



Considerations for Underwater Investigation and Salvage of *Deepwater Horizon*

David Rosenberg

Abstract/ Executive Summary

Deepwater Horizon contains perishable evidence and potentially stores pollutants, and as with many sunken ships this warrants a baseline survey and ongoing monitoring.

Undoubtedly, the magnitude of the consequences of the Macondo blowout make her circumstances unique, but what can we learn from *Deepwater Horizon*? There may be information aboard, nearby the site or throughout the Gulf of Mexico which is valuable to understanding the events before, during, and after the well blowout.

Investigations to date by others reveal unknown facts and/or data which may improve the understanding of this catastrophe and efforts to manage the risk of deepwater drilling. Based on previous testimony it is possible that equipment and material samples may reveal useful information. These include barriers (mud, cement) as well as controls (BOP equipment) and parts of these may be physically intact aboard *Deepwater Horizon* or on the seabed in equipment containers, hoses, pipes, etc.

In order to justify the risks and expense of undertaking investigation or salvage, it is important to identify what information is being sought and how this will improve the uncertainties in our understanding of events. Likewise due to the nature of ongoing investigations and legal proceedings information and any recovery or salvage must be collected in a valid manner and according to a Court-governed consensus.

This White Paper has been prepared by the Deepwater Horizon Study Group (DHSG) at the Center for Catastrophic Risk Management. It addresses the general challenges of investigation and salvage in deepwater, available technology and experience base, as well as a brief discussion including four semisubmersible drill ships-- including *Deepwater Horizon* and others which may yield relevant experiences.

The DHSG is comprised of representatives from the public, academia, and industry including professionals in the fields of engineering human and organizational systems, deepwater drilling, as well as environmental science and policy. The goal of the DHSG is to improve the quality of decisions by Government, Industry and the Public by sharing factual data and analysis in a collaborative effort.

Table of Contents

| | | |
|-----|--|----|
| 1 | Introduction..... | 3 |
| 1.1 | Site..... | 3 |
| 1.2 | Deepwater Horizon Drilling System..... | 4 |
| 1.3 | What Can Be Learned From Deepwater Horizon?..... | 5 |
| 2 | Proposed Solutions..... | 6 |
| 2.1 | Deepwater Assets..... | 6 |
| 2.2 | Previous Experiences..... | 9 |
| 3 | Summary..... | 12 |
| 4 | Appendix – Semisubmersible Drill Ship Evaluation..... | 12 |
| 4.1 | Semisubmersible History and Mission..... | 13 |
| 4.2 | Deepwater Drilling System..... | 14 |
| 4.3 | Aban Pearl (2 nd Gen. Aker H-3, 1977)..... | 16 |
| 4.4 | Deepwater Horizon (5 th Gen. Reading & Bates Falcon 8-series)..... | 17 |
| 4.5 | Deepwater Nautilus (5 th Gen. Reading & Bates Falcon 8-series)..... | 17 |
| 4.6 | Transocean Marianas (Earl & Wright Sedco 700 Enhanced)..... | 18 |
| 5 | References..... | 19 |

Figures

| | | |
|------------|---|----|
| Figure 1.1 | – Vicinity map showing the Mississippi Canyon 252 block in relation the Louisiana coast.. | 4 |
| Figure 1.2 | – Bathymetric map of MC-252 showing the planned locations and coordinates of Macondo wells ‘A’ and ‘B’..... | 5 |
| Figure 3.1 | – Jialong submersible..... | 8 |
| Figure 3.2 | – Sonar scan and map of the Macondo site..... | 8 |
| Figure 3.3 | – Close up of sonar scan of Deepwater Horizon..... | 9 |
| Figure 3.4 | – Diver hot tap similar to techniques adapted for ROV use (ASA)..... | 10 |
| Figure 3.5 | – Illustration depicting the 1974 recovery of a submarine in 17,000 feet of water..... | 10 |
| Figure 3.6 | – Illustration of the lifting connection used to salvage the Kursk..... | 11 |
| Figure 3.7 | – Illustration of the underwater cutting arrangement used during the salvage of Kursk...11 | |
| Figure 4.1 | – Photo of Bluewater Rig No. 1, the world's first semisubmersible drilling vessel..... | 13 |
| Figure 4.2 | – Illustration of Offshore Drilling Technology—typical arrangement for a semisubmersible drilling rig..... | 15 |
| Figure 4.3 | – Aker H-3 design semisubmersible Treasure Seeker..... | 17 |
| Figure 4.4 | – Aerial view of Deepwater Horizon..... | 17 |
| Figure 4.5 | – View of Deepwater Nautilus..... | 18 |
| Figure 4.6 | – Aerial View of Transocean Marianas..... | 18 |

Tables

| | | |
|-----------|---|---|
| Table 3.1 | – Submersibles commercially available and rated for 5,000 ft. water depth or greater..... | 7 |
|-----------|---|---|

1 Introduction

The problem of perishable evidence aboard *Deepwater Horizon* as well as stores of oil or other potential pollutants which may be released in the future is a common concern with many sunken vessels. Release of (oil based) cargoes from shipwrecks has become an increasingly significant concern as many early 20th century steel vessels which sank are now succumbing to the inevitable effects of corrosion and structural collapse. When this happens, tanks which were previously intact can breach, resulting in a release of contents. Baseline and regular surveys are necessary to monitor the structural integrity of tankage and the hull as it deteriorates on the seabed.

Additionally, there may be information valuable to understanding the events of the Macondo well blowout. What can the vessel and other equipment or materials reveal? Potential new information could be learned from samples which may remain in the mud circulation, cementing equipment and stores, for example.

Objects from *Deepwater Horizon* have been found as far away as Florida on Panama City Beach, Miramar Beach in Walton County, and in the waters of East Pass in Destin. Others, including the Blow Out Preventer (BOP) Stack are custody of the United States under the direction of the Department of Justice (DOJ) and Federal Bureau of Investigation (FBI). A contractor has been engaged to investigate the recovered equipment, and the wreckage of Deepwater Horizon has been declared a restricted site by the United States Government.

In order to justify the risks and expense of undertaking investigation, salvage other deepwater operations, it is important to identify what information is being sought and how this will improve our understanding of the event and future prevention. This has been the previous experience from other investigations involving the Federal Court system, Government (Department of Justice) and multiple legal interests during the rebuilding of flood protection systems following Katrina.

Given the legal environment surrounding Deepwater Horizon, systematic cataloging of physical and other evidence is necessary, including recording in-situ conditions, establishing chain-of-custody, and conducting and reporting testing or analysis. The BOP, for example, is being investigated under a three-tier system in which certain persons are able to attend while others watch via live or recorded video. Because *Deepwater Horizon* is on the seabed near the Macondo site, potential solutions for accessing and investigating require specific deepwater capabilities such as ROVs, Submersibles and supporting vessels and marine systems.

1.1 Site

The Macondo well reservoir is located approximately 50 miles Southeast of New Orleans, Louisiana in the United States Federal Jurisdiction of the Gulf of Mexico, within the internationally-recognized 200-mile limit from shore. The site is designated Mississippi Canyon (MC)- 252, a 5,760

acre or 3 mile x 3 mile area leased by the US Department of Interior to BP for rights to oil & gas exploration and production.¹

This location is in a region known as the Central Planning Area and the lease was part of the 2006 lease auction held by the Government in order to solicit fair market value for these rights on the behalf of the Public. BP and other Leasees have constructed over 500 deepwater wells beyond the 600-ft depth limit of the original Outer Continental Shelf (OCS) portion of the GOM.

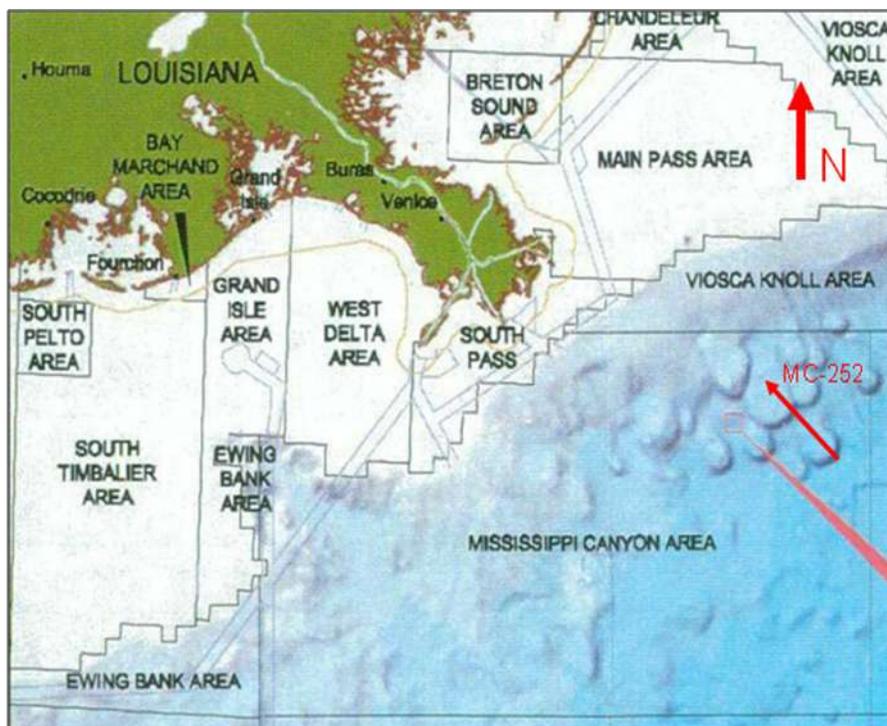


Figure 1.1 – Vicinity map showing the Mississippi Canyon 252 block in relation the Louisiana coast.²

The Macondo (MC-252) wells “A” and “B” are located 315 feet apart in approximately 5000 ft of water depth (Figure 1.2). Drilling began on October 7, 2009 using the rig *Transocean Marianas*, as specified in permitting documents. In November that rig was damaged by Hurricane Ida and towed to a shipyard for repairs while drilling work resumed in February 2010 using the *Deepwater Horizon*.

1.2 Deepwater Horizon Drilling System

The deepwater drilling system consists of the semisubmersible drill ship, riser and subsea hardware including the blow-out preventer (BOP) stack and underwater work systems.

¹ BP/MMS, 2009.

² BP/ MMS, 2009.

Deepwater Horizon is a fifth-generation semisubmersible Mobile Offshore Drilling Unit (MODU), or more generally known as a column-stabilized unit (CSU) by classification societies such as the American Bureau of Shipping (ABS) and Det Norske Veritas (DNV.) Built in 2001 by Hyundai Heavy Industries, she measures 396 ft x 256 ft with a published total displacement of approximately 58,000 tons (US) and, variable rated deck load of 8,000 tons. Capabilities included operating in water depths up to 8000 ft using dynamically positioned (DP) station keeping, drilling to 30,000 feet and accommodations for 130 crew, contractors, and visitors. More about *Deepwater Horizon* and other semisubmersibles can be found in the Appendix.

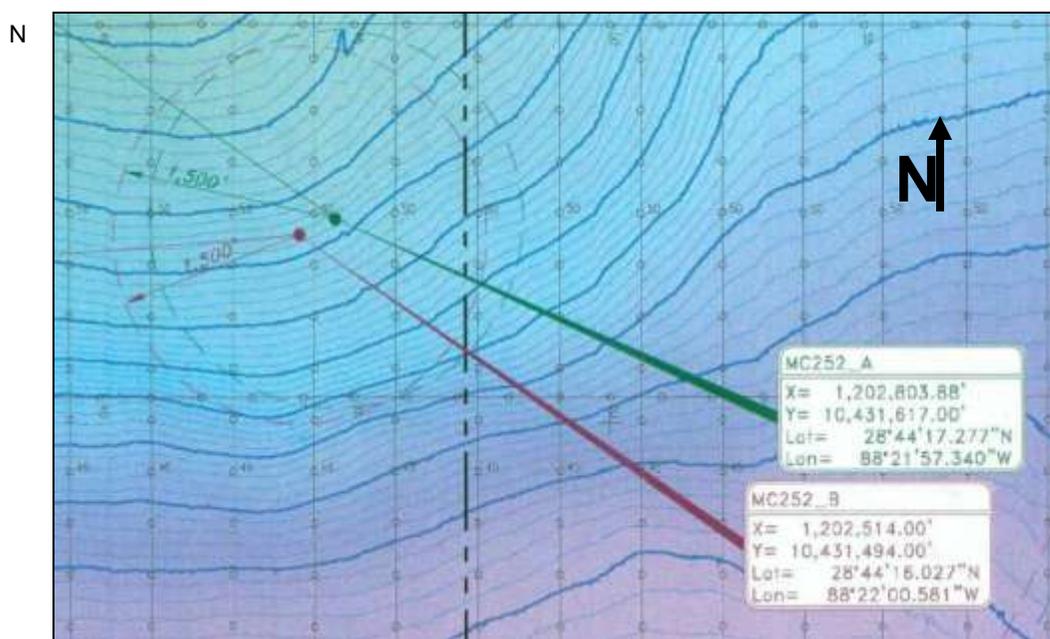


Figure 1.2 – Bathymetric map of MC-252 showing the planned locations and coordinates of Macondo wells ‘A’ and ‘B’.³

1.3 What Can Be Learned From Deepwater Horizon?

All shipwrecks are in a constant state of decay, which eventually results in loss of tank and hull structural integrity and the potential for oil or other unwanted releases. Baseline evaluation and ongoing monitoring are important to effectively managing the associated risks.

There also may be information aboard or nearby the Macondo site and Gulf of Mexico which is valuable to understanding the events surrounding the blowout. Investigations to date reveal unknown or uncertain facts and/or data which may improve the understanding of this catastrophe and efforts to manage the risk of deepwater drilling. These include barriers (mud, cement) as well as controls (BOP spare parts, surface systems) and other items physically intact aboard *Deepwater Horizon* or on the seabed. It is possible that equipment and material samples may reveal useful information, such as mud and cement which may be intact aboard *Deepwater Horizon* or on the

³ BP/ MMS. 2009.

seabed in equipment containers, pipe or hoses. Also, aside from a general hull and tankage evaluation as previously discussed, a general inventory of the equipment, parts, and materials aboard the vessel is warranted. Such efforts are similar to the inventory of materials excavated from canal floodwall breaches following Hurricane Katrina.⁴

2 Proposed Solutions

Possible solutions for the underwater investigation of *Deepwater Horizon* and the Macondo well site include existing ROV and submersible systems, as well as deepwater oil recovery and salvage techniques previously used on other projects. These include the 2004 recovery of oil from the tanker *Prestige*, as well as two separate submarine salvage efforts—a clandestine operation by the United States in 1974 and the well-publicized multinational effort to recover the Russian *Kursk* in 2001. Other sites could warrant investigation, as equipment containers from *Deepwater Horizon* have been found as far away as Florida on Panama City Beach, Miramar Beach in Walton County, and in the waters of East Pass in Destin.

Collection of information should include an initial survey and appropriate chain-of-custody in agreement with the various parties involved. Such a protocol was previously used during the excavation of failed I-Wall panels during canal floodwall repairs post-Katrina⁵ and already similar court-governed procedures are in place for the investigation of the recovered BOP Stack.

The following are possible solutions for underwater investigation:

- Review sonar, ROV, other footage and dive logs and operator interviews.
- Review any Sonar and visual surveys of debris field and plan any additional as necessary.
- Salvage damaged riser sections as warranted.
- In-situ underwater investigation of the *Deepwater Horizon* and Macondo site, including inventory.
- Identify and/or retrieve “perishable” items which are of significant interest for priority consideration.
- Salvage of *Deepwater Horizon* in part or entirely.
- Investigate other ocean, transportation, and coastal sites and facilities as warranted.

2.1 Deepwater Assets

Before the age of ROV's, offshore oil & gas operations utilized divers and submersibles for underwater operations and subsea well tasks such as guiding drill string and other rigging, assembling and operating valves and piping, as well as the inevitable salvage. While in 1960 August

⁴ Rosenberg. Observations from the T-wall repair of the 17th Street Canal breach. Unpublished, 2009.

⁵ Ibid.

Deepwater Horizon Study Group – Working Paper

Considerations for Underwater Investigation and Salvage of Deepwater Horizon

Piccard and Don Walsh had conquered the depths of the Marianas Trench at greater than 35,000 ft in the submersible *Trieste*, subsea oil & gas was still largely dependent on having a set of human hands physically present at the work site.

As few deep saturation bell diving systems are rated for duty below 1000 ft and the deepest experimental commercial dive being 2300 ft, submersibles provided a workable alternative as the industry definition of deepwater moved from hundreds of feet to thousands. They were widely deployed during the 1970's when remotely operated technologies were not yet capable or reliable enough for the oilfield. Submersibles allowed the necessary sense of view, awareness of the site, and dexterity for tasks not yet available by remote operation from the surface using video and other instruments. Even today with advances in remote technology these same senses are all still more acute in submersibles as opposed to ROV, and these benefits are often cited by submersible pilots.

While deepwater drilling systems have evolved to incorporate remotely-operated technologies, submersibles are still regularly used and maintained for deep ocean search salvage & rescue, scientific research, shipwreck exploration, and entertainment (media production). This operational and experience base is well suited to support the underwater physical investigation of the *Deepwater Horizon* and Macondo well site. The available experience with shipwrecks and the technologies to examine them, for example, would be particularly useful to examining *Deepwater Horizon* in-situ.⁶

Eight commercially available submersibles-- not all operational-- have been identified which are capable of accessing the 5000 ft water depths at Mississippi Canyon-252 block (Table 3.1).

Table 3.1 – Submersibles commercially available and rated for 5,000 ft. water depth or greater.⁷

| Name | Model/Type | Depth Rating (feet) | Operator | Nation | Occ. |
|--------------|------------|---------------------|---------------------|--------|------|
| Alvin | US Navy | 14,600 | Woods Hole/US Navy | US | 3 |
| MIR 1 & 2 | MIR | 19,685 | PP ShirshovInst. | Russia | 3 |
| Nautile | Nautile | 19,685 | IFREMER | France | |
| Pisces IV | Pisces | 6,499 | HURL, Univ., Hawaii | US | 3 |
| Pisces V | Pisces | 6,283 | HURL, Univ., Hawaii | US | 3 |
| Shinkai 6500 | Shinkai | 21,325 | JAMSTEC | Japan | 3 |
| Jiaolong | Jiaolong | 23,000 | | China | |

⁶ Deep Ocean Group. 2010 Report on Macondo Oil Spill.

⁷ Marine Technology Society (MTS), Manned Underwater Vehicles Comm. June, 2010 & China Brief, 2010. Table 3.1 shows Submersible assets capable of 5,000 ft. and commercially available. Submersibles are typically smaller than a submarine and designed for depth rather than range of travel. Three distinguishing features are their transportability from site to site, ability to be launched and recovered from a support vessel, and economic commercial operations.

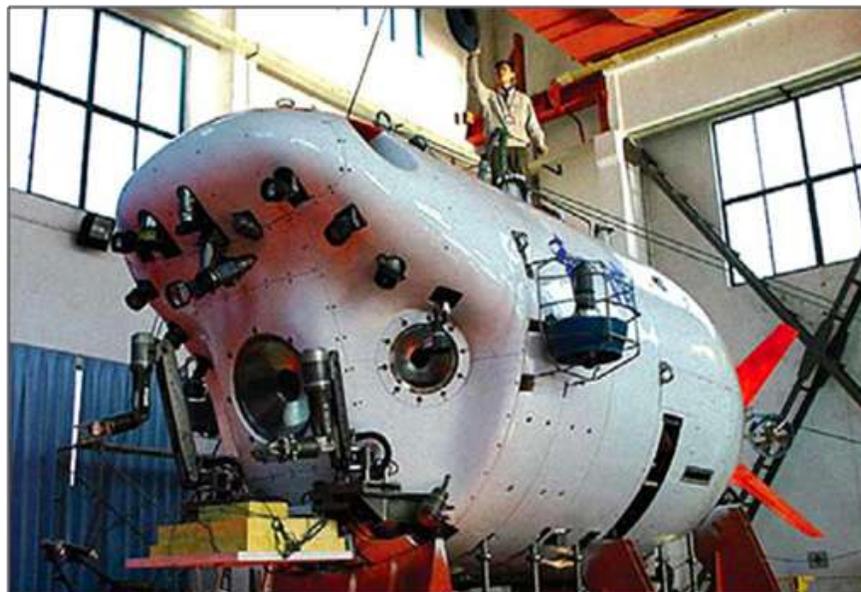


Figure 3.1 – Jialong submersible.⁸

Three of these are operated within the United States, including the Pisces IV and V at the University of Hawaii/ HURL and the Alvin operated by the Woods Hole Oceanographic Institute (WHOI). Alvin has been diving in the GOM on environmental missions. Worldwide commercially available and depth-capable systems also include the French Nautilus, Russian Mir 1 & 2, Japanese Shinkai 6500, and the newest—the Chinese Jialong (Figure 3.1).

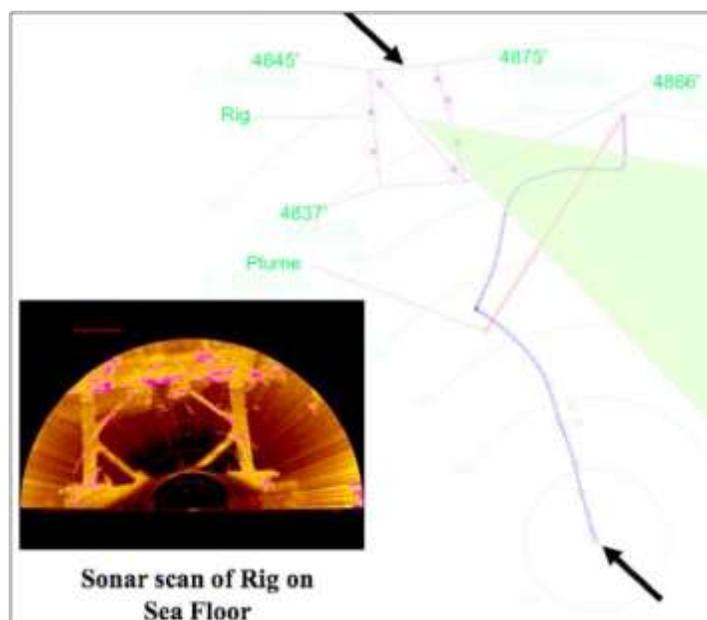


Figure 3.2 – Sonar scan and map of the Macondo site.⁹

⁸ China Daily, 2010.

⁹ USCG, 2010.

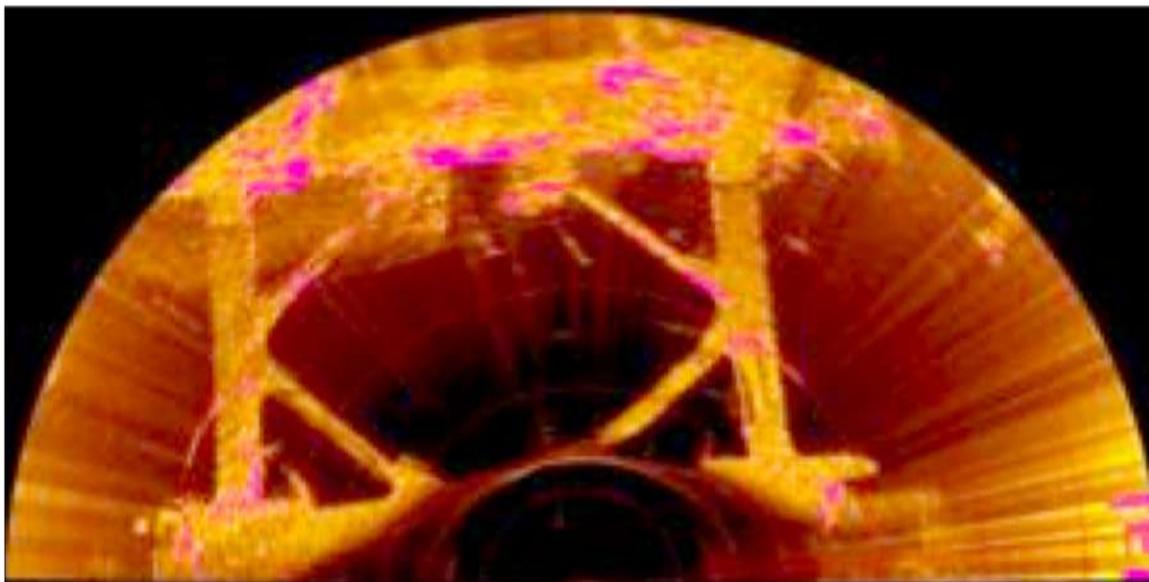


Figure 3.3 – Close up of sonar scan of Deepwater Horizon.¹⁰

Deepwater Horizon is resting on the seabed approximately 1500 ft. from the well, in a maximum water depth of 4886 ft. Publicly-available sonar information indicates that she is intact, although her structural integrity may be compromised by the massive fire which burned for two days before the vessel sank.

2.2 Previous Experiences

A growing experience base exists for surveying, securing, and salvaging vessels in deep water, including recovery of oil from sunken and deteriorating ships as well as notable salvage projects of submarines. Release of (oil based) cargos from shipwrecks has become an increasingly significant issue as many early 20th century steel vessels which sank are now succumbing to the effects of environment—namely corrosion and structural collapse which opens formerly secured stores of fuel or petroleum-based cargo.¹¹ Notable recent experience with this problem in deepwater was acquired on the tanker *Prestige*, which sank off the coast of Spain in approximately 12,000 ft of water in November 2002.

Soon after the oil tanker *Prestige* sank, it was discovered that product was leaking. A survey effort with the French submersible *Nautilie* was followed by oil recovery in 2004 using purpose-built subsea hardware installed on the hull. Several teams worked simultaneously to develop alternatives for accomplishing the work, resulting in the upgrade of existing ROV systems and purpose-built equipment which allowed the oil to be pumped to a Floating Production Storage and Offloading

¹⁰ USCG, 2010.

¹¹KORDI, Sung Hoon Byun et al., “Survey of Latent Hazard of a Sunken Tanker, *Kyung Shin*,” Korea Research Institute of Ships and Ocean Engineering, Deajon, Republic of Korea, 2002.

(FPSO) unit on the surface. Similar operations are more commonly carried out in diver depths, and Figure 3.4 shows an example of this type of equipment.

Complete or Partial salvage of Deepwater Horizon may be warranted in order to determine the causes of the accident and in honor of the deceased and to help bring “closure” for surviving family members. Such an undertaking—if at all possible—must be weighed against the risks of what would be an unprecedented challenge. The combination of the Deepwater Horizon’s size and the water depth in which she now rests makes complete salvage unique, although there are similar historical precedents, including the 1974 recovery of a Soviet submarine from a depth of 17,000 ft and the more recent 2001 recovery of the Russian submarine *Kursk*.

All of these projects adapted existing or cutting-edge technologies in order to accomplish firsts of their kind in deep sea work and salvage. Equally significant and of no less importance is the challenge of assembling the team of people and organizations— from vessel crew and craft workers, to design teams, major industrial corporations, governments, and the public interest.



Figure 3.4 – Diver hot tap similar to techniques adapted for ROV use (ASA).

The *Hughes Glomar Explorer* incorporated advancements in that era of deep sea scientific drilling technology such as dynamic-positioning thrusters in place of conventional mooring lines, and a plethora of automated and mechanical improvements to deepwater drilling systems which in this case served a heavy-lift function.

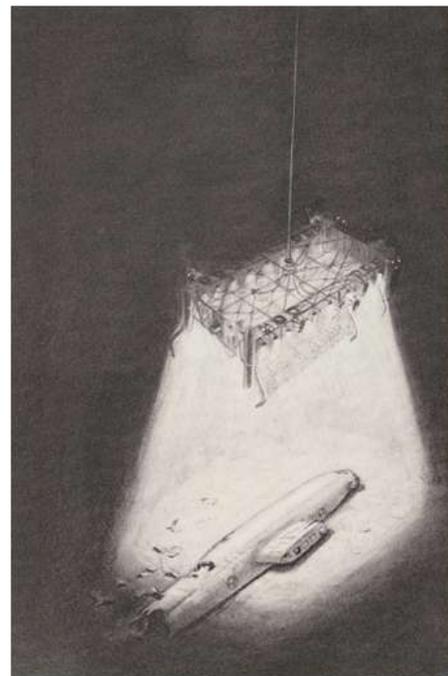


Figure 3.5 – Illustration depicting the 1974 recovery of a submarine in 17,000 feet of water.

The general approach for the Glomar Explorers mission was to utilize a steel frame “claw” lowered on a high-strength riser which assembled in sections much like a drill string on a 2½ day

trip to the work site below (Figure 3.5).¹² The 180 ft x 50 ft x 20 ft tall hydraulically operated “claw” was outfitted with its own propulsion, sonar, lights, and camera systems and designed to recover its cargo through a set of doors on the bottom of the ship and into a “moon pool” inside of the hull.

More recently in 2001 the submarine *Kursk*, in which more than 100 Russian sailors perished, was recovered from a depth of 350 ft using a specially built lifting system attached directly to the hull through cutouts made in the hull specifically for this purpose (Figure 3.6). A system of wire cables and deck-mounted lifting equipment rated for approximately 25,000 tons raised the sub off of the seabed and eventually delivered her to dry dock. Additionally, the bow of the sub was cut off using an abrasive wire sawing (Figure 3.7).



Figure 3.6 – Illustration of the lifting connection used to salvage the Kursk.¹³

It is possible that at least portions of Deepwater Horizon could be salvaged using these types of deepwater rigging and lifting techniques and existing heavy-lift vessels.

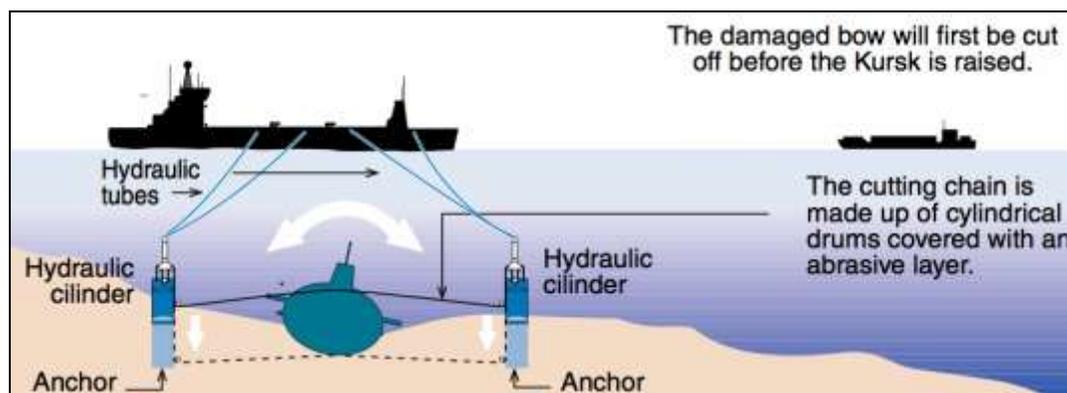


Figure 3.7 – Illustration of the underwater cutting arrangement used during the salvage of Kursk.¹⁴

¹² Figure 3.5 by Daniel Lechon. Collier and Varner. *A Matter of Risk* (Random House: New York, 1978).

¹³ Huisman, Photo of Kursk Salvage.

http://www.huismanequipment.com/en/products/special_projects/salvage_equipment.

3 Summary

Baseline investigation and ongoing monitoring of Deepwater Horizon is warranted to prevent any further release of materials from the vessel and to preserve “perishable” information.

The following are possible solutions for underwater investigation of *Deepwater Horizon*:

- Research available sonar, ROV, other footage and dive logs, interviews, and testimony.
- In-situ underwater investigation of the *Deepwater Horizon* and Macondo site, including inventory.
- Identify and/or retrieve “perishable” items which are of significant interest for priority consideration.
- Salvage damaged riser sections as warranted.
- Salvage of *Deepwater Horizon* in part or entirely.
- Investigate other ocean, transportation, and coastal sites and facilities as warranted.

4 Appendix – Semisubmersible Drill Ship Evaluation

This appendix researches semi-submersible drill ships with respect to hull and machinery selections and their mission for deepwater drilling. The following three ships are included:

- Aban Pearl (2nd Gen. Aker H-3, 1977)
- Deepwater Horizon (5th Gen. Reading & Bates Falcon 8-series, 2001)
- Deepwater Nautilus (5th Gen. Reading & Bates Falcon 8-series, 2000)
- Transocean Marianas (Earl & Wright/ Sedco 700 Series Enhanced, 1979/1998)

In addition to Deepwater Horizon and her sister ship Deepwater Nautilus, the above represent popular designs including the 2nd/3rd generation Aker H-3 and Sedco 700 series. A market turnaround in deepwater oil & gas exploration during the 1990's prompted upgrades to many of these older rigs, extending their capabilities to drill in water depths up to 10,000 feet.

5th generation semisubmersibles are designed specifically for deepwater conditions, with high pressure/ high capacity pumps & drilling mud systems, advanced drilling & pipe handling equipment, and upwards of 58,000 hp power plants. Some semisubmersibles, including Deepwater Horizon, utilize dynamic positioning systems for station keeping as the cost of installing moorings in these depths is significant both in direct costs and rig time.

¹⁴ Smit 2001 Kursk salvage, <http://www.kursksalvage.com>.

4.1 Semisubmersible History and Mission

Semisubmersible vessels are known as column stabilized units and have been built with a variety of hull shapes, including vee, triangular, pentagon or ring, but the most typical arrangement consists of submerged pontoons (usually two) and columns connecting to a topside deck. They have played a key role in the development of deepwater offshore oil & gas resources, providing a stable working platform for drilling and well completion.

As far back as the early 1900's, coastal drilling was accomplished from piers and wharves—the first foray into the offshore environment—and by the 1930's, reached water depths of approximately 40 feet, with site exploration by geologists past 100 feet. In the Gulf of Mexico submersible platforms were designed to be floated into location and ballasted to ground themselves on the ocean floor to provide a stable drilling platform, however on the US West Coast the continental shelf and water depth drops rapidly offshore, and thus a floating solution was sought during the 1950's. The results were early efforts to mount drilling rigs on conventional-hull vessels such as the 174-ft. *Submarex*, followed by the purpose-built *CUSS I* which was sponsored by a partnership of oil companies and completed in 1956. The *CUSS I* was the first to address the technical challenges of drilling from a floating platform, including using a drilling riser which utilized gimbals and slip joints to accommodate vessel motions. These and other parts of the Deepwater Drilling System will be discussed in more detail later in this report.

The semisubmersible hull was introduced practically by accident in the early 1960's when it was observed that a submersible hull, while under tow in the Gulf of Mexico, was unexpectedly stable. This led to the conversion of the Blue Water Drilling Corporation's bottle-design Rig No. 1 into a semisubmersible design by partially flooding the ballast tanks in order to dampen motions (see Figure 2).



Figure 4.1 – Photo of Bluewater Rig No. 1, the world's first semisubmersible drilling vessel.¹⁵

¹⁵ Source: Friede & Goldman (no date) Photo of Bluewater Rig No. 1. <http://www.wikipedia.com>.

4.2 Deepwater Drilling System

Deepwater drilling utilizes the same basic principle of rotary drilling used almost exclusively by the industry—onshore and offshore since the early 1900's. Rotary drilling uses a cutting bit suspended into the well on pipe sections or drill string (see Figure 4.2). Mud is continuously pumped into the well in order to lubricate the bit and lift drill cuttings (rock and sand) back up to the drill ship, where they are separated from the mud so that it can be re-circulated. The derrick structure is used to handle pipe sections and thread them together as the string is lowered into the hole or “tripped”. The top drive, originally developed in the 1940's and adapted from locomotives, provides the rotational force to the drill string.

In order to address the specific challenges of drilling from a floating platform and deepwater, a number of items are necessary. This includes a drilling riser, handling systems/ motion compensators, subsea Blow Out Preventer (BOP), and underwater work systems, as described in “The History of Oilfield Diving” (Swan 2006):

“During the latter part of the 1950s there was continual improvement in drilling from a constantly moving vessel, a technology that took a big step forward with the completion of the CUSS I in late 1956. Instead of using a funnel on the bottom and trying to stab the drill string into the hole each time with (or sometimes without) a diver, or by tending it from two guide wires, the engineers developed what was called a marine riser. This was a conductor pipe which connected the vessel to the blowout preventer stack, inside which the drill string was lowered into, and withdrawn from, the hole.

Once the marine riser was in place, the difficulty of missing the hole was eliminated and there was the further advantage that the drilling mud flowed up the marine riser instead of returning to the vessel through a hose. As with the drill string itself, there was the question of compensating for the motion of the vessel. This was addressed by connecting the riser to the BOPs with a ball-joint to absorb the vessel's lateral motion, and with a slip-joint at the surface to take care of the heave. At first the weight of the riser, which consisted of individual sections—the number being dependent on the depth—was supported by a flotation tank which incorporated the slip-joint. When that proved too cumbersome, the flotation tank was replaced with a system of counterweights. This in turn was superseded by hydraulic tensioners. Before long the area beneath the rig floor of a drilling vessel was taken up with innumerable hydraulic tensioning devices supporting everything from guide wires to hydraulic hoses.”

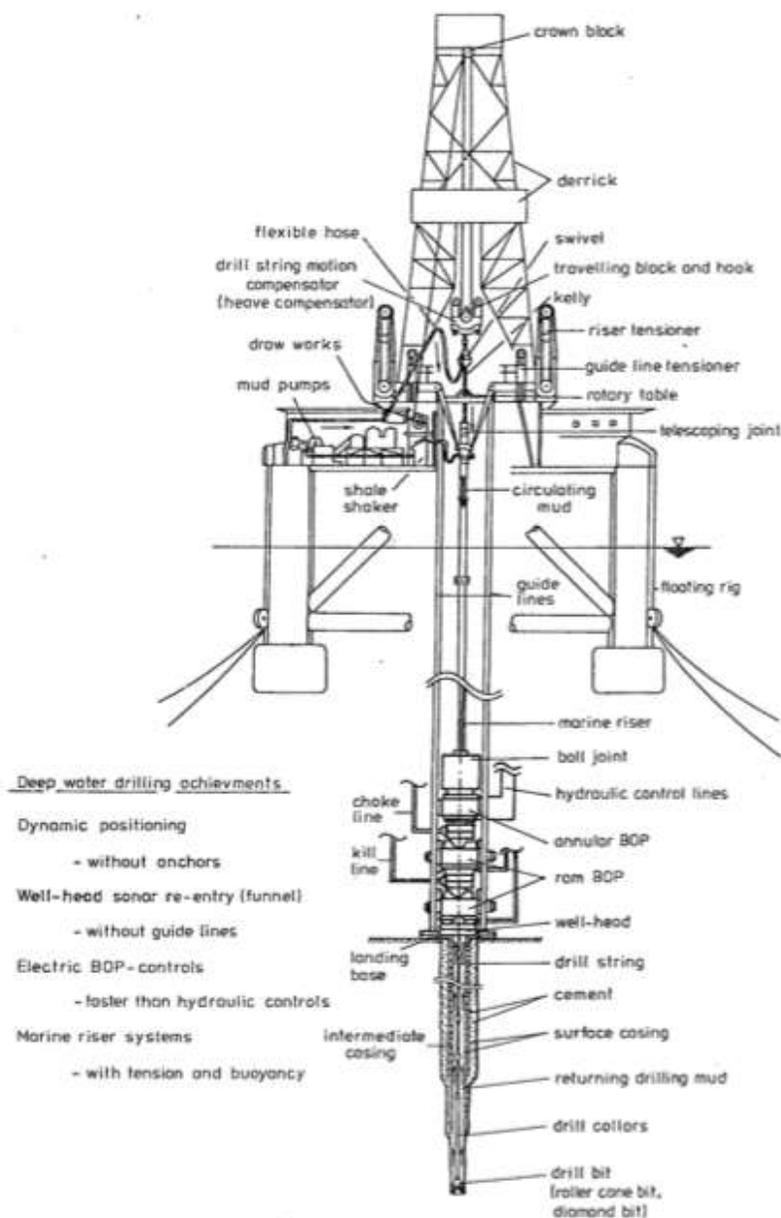


Figure 4.2 – Illustration of Offshore Drilling Technology—typical arrangement for a semisubmersible drilling rig.¹⁶

During the interim half-century, as these challenges are mastered, new ones arise as deepwater is re-defined—first in hundreds of feet, then thousands. Some of the more recent advances include the following (Visser, 1985):

- dynamic positioning utilizing controllable pitch thruster propulsion units and computerized automatic station-keeping systems;

¹⁶ Clauss, 1992.

- reentry systems utilizing television and sonar instead of guidelines;
- electro-hydraulic blow out preventer control to reduce signal transit time; and
- marine risers equipped with syntactic foam buoyancy material and improved riser couplings.

Underwater work systems are also a necessary part of the deepwater drilling system for site preparation, inspection, guiding and operating tools, and the inevitable salvage. While divers were initially used for these tasks, as deepwater drilling surpassed 1,000 ft. circa 1970's Remote Operated Vehicles (ROVs) became the standard. Television systems were introduced in the 1950's which enabled simple observation, followed by small ROV's in the 1970's which were essentially swimming cameras. Underwater work tasks such as rigging equipment or operating valves required divers, whose practical depth limit is approximately 1,000 ft. using helium-oxygen "saturation" diving techniques and equipment.

Today's deepwater drilling rigs have dedicated ROV systems on board and subsea hardware is a major component of subsea oil & gas field development. In the 1960's development of underwater robotics and automation was progressing but these systems seldom functioned as intended—an inconvenient and perhaps expensive outcome—but not catastrophic. At the time, deepwater drilling was still generally limited to a range accessible by divers who, with the obvious advantages in dexterity, could easily remedy the situation in a matter of hours or days.

By contrast, the failure of BOP stack to contain the Macondo reservoir—despite various attempts to activate its functions-- illustrates the need for high reliability operations. Once construction of the well has started, it becomes extremely difficult if not impossible to modify the subsea BOP hardware. Standardized interfaces including hydraulic power ports ("hot stabs") and torque-drive couplings can be operated by an ROV to activate valves and other functions.

4.3 Aban Pearl (2nd Gen. Aker H-3, 1977)

The Aban Pearl (formerly Bulford Dolphin, Treasure Seeker) is an Aker H-3 design with twin pontoon and 8 columns originally built in 1977. The H-3 is perhaps the most popular semisubmersible design ever with over 35 vessels & conversions still in use by 2005. Considered a 2nd generation vessel, many H-3's have been converted for deepwater use and are also known as H-3.2 design.

She sank in approximately 350 ft. water depth off the coast of Venezuela in May, 2010 and is included in this evaluation because conditions or considerations of her investigation, monitoring, and possible salvage may hold lessons for the same of the Deepwater Horizon.



Figure 4.3 – Aker H-3 design semisubmersible *Treasure Seeker*.¹⁷

4.4 Deepwater Horizon (5th Gen. Reading & Bates Falcon 8-series)

Deepwater Horizon is a fifth generation Reading & Bates Falcon 8-series rig with dynamic positioning capability capable of operating in 8,000 ft. water depths. The hull arrangement is twin pontoon with four columns, built by Hyundai shipyards, Korea, 2001. Published data about various characteristics are in the table below.



Figure 4.4 – Aerial view of *Deepwater Horizon*.¹⁸

4.5 Deepwater Nautilus (5th Gen. Reading & Bates Falcon 8-series)

Deepwater Nautilus is a sister of *Deepwater Horizon*, and while *Nautilus* is equipped with two thrusters, she keeps station via an anchor mooring spread instead of DP. The tradeoffs between using DP station keeping vs. deepwater moorings include higher fuel bills on DP vessels (\$3,000-\$4,000 a day higher), while moored vessels are burdened with a \$20,000- \$40,000 a day incremental increase for anchor handling vessels, and often the capital expenditure on pre-set mooring systems which can run to tens of millions of dollars (Keener 2003.) Typically, semisubmersibles are towed or carried on a lift boat for transit.

¹⁷ Later renamed *Aban Pearl*.

¹⁸ Source: Transocean 2010. Vessel Information.



Figure 4.5 – View of Deepwater Nautilus.

4.6 Transocean Marianas (Earl & Wright Sedco 700 Enhanced)

Transocean Marianas is a 1970's era rig which underwent a major conversion for deepwater service in 1998. She was the originally permitted vessel to drill the Macondo well, starting construction before being damaged and replaced by Deepwater Horizon. The Marianas is now working on location in Nigeria.



Figure 4.6 – Aerial View of Transocean Marianas.¹⁹

¹⁹ Source: Transocean.

5 References

- ABS 2010. Vessel Information. <http://www.eagle.org>.
- ASME, “Hughes Glomar Explorer—An ASME Historic Mechanical Engineering Landmark.” July 20, 2004, Houston, TX.
- Collier and Varner. A Matter of Risk (Random House: New York, 1978).
- Deep Ocean Group. 2010 Report on Macondo Oil Spill.
- Fontolan. M. “Prestige Oil recovery from the sunken part of the vessel” Petroleum Association of Japan, Oil Spill Symposium 2005, Tokyo, Japan.
- Huisman, Photo of Kursk Salvage.
http://www.huismanequipment.com/en/products/special_projects/salvage_equipment.
- Hurd, D.R., “Deep Water Drilling Support Using Manned Submersible Pisces VI” OTC 1979.
- Keeneer C., Ibukun K. and Allan R., 2003. “Transocean’s 5th gen rigs efficient record-setters” IADC, May-June 2003.
- KORDI, Sung Hoon Byun et al., “Survey of Latent Hazard of a Sunken Tanker, Kyung Shin,” Korea Research Institute of Ships and Ocean Engineering, Deajon, Republic of Korea, 2002.
- Lafay et. al., “ECG changes during the experimental human dive HYDRA 10 (71 atm/7,200 kPa),” Undersea & Hyperbaric Medicine, Vol 22. No. 1, 1995.
- Lechon, D. 1978 (Illustration). See Collier and Varner.
- Marine Technology Society (MTS). Research Submersibles Manned Underwater Vehicle Committee. 2010. Also, Marshall, P., Personal communication RE: Submersibles, Deepwater salvage, 2010.
- Office of Naval Research, “People Under the Sea: Submersibles- 1900- 1960.”
<http://www.onr.navy.mil/focus/blowballast/people/submersibles1.htm> .
- Rigzone 2010. Rig Data points. <http://www.rigzone.com>.
- Rosenberg, Observations from the T-wall repair of the 17th Street Canal breach. Unpublished, 2009.
- Smit, Kursk salvage, 2001. <http://www.kursksalvage.com>.
- Swan, The History of Oilfield Diving. Pelican Press, 2006.
- Taylor, L., personal communications RE: Submersible operations, 2010.
- Visser, “Deep Water Drilling and Production Capabilities,” Dept. of Interior Hearing. Washington D.C. May 1977.