SEARCH SURVEY for S/V TENACIOUS
Gulf of Farallones and Approaches to San Francisco Bay

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ABSTRACT

On January 28th, 2007, Jim Gray sailed his 40 foot sailboat, Tenacious, on a day cruise to the Farallon Islands off San Francisco and was reported overdue when he didn't return as scheduled. The immediate and comprehensive above water search for Jim and Tenacious was suspended on February 16, 2007. Shortly after this, Fugro Pelagos, Inc., conducted an extensive search of the seabed to look for evidence of the whereabouts of the sailing vessel, Tenacious. Approximately 1000km^2 was surveyed between February, 2007 and May 31st, 2007 when the effort was suspended.

This paper summarizes the search survey for S/V Tenacious, the areas and techniques used in the survey, the findings of the survey, and the results and recommendations provided by Fugro Pelagos, Inc.

1. INTRODUCTION

In February of 2007, a team of personnel assembled by Donna Carnes organized an underwater search for evidence of the whereabouts of the sailing vessel Tenacious. To achieve the seabed search, Fugro Pelagos, Inc (FPI) was contacted to conduct the operations. The 40ft S/V Tenacious had originally been scheduled to sail during daylight hours between San Francisco Bay and the Farallon Islands on January 28, 2007. The vessel was reported missing late that day when she did not return to homeport in San Francisco Bay. After many days of initial search operations led by the US Coast Guard, no evidence of the vessel was located on the ocean surface or along any accessible coastlines. Eventually, the original search team concluded the vessel may have encountered some type of failure that led to sinking. At the time, FPI was conducting seabed mapping for the State of California, between San Francisco Bay and Tamales Bay operating on a 170ft research vessel. During the next several months, FPI operated a variety of mapping and search systems aboard four different vessels, searching over 300 sq nautical miles, in an attempt to locate the vessel on the seafloor. The search was carried out between the Farallon Islands and mainland California, from Drakes Bay to the Golden Gate.

Jim Gray Tribute, May 31, 2008, Berkeley, CA, USA.

2. THE SEARCH SURVEY

Standard search techniques and survey line plans were developed to ensure the best possible success for finding the vessel. First, the most likely location to search for Tenacious was selected. This information was provided by the Team assembled by Donna Carnes (Bob Bilger and others) and was based on several factors, including knowledge of the last known location of the vessel and the last location of direct communications (cell phone). Additionally, any evidence of visual or radar detection during the day (or evening), and the likely transit of Tenacious were all used to best determine likely areas to search. Three areas were originally identified and were used as the boundaries to define the optimum sequence at the search operations. (Figures 1A and 1B, 2A and 2B).

For purposes of mapping and detecting targets on the seafloor, data were to be collected using an acoustic device known as a multibeam echo sounder, or MBES. The specification is for obtaining 100% coverage of the seabed with a resolution of soundings every 2.0m and the ability to detect and identify any object greater than 1.0m cube in size. As it implies the sonar /device works via the use of acoustic energy. Sound travels very well and predictably in seawater. Sonar mapping devices can be very precisely tuned to transmit-and–receive very accurate images of the seafloor. They work on the same theory and technology employed on every vessel for measuring the water depth (fathometer) or for finding fish (fish finders). Using either a side scan sonar (also known as a side-looking sonar) or this newest technology known as multibeam echosounder backscatter, it is remarkable how accurately we can map or view the seabed. Remembering that it is all based on acoustics, in the end the image looks a lot like a black-and-white (and grey-tones) aerial photograph. Rocks look like rocks, sand looks benign and flat, pipelines and cables look like pipelines and cables, barrels look distinctive as do other man made features, such as vessels and aircraft (Figure 3). The larger survey vessels operate 24 hrs/day, continuously covering the area by transiting along very precisely located survey lines, then move over an appropriate distance and do the same in the opposite direction, ensuring 100% coverage of the search area, much like mowing the lawn. Using highly accurate Integrated Navigation Software combined with Differential GPS updates from satellites, we know the exact position of the vessel within 1-2 meters and can therefore pinpoint the position of any target or feature on the seabed with nearly the same accuracy. For the purposes of this search, we used the multibeam echosounder backscatter system because it was already mobilized on R/V Pacific Star and could operate it at 7-8 knots for rapid mapping.

The image produced by the side scan sonar is typically more clear and precise, but the device must be towed on a cable, so the operations are much slower. In this case, the water depths and the size of Tenacious make it fairly easy to detect with either system. As the survey progressed and expanded, we added vessels and additional sensors, using a total of two multibeam echosounder systems and a side scan sonar system. A Geophysicist was included onboard to review and interpret all of the data and prioritize likely targets or features that will be listed for inspection. It is all an interpretation with likely obvious answers, but we cannot be certain of what we have found until we positively identify them via visual inspection (Figures 4 and 5).

The visual inspection was completed using a relatively small Remotely Operated Vehicle (ROV). An ROV is essentially an underwater robot that is connected to the vessel via a long electro-mechanical cable (known as a 'tether'). At a minimum, all ROVs consist of horizontal and vertical thrusters and a video camera. They can be as complicated as also having manipulators for picking up things and turning valves and have many other types of tools for underwater construction applications. The system used for identifying features on this deployment was intentionally chosen to be as small and as maneuverable as possible. An ROV Pilot uses a joy stick and monitors the video signal from the ROV while sitting in front of monitors in the lab located on the mother ship. If you walked in on the ROV Pilot, you would immediately be reminded of someone playing a video game. The mother ship for the ROV operations has the same type of precision navigation system as the search vessel. Once on site, we deployed the ROV into the water and the Pilot would drive it along the seafloor looking for targets. In addition, an underwater tracking device that acoustically (again, sound is a remarkable tool underwater) and precisely tracks the location of the ROV as it moves along the seabed. Via the integrated navigation system, the Pilot knows precisely where the ROV is located in the world, and also the location of the search target. He actually drives the ROV toward the target of interest by monitoring the navigation screen until the visibility is clear enough to use the video camera to inspect the target. Off California, good visibility is usually no better than 20-30 feet. If conditions really get stirred up, visibility sometimes is less than 1-2 feet. To ensure that we can continue working, searching, and eventually viewing, a very high frequency scanning sonar on the ROV operates very much like a acoustic RADAR. The images from this sonar device are very sharp and allow the Pilot to see acoustically until he can see visually with the video system.

In the end, acoustic images of likely targets to investigate from the search vessel (Pacific Star) were generated and analyzed. Then video images and photographs were collected to verify the targets.

The search operations progressed as follows. The map provided in Figure 1A shows the entire area investigated with the multibeam echosounders, the side scan sonar and the visual inspection of discreet targets with the cameras on the ROVs. Figure 1B illustrates the proposed boundaries of each of the survey areas. Figure 2A demonstrates the seabed bathymetry mapped with the search area, and Figre 2B is a composite of the seabed imagery illustrating areas of hard seabed, rock outcrops and sandy zones.

The initial search area was a two-nautical-mile-wide corridor east of the Farallon Islands, but eventually encompassed most of the area between the Farallon Islands, Point Reyes and the Golden Gate. In general, as the survey of a sub-area was completed, and no likely seabed objects were found, additional areas were added to the scope of work. The survey areas were designated in approximate chronological sequence as P1 through P9. The areas designated A1 through A6 are regions that were surveyed as part of the North Central California Mapping Project, Phase 2 (NCCMP), that coincidentally was being carried out by Fugro Pelagos at the time the Tenacious search effort got underway. Data from the NCCMP survey were reviewed for any evidence of a wreck on the seabed.

The actual surveyed area, as of May 31, 2007, when survey work was suspended, is shown in Figure 1A. In all, about 1000km^2 of seabed was surveyed. All the areas were investigated with the following exceptions: the deep water (>200m) portion of P4, the coastal shallow (<20m) portion of P5, the eastern two thirds of P8, the northern half of P7 and almost all of P9. The figure also shows the locations of the seabed objects classified as being of interest (red dots); about half of these were investigated by the ROV and were identified as wrecks, debris or rocks. None proved to be the wreck of or debris from Tenacious.

Some aspects of the survey progress and planning were dependent on the availability of vessels, survey equipment and personnel. In all, four vessels were involved in the survey work, *M/V Michael Uhl*, *M/V New Superfish*, *M/V Pacific Star* and *F/V Quicksilver*. Weather proved to be a major concern throughout the survey and resulted in numerous delays.

Previous surveys of the area, notably a survey conducted in 1989 by the US Geological Survey (USGS Open-file Report 2004-1082), were consulted and some of the comments below regarding seabed type and the general geology of the area are derived from these sources.

2. FINDINGS (Refer to Figures 1A and 1B)

Area P1: The first area survey was area P1. The boundaries of this area were defined by the limit of cell phone coverage, east boundary, a line between Southeast and Middle Farallon Islands, west boundary. The survey area was a corridor 3.6km wide. The reasoning behind this was that this was the logical corridor that *Tenacious* would have taken on its journey to and from the Farallon Islands, and was beyond cell phone range. The width of the corridor was extended southward to a width of 5.6km, to encompass a possible return path for *Tenacious* had she rounded to the south of Southeast Farallon Island.

The survey was carried out using the MBES system and approximately 200% coverage of the seafloor was achieved. The seabed in this area was found to be sandy, probably fine sand, with very little vertical relief, typically less than 0.1m.

Area P2: As in the case of area P1, area P2 was outside the cell phone coverage circle. As the last sighting of the sailboat had it heading northerly, and the winds were generally easterly, it was thought the vessel may have been tacking northeasterly on its return voyage to the Golden Gate. Area P2 also includes the southern limit of the north traffic lanes, where a possible collision with a freighter may have taken place.

The survey was carried out using the MBES system and approximately 200% coverage was achieved. The seabed in this area was found to be sandy, probably fine sand, with very little vertical relief, typically less than 0.1m. Areas of coarser sand are also evident, but again there is very little vertical relief.

Area P3: Area P3 was added once the P2 survey was completed. Area P3 essentially extended the initial area P1 corridor towards the Golden Gate and assumed that *Tenacious* took a direct route to the Golden Gate. While this area was within cell phone coverage, there is the potential for a collision with a freighter, as this is part of the precautionary zone around the San Francisco Pilot boarding area.

The survey was carried out using the MBES system and approximately 200% coverage was achieved. The seabed in this area was found to be sandy, probably fine sand, with very little vertical relief, typically less than 0.1m. Areas of coarser sand are also evident, but again there is very little vertical relief.

Area P4: Area P4 was added once the P3 survey was complete, and seabed objects in areas P1, P2 and P3 had been investigated by ROV.

Area P4 encompasses the Farallon Islands. *Tenacious* may have struck one of the islands and either sunk immediately or in the near vicinity of the islands. The outer boundary was set at a 5nm-radius circle centered halfway between the Southeast and North Farallon Islands. The radius was selected based on the assumption that the vessel, once holed, may have sailed on for several miles before sinking.

The survey was carried out using the MBES system and approximately 200% coverage was achieved. The bulk of area P4 was surveyed by *M/V Pacific Star*. However, *F/V Quicksilver* conducted the survey near the islands as a vessel the size of *M/V Pacific Star* is not able to maneuver safely close to the islands. The survey was also limited by depth as the MBES systems used had a practical limit of 200m. Thus the deeper areas west of the islands were not covered by the survey. In the very shallow water near the islands the survey limit was defined by safety considerations. Typically the survey data reached depths of 4-5m, but in particularly rough areas and areas where surf was a problem the minimum depths surveyed may be as much as 10m.

The islands consist of plutonic rock and are hard and rough, not easily weathered or eroded. The island coastlines are typically very steep with little evidence of beaches or sandy areas. Generally what is observed above the waterline (see for example Figure 6A) and continues below the waterline (Figure 6B). The areas immediately around the islands show a very rough seabed with sharp pinnacles up to 20m in height.

Area P5: Area P5 was added once the P4 survey was complete. Area P5 is essentially a pie-shaped area that fans out to the northeast from the Farallon Islands and widens to include all of Drake's Bay, from Point Reyes to 3.3km north of Bolinas Point. Cell phone coverage in this area is poor near shore and nonexistent offshore. This area was surveyed as it was possible that *Tenacious* headed for Drake's Bay, as opposed to returning directly to San Francisco Bay. Area P5 includes about 10km of the north traffic lanes.

About 30% of area P5 is covered by the NCCMP survey. The NCCMP survey data were reviewed and checked for possible wrecks on the seabed. This review was carried out very early in the search effort, while *M/V Pacific Star* was surveying areas P1 and P2, as these data were already available.

Of the remainder of area P5, initially just the portion that includes the traffic lanes and the traffic separation zone was surveyed as it was deemed this was the most likely area that *Tenacious* might have run into difficulties (collision). This portion of area P5 was surveyed by the *M/V Pacific Star* using the MBES system and approximately 200% coverage was achieved. The seabed in area P5 was found to be sandy, probably fine sand, with very little vertical relief, typically less than 0.1m. Areas of coarser sand are also evident, but again there is very little vertical relief.

Area P6: Area P6 was added once the P4 survey was complete. Area P6 is essentially a southward extension of area P3 and widens the surveyed corridor across the precautionary area. This area was included as it was possible *Tenacious* took a direct route to the Golden Gate, but kept south of the San Francisco Pilot boarding area and intended to approach the Golden Gate along the southern edge of the traffic lanes. While this area was within cell phone coverage, there is the potential for a collision with a freighter.

The survey was carried out by *F/V Quicksilver* using the SSS system and approximately 200% coverage was achieved. The seabed in this area was found to be sandy, probably fine sand, with very little vertical relief, typically less than 0.1m.

Area P7a: Area P7 was added once the P6 survey was complete. Area P7 is essentially an eastward extension of area P3/6 and covers the approach to the Golden Gate, stopping at Mile Rocks. This area was subsequently renamed area P7a, which covered the southern edge of the traffic lanes approaching the Golden Gate. It was thought that *Tenacious* would have taken this route as the final destination, the San Francisco Marina Yacht Harbor, lies to the south of the traffic lanes. The area was also extended past Mile Rocks, through the Golden Gate and on to the entrance to the marina. While this area is well within cell phone coverage, there is the potential for a collision with a freighter. As the *Tenacious* would have arrived at the Golden Gate after dusk, the chance of collision even this close to shore cannot be discounted.

The survey was carried out by *F/V Quicksilver* and the by *M/V New Superfish* using SSS systems and approximately 200% coverage was achieved. The seabed in this area was found to be sandy, probably fine sand, with very little vertical relief, typically less than 0.1m, except just west of the Golden Gate where there were rocky outcrops.

Area P8a: Area P7 was added once the P5 survey was complete. Area P8 essentially covers the remainder of the area *Tenacious* might have gone on an approach to the Golden Gate. This area was subsequently renamed area P8a, which covers just the precautionary area. While this area is within cell phone coverage, there is the potential for a collision with a freighter.

The survey was carried out by *F/V Quicksilver* and the by *M/V New Superfish* using SSS systems and approximately 200% coverage was achieved. The seabed in this area was found to be sandy, probably fine sand, with very little vertical relief, typically less than 0.1m.

Area P9: Area P9 was added once the P8a survey was complete. On the premise that *Tenacious* had sailed north-northwest from the Farallon Islands (approximately the course she was following when last sighted), she would have eventually crossed the north traffic lanes west of Point Reyes. Area P9 covers the traffic lanes off Point Reyes.

The survey was carried out by the *F/V Quicksilver* using a SSS system and approximately 150% coverage was achieved. The seabed in this area was found to be sandy, probably fine sand, with very little vertical relief, typically less than 0.1m.

Overall Seabed Survey: In summary, 588.9km^2 were surveyed using MBES systems and 235.4 km^2 were surveyed using SSS systems, for a total of 824.3km^2 surveyed as part of the seabed search for the wreck of *Tenacious*. Additionally, 210.8km^2 of data, from the NCCMP survey (MBES data) were analyzed and reviewed, bringing the total area checked for seabed objects to 1035.1 km^2. In about 99% of this area the seabed consists of relatively smooth fine to medium sand, with an estimated detection probability for an object the size of *Tenacious* at better than 99%.

3. RESULTS AND RECOMMENDATIONS

The performance of all acoustic mapping systems, be it resolution or positional accuracy, has a range dependence, with performance typically worse at longer range. There is also an environmental component, more so for the SSS systems, where, for example sea state and seabed type play a role in system performance. It should also be noted that where poor performance was encountered it was common practice to rerun a survey line. Similarly, when situations arose where a seabed feature was of particular interest, additional survey work was carried out specifically to improve or get additional data on such features.

The bulk of the SSS survey was conducted in such a way that 200% coverage of the seabed was achieved. Thus any area of the seabed was covered at least twice and any temporal features in the data that might obscure the seabed, for example schools of fish or the bubbles from vessel wakes (a problem in the traffic lanes), could be discounted. A small part of the SSS survey was conducted with 120% coverage.

The typical system performance of the MBES and SSS systems employed is more than adequate to detect and characterize an object of the size of *Tenacious*.

The MBES and SSS data were examined in real time as the survey progressed, and these data were reviewed offline a second time, and anomalous seabed features were classified as possible debris and wrecks. Seabed features found in the sonar data ranged from small objects, typically identified as crab traps, to a large, a 120m wreck. Those seabed features deemed to be of approximately the correct size and having a manmade appearance, were selected for further investigation. In some cases this involved obtaining additional sonar data of the features and in half of the cases the features were visited by an ROV equipped with a video camera.

Side scan sonar data obtained in 1989 by the US Geological Survey (USGS) covered much of the area involved in the search. These data, from the USGS Open-file Report 2004-1082, downloaded from the USGS web site (http://pubs.usgs.gov/of/2004/1082/html/INTRO.HTM), and were also reviewed as part of the seabed feature classification process. These data do not have as high a resolution as the data collected during this search, and are not suitable for identifying small seabed features. Nevertheless, it is possible to find high reflectivity features in these data, which are typically evidence of debris or wrecks and, while not resolved, are detected. Thus a given feature found during the search, which correlates to a high reflectivity spot in the 1989 data set, may be considered to have been on the seabed since 1989, and is thus unlikely to be associated with the disappearance of *Tenacious*.

A small VideoRay ROV, provided by Blitz Solutions, was deployed from *F/V Quicksilver*. A Deep Ocean Engineering Phantom ROV was deployed from *M/V New Superfish*. The investigations by ROV were typically very brief. Once it became clear that a feature was not related to *Tenacious,* the ROV was recovered on deck. There was no attempt to make any detailed identification of the features, and risk entangling the ROV in a debris field. Currents on the seabed were typically ~0.25 knots. Some ROV dives near the Golden Gate had to be scheduled for slack water, as well as low traffic times. In most cases the seabed near the features consisted of fine rippled sand. Most objects were found to have Plumose anemones growing on them, an indication that the objects had been on the seabed for some time. The objects also tended to have small fish and invertebrates (crabs, starfish) as well as shell hash associated with them, again an indication that these objects had been on the seabed for quite some time (years).

3. RESULTS OF THE DATA SET

As noted, the final data set resulted in nearly 300sq miles of high resolution seabed mapping data, collected at the highest possible resolution and encompassing 100% of the seafloor within the boundaries identified. Some of those data analyzed were from the previously described, coincidental seabed survey for the State of California. The additional data in the vicinity of the Farallon Islands and the transit lanes and approaches between the Golden Gate and the Islands were collected at the same standards required for the State project. Through the urging of Donna Carnes, these data were identified to the various State and Federal agencies responsible for mapping within the 3.0 mile limit and within the Federal Farallon Marine Sanctuary. The various scientists and stakeholders responsible for these regions immediately recognized the significance of this data set for both its scientific applications and financial cost to acquire and process. Through the direct efforts of Donna Carnes, these data were eventually donated, in the name of Jim Gray, to support multiple research activities.

Figure 1A: Areas Surveyed by Fugro Pelagos, Inc.

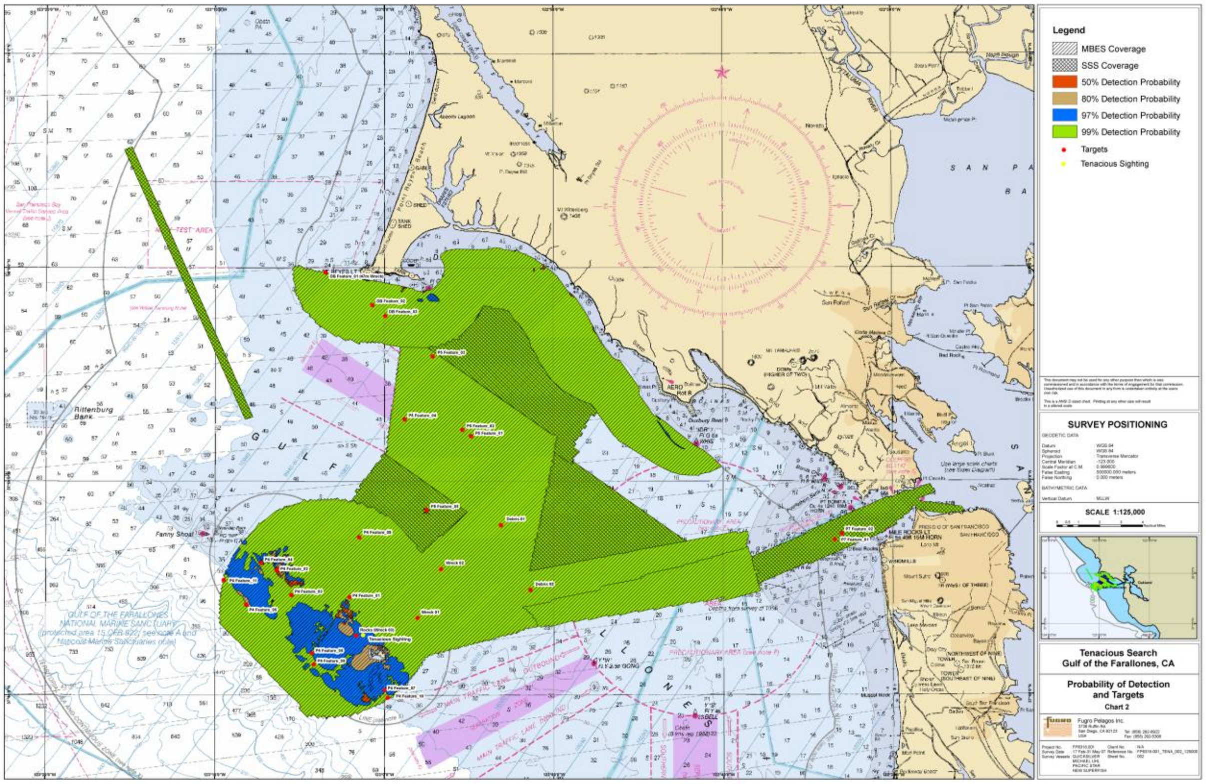

Figure 1B: Planned Survey Areas

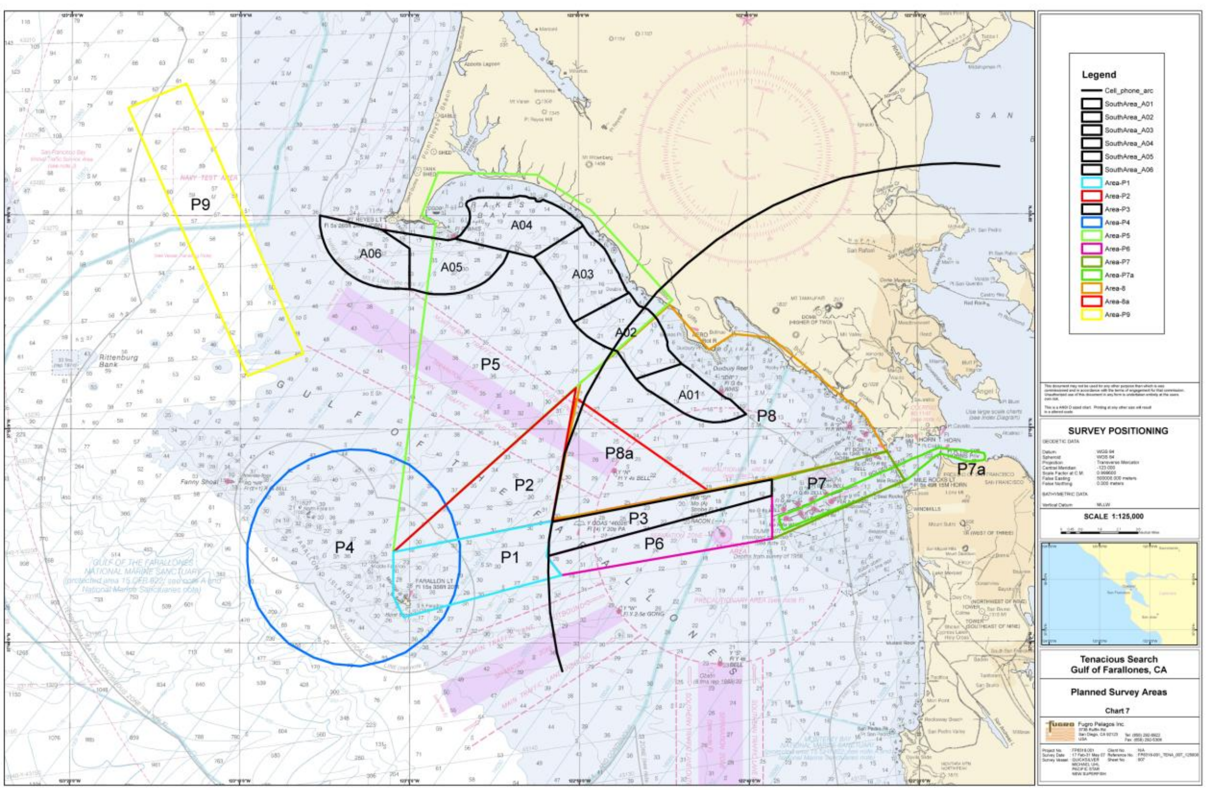

Figure 2A – Bathymetric trends within the area surveyed (colorized based on depth variation)

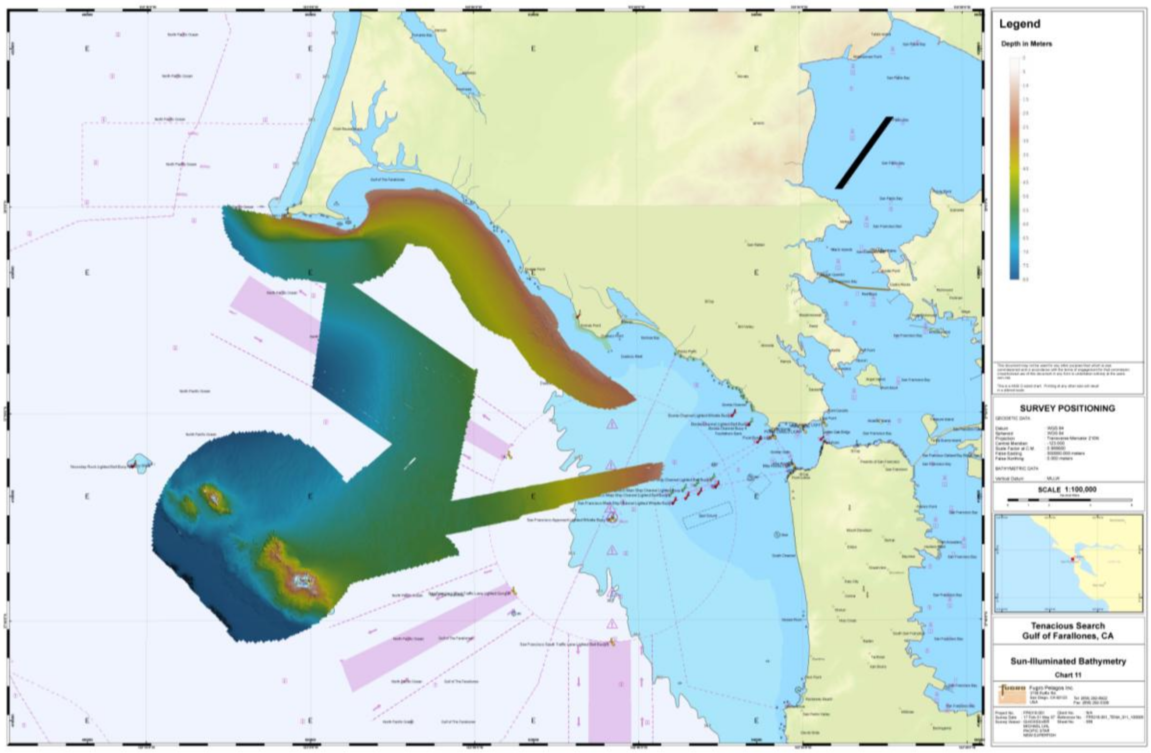

Figure 2B – Seabed imagery within the area surveyed (grey-scale variations indicating bottom-types)

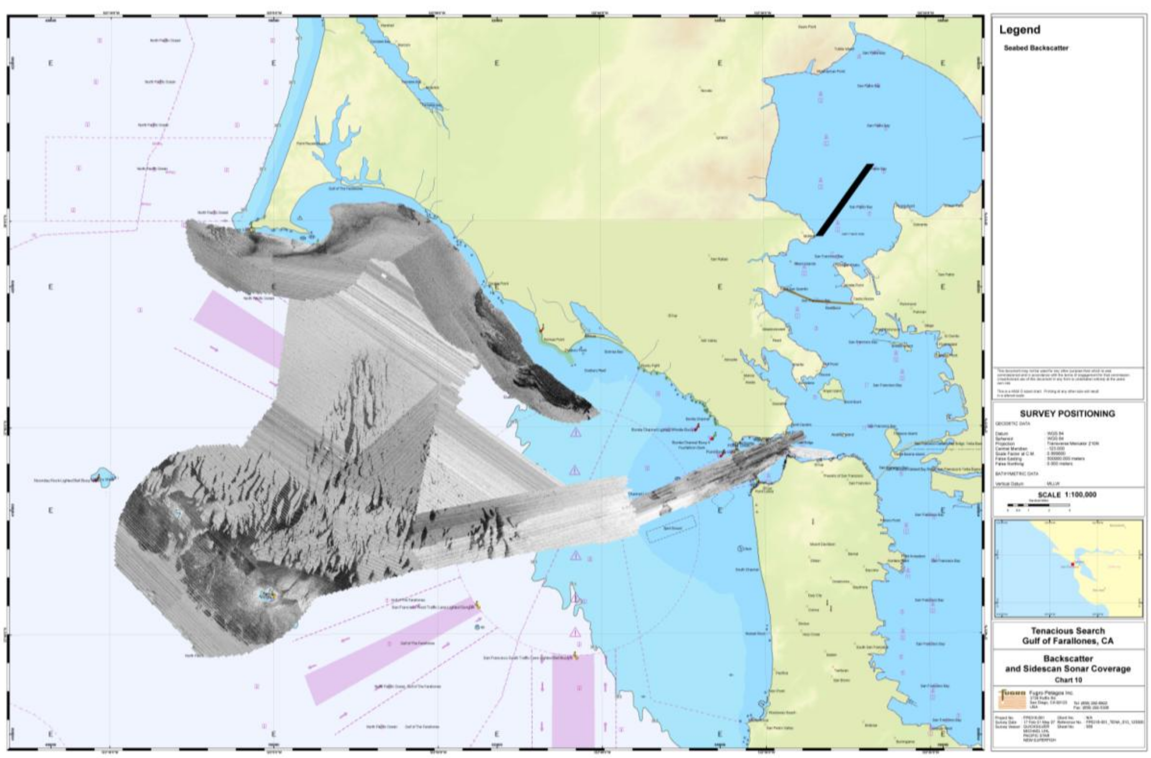

Figure 3 – Debris02 – Confirmed debris

Location: N37° 44’ 55.3” W122° 51’ 21.6” (N4177942.9 E512687.0); wd 56m

Dimension: 25.5 X 9.0 X 0.2m

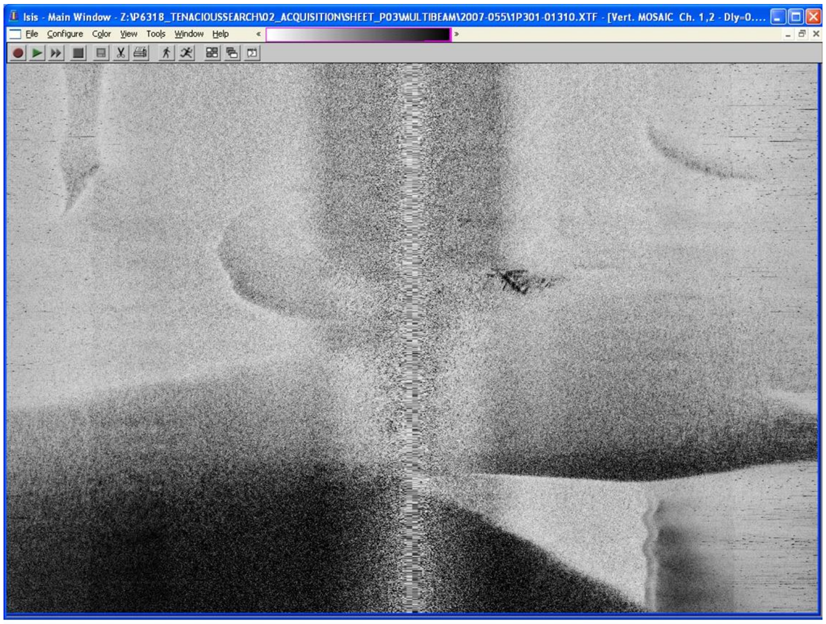

Figure 4 – ROV image of old sunken vessel

Figure 5 – ROV image of biological growth and fishing net on old wreck

Figure 6A – North Farallon Island

Figure 6B – Underwater photo near North Farallon Island