive caches. They have been fired, dropped, intentionally set (e.g. offensive and defensive mines), or disposed of (either officially or clandestinely) a day ago to more than a century ago.

With their primarily metal construction, detection of UXO items is usually less difficult than discrimination and identification. The real expertise lies in the ability to discriminate between UXO items (proud or buried) and other discarded items that are commonly found on the ocean floor. Discrimination is critical in reducing false positive UXO identifications, while identification allows ordnance specialists to choose the proper disposal procedure such as render-safe, blow-in-place (intentional detonation; Figure 3), or removal.

Ordnance location, identification and eventual disposition are all compounded by numerous environmental factors. Water depth, temperature, salinity, and turbidity all play a part in locating and identifying UXO. The use of an ROV, or investigatory AUV, in close proximity to an item on the bottom, can very quickly stir up mud and silt; thus making it impossible to identify and photograph until all sediment has settled. UXO in shallow waters (190 feet or less) can easily be dived on by ordnance specialists, identified, rendered safe, and then recovered. However, UXO in 3,000 feet of water leaves very few options for exact munitions classification, by the lack of physical contact (hands-on) inspection and subsequent disposal.

Expertise

Determination of the exact classification of the UXO for assessing its hazard potential is just as important as accurate navigation is to its location. Armed or unarmed, fuzed or not fuzed, conventional or chemical, are all highly important factors to be considered when identifying a UXO. As exploration moves past the 500-fathom curve and into the 1,000-fathom curve, where ordnance is known to have been dumped, it becomes extremely important to not only locate but to also identify UXO. An Explosive Ordnance Disposal (EOD) technician is required to identify, characterize and make recommendations as to disposition. They can also make recommendations on courses of action should that be requested.

Explosive Ordnance Disposal technicians are trained and equipped to deal with explosive threats ranging from unexploded sub munitions to improvised weapons of mass destruction and terrorist devices. A large majority of EOD personnel are trained by the Department of Defense through the Naval School Explosive Ordnance Disposal (NAVSCOLEOD). In general, training utilized within each military branch is focused on ordnance used by that branch and that of their opposing forces. Underwater munitions therefore fall primarily under the jurisdiction of the U. S. Navy.

The primary mission of Navy EOD specialists is to support deploying aircraft carrier battle groups (Carrier Strike Groups) and Amphibious Ready Groups (Expeditionary Strike Groups). Dedicated EOD support is also provided to critical shore stations around the globe to ensure rapid response to any ordnance or terrorist incident. Capabilities range from underwater mine countermeasures to rendering safe hazardous ordnance for Special Operations missions, of which includes land-based munitions, such as booby-traps or improvised explosive devices.

Explosive Ordnance Disposal Specialists

Following discharge or retirement from service, many highly trained EOD personnel, such as Master EOD technicians and Special Operations Officers, continue to utilize their capabilities in the private sector. Federal mandates state that only certified EOD technicians possess the qualifications required to perform range clearances in the private sector. In addition to continuing hands-on experience, these certified experts also expand their EOD support capabilities through mine warfare training and education, symposium participation, consulting, management, and research and development. It is these persons who possess the credentials necessary to perform UXO assessments for geohazard surveys.

Application of AUV, ROV, and EOD Expertise in a GeoHazard Assessment

Survey Planning

Beginning late December 2004 and continuing through early January 2005, C & C Technologies performed a routine geohazard survey in water depths greater than 3,000 feet. The survey area was planned to actually overlap the bounds of an ordnance dump because existing infrastructure limited placement options. Having previously encountered UXO targets more than 3 miles outside the bounds of a designated dump during a similar survey in 2002[13], C & C Technologies recommended and planned to acquire 410 kHz side scan sonar data within selected areas of the project. The pre-planning for acquisition of high-resolution data during initial survey design, reduced field time and subsequent survey costs.

AUV Survey

The pre-planned acquisition of high-resolution, 410 kHz, side scan sonar data within the critical areas suspect to contain UXO, revealed a trend of unknown sonar contacts on the seafloor. Figure 4 presents a sample of this high-resolution AUV data. The linear debris zone, actually located more than 3 miles outside of the designated boundary of the munitions dump, was interpreted as a possible string of UXO, likely dumped from a moving vessel. Most of the targets ensonified during the survey were located outside, but relatively adjacent to the dump boundary. Additional sonar contacts delineated on all survey lines indicated the trail of targets extended over most of the coverage area (Figure 5).

ROV Surveys

Upon review of the AUV survey results, project managers chose to conduct a visual inspection of the most crucial contacts found nearest to the proposed seafloor operations. Water depths required the utilization of a heavy work class ROV. Videographic and photographic data were recorded at each of the crucial contact locations, by positioning the ROV at the coordinate of each sonar contact found on AUV data. This allowed the project team to firstly ground truth the navigational accuracy of the AUV, subsequently prove or disprove each object's existence, and then attempt to identify it as natural or manmade.

ROV video and photographic data, not only confirmed the high-resolution side scan sonar contacts as potential UXO targets, but also identified the existence of an additional potential UXO not previously resolved within the acoustic data. In Figure 5, Contact 2 from the first ROV survey (green symbols) was an additional potential UXO found during the survey. Additionally, the images indicated that the objects were partially buried by seafloor sediments. These new findings raised new concerns that buried potential UXO existed undetected with the methods used to date. As a result, a second ROV survey, using an object detection tool, was deemed necessary to investigate these concerns.

A gradiometer (TSS Pipe-tracker) system was utilized during this second ROV survey to determine the existence of buried or otherwise previously undetected targets within the most critical area surrounding the proposed seafloor disturbance. Two previously identified UXO targets were used as a base line reading for the gradiometer, and a number of parallel lines were acquired across the critical zone. Gradiometer results identified five additional potential UXOs in the area. Figure 5 displays these additional UXO locations (red symbols) with respect to all previous data. Videographic and Photographic data indicated that two of these locations were completely buried, and no object could be seen at or on the seabed surface.

The construction contractor, having previously experienced UXO in the North Sea, was concerned for safety of personnel and equipment. It was thus determined the best course of action would be to conduct in-depth research into these seven unknown UXOs and assess possible risk and mitigation. Project management then set out to find the appropriate expertise to consult with regarding all survey findings. EOD specialists from Applied Marine Technology, Inc. (AMTI) were brought on to the project and tasked with thoroughly assessing the project specific UXO risk.

UXO Research and Hazard Criteria

AMTIs EOD specialists were tasked with the identification and hazard assessment of potential UXO. Upon receipt of all survey results and pertinent data, AMTI researched historical records from more than 20 different government agencies, DoD commands, and private sector businesses with association to the specific Ordnance Dump Zone. Extensive research was conducted through office visits, ordnance publications research, Internet searches (unclassified and classified), phone conversations, and e-mail. In addition, EOD specialists, U.S. Navy Sea-Air-Land (SEAL) team members, and scientists employed by AMTI were consulted regarding the project specific findings.

At the operational level, the Gulf of Mexico was a site in which the unregulated DoD practices for ordnance disposal at sea during the 1950s and 1960s were conducted. Large stockpiles of military munitions from Alabama and Texas were transported to Baithwaite, Louisiana, at which point the munitions were loaded onto ships and barges. From the Port of Baithwaite, the vessels proceeded to the open waters of the Gulf of Mexico and disposed of the munitions either through dumping or demolition operations. The lack of manifests, reports, or other documentation identifying the type and condition of the disposed munitions supports the elevation of the risk assessment.

Several major concerns needed to be addressed in order to assess the risk these specific targets presented. First and most importantly was to ascertain if any of these items were fuzed and armed. If fuzed, they would be in a highly unstable condition. If not fuzed, their condition could be considered a little more stable. However, even if unfuzed, an ordnance item still has the potential to detonate under the right circumstances. Generally, exact munitions classification of potential UXO targets is not possible due to the effects of long-term exposure to the marine environment. Artificial light conditions of deepwater photo images, orientation of the ROV and burial (either full or partial) can also obscure the target and make it difficult to determine exact physical dimensions. These potential UXO existed almost 3,000 feet below sea level where the water temperature is between 32 and 37 degrees Fahrenheit. They were well preserved and had minimal sea growth on them, however, the only way to exactly classify these items at this water depth would be to remove them with an ROV and bring them to the surface for hands-on identification. This was neither feasible nor recommended for this project.

UXO Identification

While several images could not be positively identified as ordnance for a variety of reasons, most of the still images clearly depict military ordnance on the seafloor. Figure 6 presents examples of two objects that could not be positively identified due to the environmental and physical conditions displayed in the photograph (left), or due to poor lighting and/or visibility within the image itself (right).

Objects however that were appropriately imaged were identified and interpreted to be several old WWII AN series bombs and a possible torpedo warhead (Figures 7 and 10, respectively). The sea growth, silt, and semi buried positions of the ordnance prevent the exact classification of much of the ordnance or the fuzing conditions. There were identifiable characteristics supporting a conclusion that some of the ordnance was dumped without fuzes. Characteristics resembling palletized projectiles, shipping bands on the bombs, and a blanked exploder well in a torpedo warhead section are indications the ordnance does not contain fuzes.

Figure 7 presents 4 images of projectiles interpreted to be old WWII AN series bombs. These projectiles seem to be lying on their sides with the base of the projectile to the left and the nose to the right (image orientation). Because all of these projectiles are in the same area, it suggests that they may have been dumped as a complete pallet, which was made of wood, which may have either broken up on impact with bottom or disintegrated over time. These bombs would normally have been transported without the nose fuzes attached. However, if the projectile were palletized and transported with the fuzes installed in the nose, the projectile would still have to be fired in order for the fuze to arm. In either configuration, these would be considered safe to handle and pose a negligible threat. Figure 8 is a photographic image of stocked WWII-era bombs, similar to those interpreted from Figure 7. Figure 9 is an image of the shipping bands used for those bombs, which were also interpreted from Figure 7.

A Possible Torpedo Warhead was interpreted from the ROV image displayed in Figure 10. Dimensions and shape suggest it is a possible torpedo warhead with a blanking plate on the nose to the right (image orientation) where an acoustic hydrophone would be fitted once fully assembled. In this condition, the ordnance would be unarmed. An example of a pristine torpedo, which has similar dimensions/properties of the object in Figure 10, can be seen in Figure 11.

Figure 12 presents the two locations that were identified in gradiometer data as being buried UXO. These locations, apparently covered by sediment, had little to no indication of the conditions of the items. The surface morphology is suggestive of artillery or naval projectiles located below the mud line, though low visibility and artificial light conditions do not allow a confident identification of the objects. In this instance, an onsite ordnance expert would have been able to request the ROV operator to maneuver to a better location for proper identification.

UXO Hazard Assessment

The concern existed of how to deal with the ordnance on the bottom and what courses of action could be recommended. Removing or blowing in place would be difficult, time consuming and cost prohibitive in these water depths. Additionally, the blow-in-place option would be environmentally unsound.

The final risk factor was based on upon observation and the relatively high percentage of older styles of ordnance seen in the photographs. Older fuzes present more risk than modern fuzes because of inherent design flaws.

A mitigating factor to the probability of an operable fuze or fuzing system is the considerable pressure being exerted on the ordnance. Calculations indicate an approximate 860,000 psf (pounds per square foot) of surface pressure exist at this water depth on UXO of similar size (Appendix). The likelihood of water penetration on these UXO is excellent, which decreases the chance of detonation even further. The culmination of data, including pictures; the configuration of the UXOs; and the limited historical data on the Gulf of Mexico did not support these UXOs being armed. It was further surmised that the most likely explosive fillers would be Trinitrotoluene (TNT), composition B, amatol, tritonal, HBX, and Torpedo Explosive (TORPEX). However, none of this could be confirmed, as a hands-on reconnaissance was not performed.

Military ordnance will contain one of many types of main charge explosive fillers (TNT, composition B, HDX, etc.). In ideal conditions, the efficacy of explosive fillers in ordnance does not deteriorate with time. However, when exposed to conditions, such as the water depth, temperature, and bottom conditions, the fillers will be affected to some extent. Explosives initiated by a booster (found in fuzes or a fuzing system) can produce the same results today as intended when originally manufactured. A potential explosive hazard is still present in unfuzed ordnance, but overall the ordnance presents less risk.

If ordnance were armed, the environmental factors support the probability of operable fuzing systems. In the absence of oxygen, such as in deeper and colder waters, for example, ordnance at a depth of 3,000 feet, where the water is between 32 and 37 degrees, corrosion in the underwater environment can be virtually stopped. Preservation can also be accomplished if the ordnance is buried or coated by silt. Based on the gathered images, the UXOs are covered and/or buried in silt. The ordnance in the photographs appear to lack oxidation characteristics, which further supports the conclusion that any fuzes may be operable.

Results of UXO Hazard Assessment

Four factors contributed to the overall assessment: historical military operations in the Gulf of Mexico, the generally good condition of the ordnance depicted in the photographs, environmental conditions, and the relatively high percentage of old-style ordnance interpreted from the photographs. In regard to the potential damage to a construction vessel, a risk assessment of low was assigned because of the extreme depth of water and the relatively low explosive weight. In regard to the potential damage to the installation equipment and infrastructure on the seafloor, a risk assessment of low to moderate was assigned. Justifications for the low to moderate rating are based on the visible ordnance and the absence of fuzing. In addition, assumptions were made regarding buried ordnance, as to the presence or absence of fuzing, which may or may not be armed.

Quantitatively, using a calculation derived by the work of Bruschi et al., 1994[14], it was determined that the project specific proposed infrastructure should survive a 286-pound explosion (WWII GP 500-pound bomb), as long as the standoff distance is greater than approximately 43.5 feet. The closest UXO existed 59 feet from the proposed seafloor disturbance, which was acceptable based upon theoretical calculations.

Better Safe than Sorry

An alternative was discussed to completely move portions of the project to avoid this debris field all together, but existing infrastructure limited the available area to move into. Although the area was farther away from the designated dump bounds, it was suspected that the trail of UXOs might actually traverse the only available area. To confirm this, a limited side scan sonar survey was conducted to verify seafloor conditions. This survey, conducted after the completed UXO assessment, confirmed that not only did the ordnance debris field extend further as expected, but the distribution of possible UXO targets also increased. This final alternative was therefore abandoned. Given the level of confidence in which the UXO assessment provided, the project continued as originally planned, with avoidance recommendations.

Conclusions

Beginning with survey design, knowledge of project-specific UXO history and probability, is the first key to a successful deepwater geohazard assessment. Following through on a well-planned survey by utilizing deepwater AUV systems, with the collection of high frequency low noise side scan sonar data, is only the beginning for a proper UXO assessment. A well-planned ROV visual inspection, performed in conjunction with buried object detection work, provides the additional data required to complete a thorough assessment of UXO risk. The efficiency of the process lays with the high-navigational accuracy of the AUV data at its origin, with the end being precise hazard avoidance criteria, UXO or other.

Explosives Ordnance Disposal experts, such as certified Master EOD technicians available in the private sector, can provide quantitative risk assessment when UXO are or could potentially be involved during a geohazard survey. Utilizing the expertise brought to a project during the planning phases of a geohazard survey, as well as being available during ROV exercises, can greatly increase the effectiveness of just such a project.

Neither technology nor a single source of expertise can provide all of the answers, but together, they are able to combine the scientific, technological, and tactical perspectives to identify and assess conditions where UXO is expected, or likewise unexpectedly discovered, during geohazard surveys.

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To gain further information, interested parties may obtain many of the ship logs and military reports at the College Park annex to the National Archives in Maryland or petition the DoD for relevant documents in accordance with the Freedom of Information Act.

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Appendix

Calculation of pressure on ordnance at depth:

Given:

One cubic foot of seawater = 64 pcf
Object estimated to be 16 in by 44 in = 704 in^2
Depth of object in seawater = 2,750 feet
Inches per square foot = 144 in^2

Such that:

Weight of seawater on object under 2,750 feet of water (pounds per square foot) is:
(64 pcf) (2,750 ft) = 176,000 psf

Yields:

$(704\ in^2 / 144\ in^2)$ (176,000 psf) = 860,444.44 psf

Figures

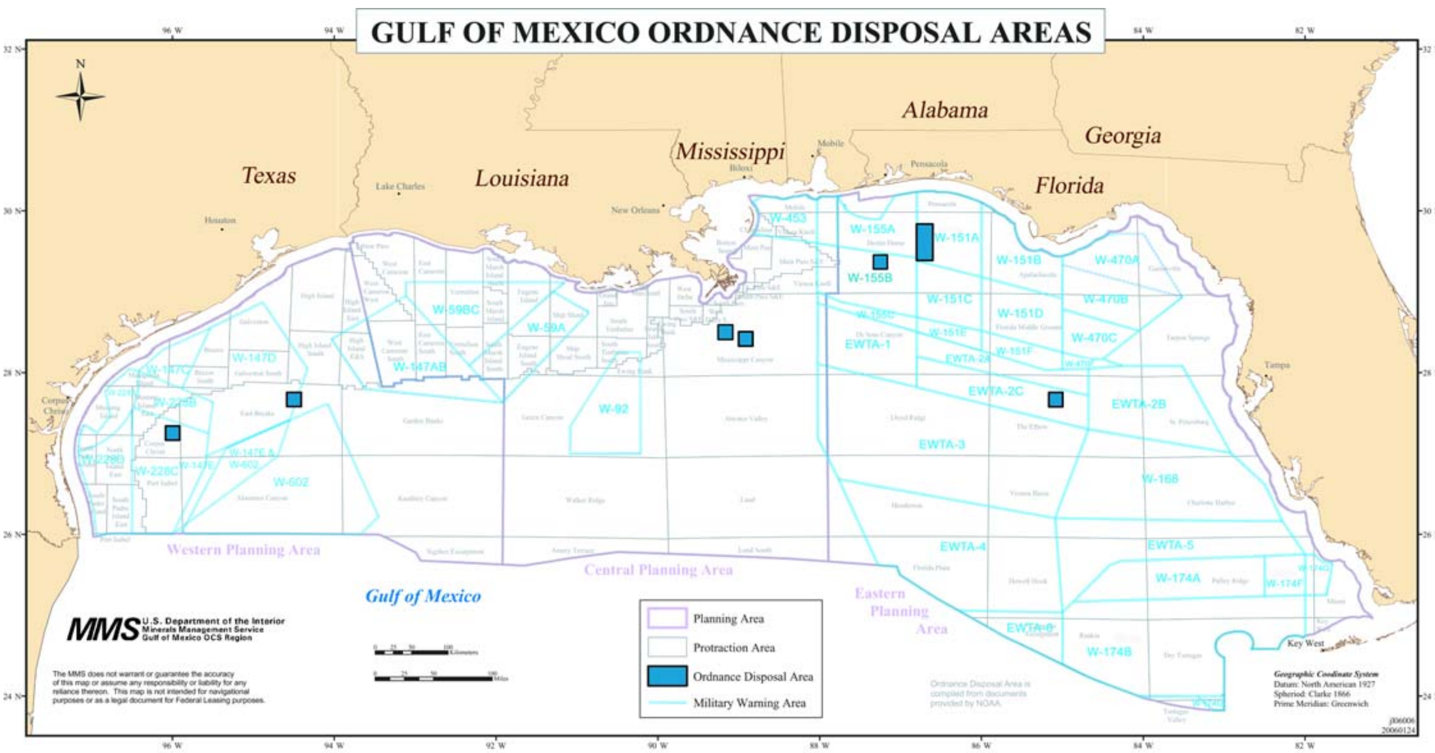

Figure 1: Minerals Management Service Map of Ordnance Disposal and Military Warning Areas in the Gulf of Mexico.

Figure 2: Possible G-Series WWII German ground mine resting in 157 feet of water, adjacent to a pipeline in the North Sea[5].

Figure 3: Intentional Detonation of a G-Series WWII German ground mine in the North Sea[5].

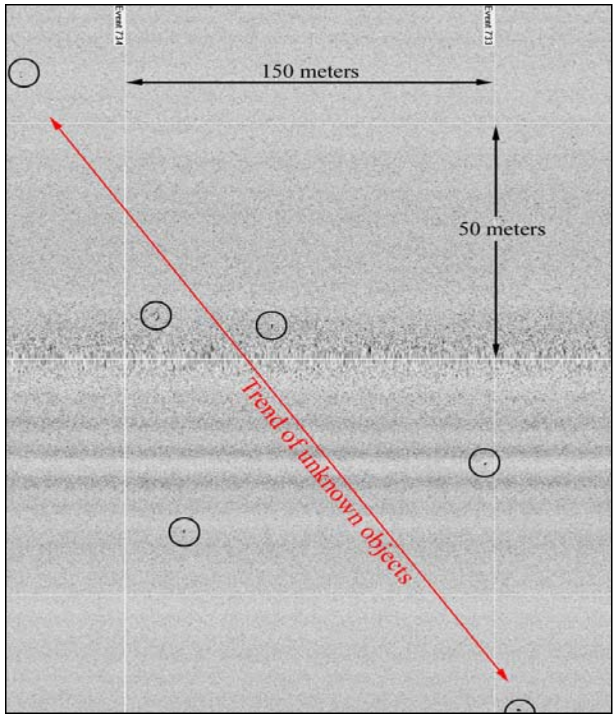

Figure 4: Trail of unknown sonar contacts in 410 kHz AUV side scan sonar data.

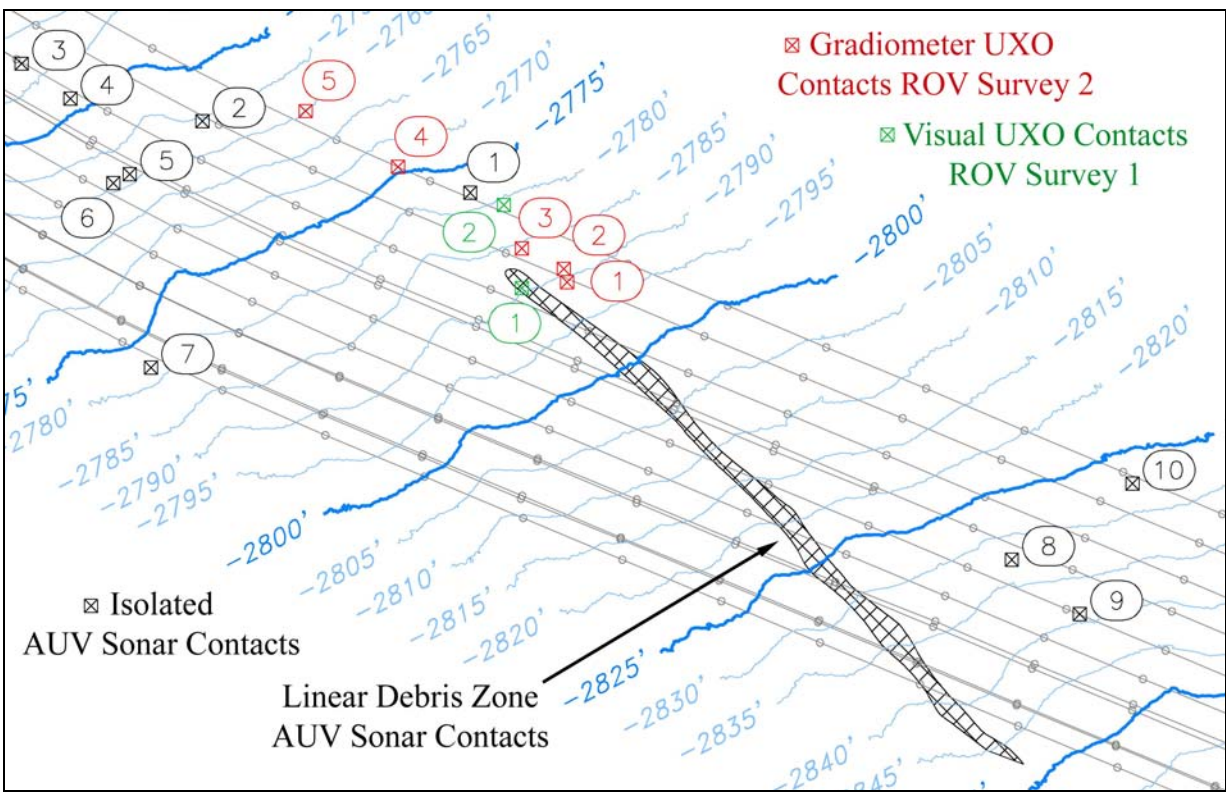

Figure 5: Combined Survey Results referenced to the AUV survey tracklines. Black contact symbols represent all sonar contacts interpreted in coverage area from 410 kHz AUV side scan sonar data. Green contact symbols represent only contacts reported to be UXO on seafloor from first ROV survey (Visual only). Red contact symbols represent only contacts reported to be UXO on seafloor or buried beneath the seafloor as interpreted from Gradiometer results from second ROV survey (Visual and Gradiometric data).

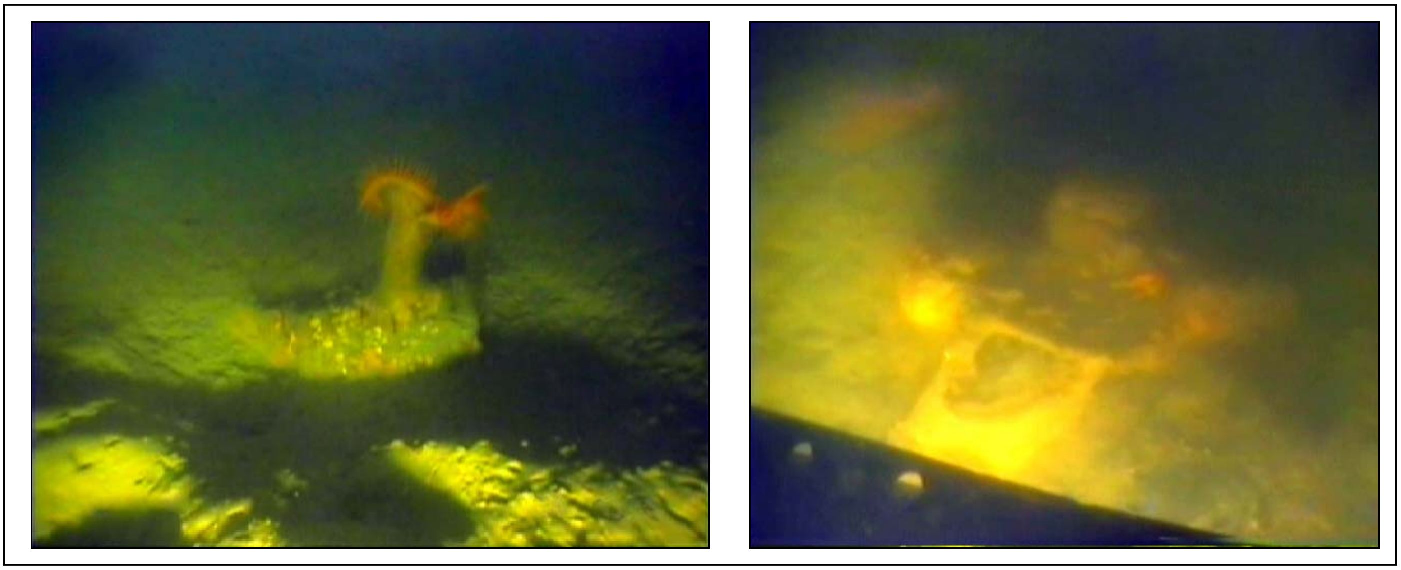

Figure 6: Unknown Objects. Positive identification of these objects is not possible given the environmental and physical conditions presented in the left still image, and poor lighting and visibility presented in the right.

Figure 7: Possible WWII-era Bombs. These images suggest each object is possibly a U.S. 500-pound Army/Navy (AN) series WWII-era bomb with the shipping bands still attached.

Figure 8: Stocked WWII 1,000-pound Bombs. Bombs dropped during WWII were highly explosive, a general-purpose bomb of 250; 500; or 1,000 pounds each[15].

Figure 9: Shipping Band. Shipping bands similar to this one, are apparent in ROV photographs[16].

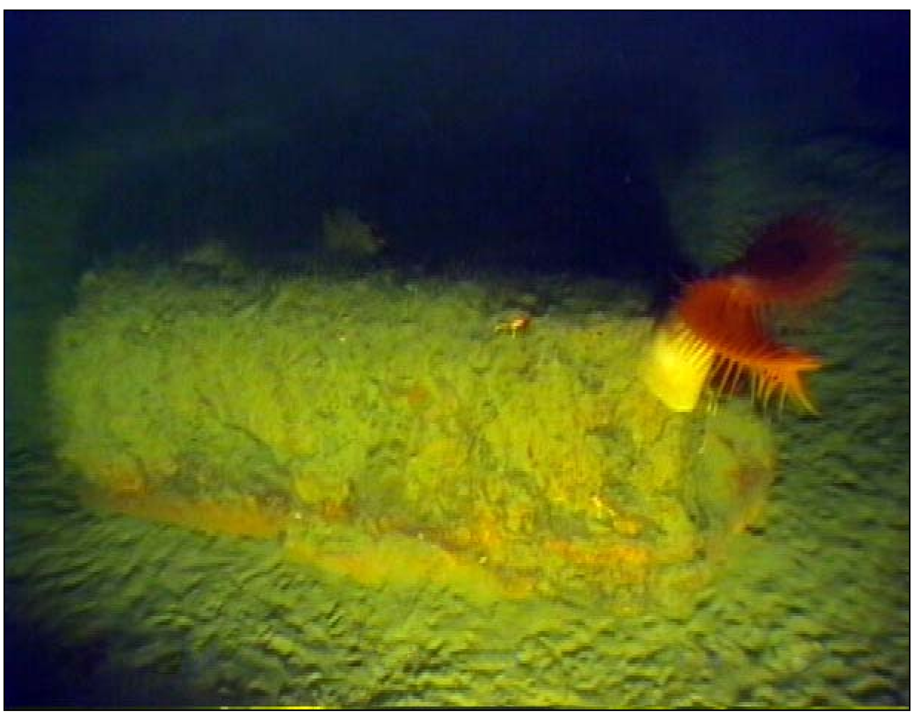

Figure 10: Possible Torpedo Warhead. Dimensions and shape suggest it is a possible torpedo warhead with a blanking plate on the nose where an acoustic hydrophone would be fitted once fully assembled. In this condition, the ordnance would be unarmed.

Figure 11: Example of a Pristine Torpedo. The object in Figure 10 appears to have the same physical properties as this torpedo[17].

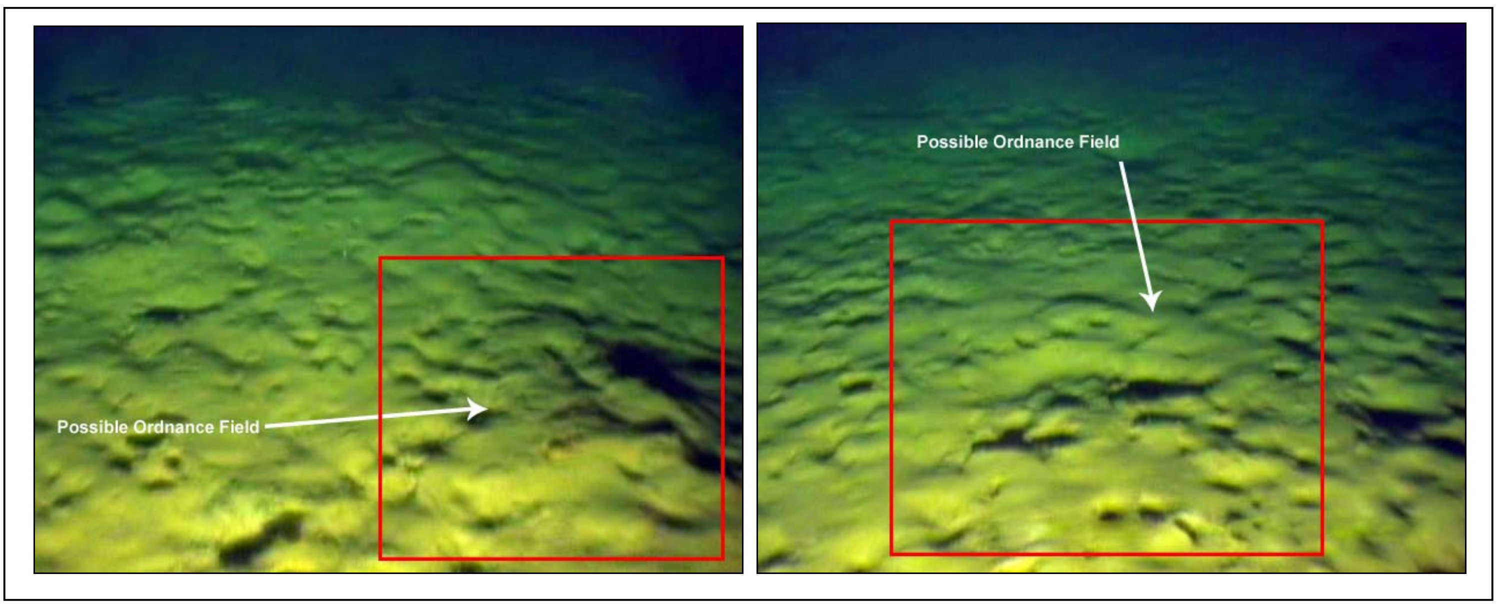

Figure 12: Possible Buried Artillery or Naval Projectiles. ROV still images at locations of positive gradiometer readings indicative of possible buried ordnance at each location.