# Prospects for using sonar for underwater archeology on the Yenisei: surveying a 19$^{th}$ century shipwreck[*]

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**Abstract.** Current progress in underwater archeology is based on a rich arsenal of high-tech appliances, among which sonar technology plays a key role; it enables scientists not only to detect submerged archeological objects, but to examine them in high definition without having to conduct diving operations or use expensive underwater unmanned vehicles. While the majority of sensational scientific discoveries using sonar have been made in saltwater environments, freshwater ones, rivers in particular, have seen limited activity. The river Yenisei in central Siberia contains an unrecorded number of shipwrecks that await being discovered and studied. In this article we focus on the peculiarities of using sonar for detecting archeological sites on the Yenisei. This article is based on the results of the 2016 expedition, which has determined the location of *Thames*, a 19$^{th}$ century British steam schooner which was wrecked on the Yenisei.

**Keywords:** Sonar, side-scan sonar, echo sounding, bathymetry, fishfinder, Yenisei, underwater archeology, shipwrecks, *Thames*, Northern Sea Route

## 1. Introduction

Underwater archeology like no other archeological discipline has been employing high-technological equipment and methods from its beginnings as an independent branch of science. While early underwater archeologists relied largely on insufficient and even dangerous methods, modern researchers have at their disposal the advantages of sophisticated electronics, including spin-offs from military and space programs. Perhaps the most indispensible tool in an underwater archeologist's stockpile of tools is the sonar. Active sonar technologies such as echo sounding and side-scan sonar have found the broadest use for detecting and studying submerged objects on a preliminary stage: this includes imaging and mapping the archeological site to determine the area of the proposed investigation. While sonar technology had found wide application for military needs since World War I, it wasn't

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until the invention of the side-scanning sonar that this technology firmly established itself in underwater archeology [1, p. 22]. Traditional sonar limits the image to a two-dimensional projection, while side-scanning is capable of providing researchers with high definition 3D imagery of the archeological site and the object itself.

Employing side-view sonar for underwater archeology was first proposed by W.D. Chersterman in the late 1960s. In the Soviet Union this technology was first applied in 1978; this process was accelerated after a contract was signed between the Soviet Academy of Sciences and the Soviet Navy, which constructed the side-scan sonar apparatuses [2].

Recent significant finds in the Arctic, attributed to side-scanning sonar technology include both of Sir John Franklin's ships – *Erebus* and *Terror*, found by Parks Canada in 2014 and the Arctic Research Foundation in 2016, the Soviet Arctic Second World War BD-5 convoy ship *Marina Raskova* and the icebreaker *Aleksandr Sibiriakov*, sunken by the German cruiser *Admiral Scheer* in 1942. Both ships were found in 2014 by the Russian Geographical Society.

The first recorded use of side-view sonar on the Yenisei took place in 1993 for assessing the condition of submerged pipelines in the vicinity of the port of Dudinka. Later, the same technology was used to survey hydrotechnical structures of the Sayano-Shushenskaya Dam on the upper Yenisei [2]. However, neither of these operations included any archeological investigations. Needless to say, the Yenisei has been a major shipping lane since central Siberia was settled by the Russians in the 1600s. Intense navigation with oceangoing vessels began in the 1870s and continues to this day. The depth of the river allows certain oceangoing craft to reach areas as far south as Lesosibirsk and even Krasnoyarsk. Domestic and foreign shipping activity has produced unique shipwrecks on the river, in its delta and in the Eniseiskii zaliv – the estuary of the river which is an inlet of the Kara Sea. The location of a number of these wrecks has been determined recently. Further development of the oil and gas mining industry on the Taymyr Peninsula, resulting in the construction of potential pipelines crossing the Yenisei. This opens new perspectives for conducting sonar and riverbed surveys, thus providing opportunities for new archeological investigations.

## 2. Existing electronic methods applied in underwater archeology

Due to its nature underwater archeology tends to incorporate various technological methods and devices for detecting and studying objects. In fact, this branch of archeology is not at all possible without technology; even underwater diving, such as scuba diving, which is considered to be a traditional method of research, employs electronics.

Taskaev compares a number of technological methods employed for detecting and positioning submerged archeological objects (Fig. 1) [3, p. 92].

As we can see from the table, the most effective device in terms of range is the side scanning sonar. Optical methods for capturing images such as cameras offer limited usage and cannot be considered effective for detecting submerged objects and their preliminary investigation. Results of the 2016 expedition *Where Thames meets the Yenisei* of Reshetnev Siberian State Aerospace University with support from the Russian Geographical Society demonstrated that underwater cameras have limited application in the murky waters of the Yenisei and its tributaries. The search for the wreckage of Joseph Wiggins's polar steam schooner *Thames* in the mouth of the river Sal'naia Kur'ia (Figs. 2, 3) at 66°22′41.5″N and 87°35′04.4″E using an underwater camera showed that fine particulate deposits (silts) from the riverbed constantly obstructed visibility and caused the automatic focusing system to capture images of silt particles instead of the river bottom. Silt outs occurred not only due to motion around the riverbed; slow (<0.5 m/s) currents from the Yenisei and the current of the

Sal’naia Kur’ia (<0.2 m/s) colliding in the river mouth create continuous movement of sediment in this area significantly affecting the visibility of the water.

| **Device type** | **Swath range** | **Riverbed penetration depth** | **Distance from river bottom** | **Definition** | **Material of object** |
|---|---|---|---|---|---|
| Side-scan sonar | 100 m | - | 5 m | 0.1 m | All |
| Acoustic Doppler current profiler (ADCP) | - | 10 m | 5 m | 1 m | All |
| Video camera | 4–6 m | - | 3–5 m | 0.03–0.05 m | All |
| Photo camera | 4–6 m | - | 3–5 m | 0.02–0.03 m | All |
| Magnetometer | - | 0.5 m | 1–2 m | - | Ferromagnetic metals |
| Metal detector | <1 m | 0.5 m | 0.1–0.3 m | 0.05–0.1 m | Metals |

**Figure 1.** Comparative table of specification of devices used in underwater archeology (source [3, p. 92]).

The acoustic Doppler current profiler may be a useful tool in the arsenal of an underwater archeologist working on the Yenisei as it can be used for conducting further investigation on submerged objects that have been covered by silt or sand. A penetration of 10 m should be considered enough for any river wreck, as ships rarely had this height from keel to deck.

Devices which react to large masses of metal such as metal detectors are relatively useless in cases when the studied object is wooden, as in case of *Thames*. They cannot be used remotely for archeological purposes, requiring the operator to be underwater as well.

More expensive tools include various remotely operated underwater vehicles (ROVs), pioneered for studying historical shipwrecks by Robert Ballard in the 1980s, and autonomous underwater vehicles (AUV) However these mobile devices will hardly find wide application in the relatively shallow waters of rivers such as the Yenisei.

**Figure 2.** Satellite image of mouth of Sal’naia Kur’ia (image from http://wikimapia.org)

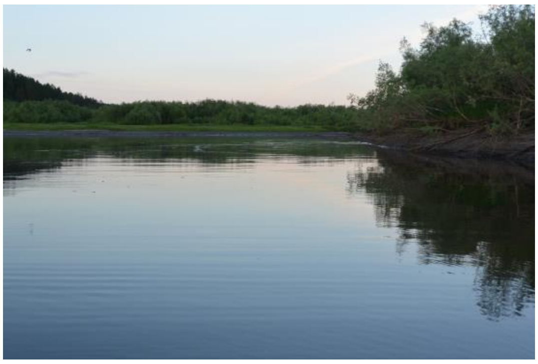

**Figure 3.** Sal’naya Kur’ia looking southwest. Photo from archive of 2016 *Where Thames meets Yenisei Expedition*.

To conclude on this passage it should be said that with the exception of side-scanning sonars, the remaining devices can be used only for supplementary or specialized purposes such as further investigation, producing high definition images and footage, determining the position on the object under a layer of sediment and detecting metal structures and artifacts. Thus, side-scan sonars are currently the most functional and productive tools for underwater archeology. They are, virtually, unlimited by depth, water clarity, (turbidity) and overhead cover [4].

## 3. Characteristics of side-scan sonars

Side-scanning sonars differ from other systems in having two arrays. Each array produces one sonar beam which follows a 90-degree arc (horizontally and vertically). The main advantage to using this technology is its ability to “see” almost any submerged object, using a sound spectrum. Side-scanning sonars are able to provide a resolution of one tenth of a degree, whereas in multi-beam sonars this resolution is equal to whole degrees. Thus, side-scanners provide the user with a sound “photograph” of the sea or riverbed tens of times better than multi-beam devices; it is more energy efficient, less cumbersome, has a simpler design and, as a result, a lower price [5, p. 66]. However, the image quality largely depends on the specifications of the concrete sonar.

The market offers a wide selection of various side-scan sonar apparatuses, making it difficult to select a specific model for using in specific environments. Let’s look at some side-scanning sonars that have found successful application in marine archeology. In Fig. 4 we have presented the specifications of two devices: the first is an example of a highly-sophisticated expensive piece of equipment, designed for deep-water application in marine environments, the second sonar in a simpler design having limited application as a recreational or amateur piece of electronics.

The table shows that the frequency for the first sonar ranges from 100 to 500 kHz, whereas the second apparatus demonstrates a constant frequency of 1,000 kHz; this enables the researcher to see the smallest details of the submerged object. However, this frequency range limits the range of the sonar to dozens of meters. In terms of marine archeology this range may be inadequate, whereas in rivers it is more than enough, as the average depth rarely exceeds 10–15 meters. The second device is more accessible for smaller groups of researches working on aboard small craft and in shallower enclosed areas of the river, such as coves, bays, river inlets and island channels. As aforementioned, we are focusing on using this technology on the Yenisei, which is a freshwater northern river with current speeds ranging from 1.5 m/s in the tailwater of the Krasnoyarsk Dam to 0.3 m/s below Dudinka. The lower Yenisei, specifically its delta and estuary are subjected to tidal currents and rises in water levels, caused by northerly winds. The riverbed in this area consists primarily out of sand and silt. This inevitably affects the clarity of the water, which as aforementioned, has negative impact on the usage of various underwater optical instruments. Dense particle suspension is known to be a source of acoustic interference [8, p. 79]. Further development in side-scanning technology includes advances in hydroacoustic antennas with controlled characteristics through phase response [9]. This might provide solutions for using sonars both in deep and shallow waters with silt outs. Another direction for the development of the side-scanner includes improvements in positioning accuracy using global navigation satellite systems (GPS/GLONASS). Recent development in phased array technology [10], which has been successfully applied since the 1990 [11] might provide further improvement in positioning accuracy of side-scanning sonars, some of which already boast an accuracy of 15 cm [12].

| | **System 3000 Towfish™** | **Starfish 990F™** |
|---|---|---|
| Model of operation | Simultaneous dual frequency | Single frequency |
| Location of digitation | Towfish | Topside box |
| Data processing and imaging capabilities | SDF or XTF or both selectable | Real time waterfall display |
| Standard system interfacing capabilities | Interfaces to all major Sonar Data Processors | USB Connection to PC/Laptop |
| Generation of firing trigger | Transceiver Processing Unit (TPU) | Topbox |
| Power consumption [W] | 120 | 6 |
| Length [m] | 1.22 | 0.378 (0.166 for the surface stack) |
| Width [m] | 0.089 | 0.097 (0.034 for the surface stack) |
| Height [m] | 0.089 | 0.11 (0.106 for the surface stack) |
| Weight in air [kg] | 29 | 2 (0.4 for the surface stack) |
| Max. depth rating [m] | 1500 | 50 |
| Transducer type and material | Single Beam-Piezo-Electric Ceramic Array | Monolithic Ceramic |
| Materials used | Stainless Steel | Reinforced red polyurethane rubber |
| Fish height from seabed determination method | Altitude Algorithm | First Return Algorithm |
| Deployment methods | Winch with coaxial; hand deployed; Kevlar reinforced lightweight cables & AUV platforms | By hand and towed from boat |
| Min. frequency [kHz] | 100 | 1000 |
| Max. frequency [kHz] | 500 | 1000 |
| Min. pulse length [μs] | 25 | 400 |
| Max. pulse length [μs] | 400 | 400 |
| Source level [dB] | 242 | 210 |
| Max. range [m] | 600 | 35 |
| Min. beam width [deg] | 0.21 | 0.3 |
| Max. beam width [deg] | 0.7 | 0.3 |
| Min. vertical beam width [deg] | 40 | 60 |
| Max. vertical beam width [deg] | 40 | 60 |

**Figure 4.** Comparison of System 3000 Towfish and Starfish 990F side-scanning sonars (source: [6; 7]).

Despite their obvious advantages, side-scanning sonars still have one significant disadvantage – a high cost. This limits smaller and underfinanced institutions and projects from applying this device for underwater research.

## 4. Results of the 2016 Yenisei archeological survey

Due to insignificant information on the location of shipwrecks on the Yenisei and their current condition, it was decided to employ a less expensive method of detecting and positioning the wrecks on the river bottom. This included preparatory archival research, the examination of historical records, maps, navigation charts and satellite imagery, employing echo sounding devices and traditional bathymetric instruments, such as the sounding line and grappling hook, submergible cable video cameras and short-term underwater diving. Since the selected wreck was supposedly located at a depth of less than 6 m, the absence of a side-scanner was not considered a major obstacle by the team.

Relevant to this article is the usage of echo sounding for detecting the location and position of the wreck of *Thames*, a nineteenth century British screw schooner, which sank in the mouth of the Sal'naia Kur'ia river – a tributary of the Yenisei – in 1878. Echo sounding, along with side-scan sonar is one of two hydroacoustic methods, employed for underwater archeology [3]. A Lowrance Elite-3x$^{TM}$ fishfinder was used during the survey; the frequency range of the device is between 83 and 200 kHz, the maximum depth of application in 244 m.

The riverbed topography displayed by the device is rather uninformative so it was decided to use the results of sounding by both sonar and sounding line to build a three-dimensional image in Surfer 13$^{TM}$ countering and surface modeling software (Figs. 5, 6).

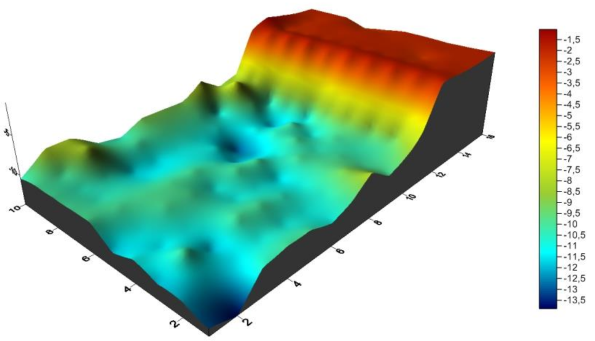

**Figure 5.** Three-dimensional model of Sal'naia Kur'ia riverbed built in Surfer 13.

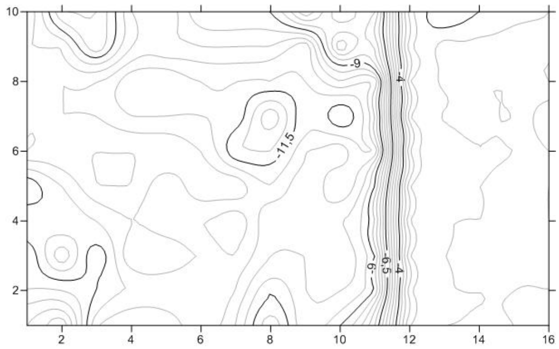

**Figure 6.** Two-dimensional counter graph of Sal'naia Kur'ia riverbed built in Surfer 13.

The survey revealed a surprisingly deep sector at the confluence of the Sal'naia Kur'ia and the Yenisei (10–13 m) on the south banks of the widening; the north bank has an average 4.5 m depth along the meander. This section stretches for 300 m in an east to west direction; the average depth along the thalweg is 10 m with drops to 13 m and rises to 8 m. As the river narrows there is a sudden rise of the riverbed to 2–2.5 m, which covers an area of 50×30 m at 66°22.762N, 87°34.713E (NW diagonal) and 66º22.722N, 87º35.00E (SE diagonal).

Trawling performed from west to east had the grappling hook repeatedly being snagged in the shallow area. It was decided that the wreck was buried here under a layer of silt and sand. As it had been mentioned, the underwater camera was unable to focus due to floating silt particles. Placing the camera on the riverbed caused silt outs that rendered it useless. Short term underwater diving (snorkeling) revealed part of what is thought to be the stern section of the schooner. Besides scarce historical records which mention the location of the wreck of *Thames* in the Sal'naia Kur'ia [13, p. 19], there is only one pilot chart of the Yenisei where the schooner's position had been marked [14, p. 28]. As there is no record of vessels with the same specifications as *Thames* sailing into the Sal'naia Kur'ia, it can be reported with a great degree of certainty that the wreck is *Thames*. Further archeological work would consist in the removal of over 7,000 m$^3$ of sand and silt from the vessel, which had been deposited onto it during the last 140 years (this massive amount of sediment suggests that most of it had been on the bottom of the Sal'naia Kur'ia when the ship foundered in 1878, sinking into the silt). This operation should be regarded as futile since most of the vessel's equipment had been removed before she sank. However, it should be noted that the hull might be well preserved as it is buried and protected from the water.

Other practical results include the first sounding of the mouth of the Sal'naia Kur'ia river.

The bathometry showed that the river was not navigable beyond its mouth, which could serve as a harbor for various vessels.


**Figure 7.** Wreck of *Thames* marked as an obstacle on 1937 pilot's chart.

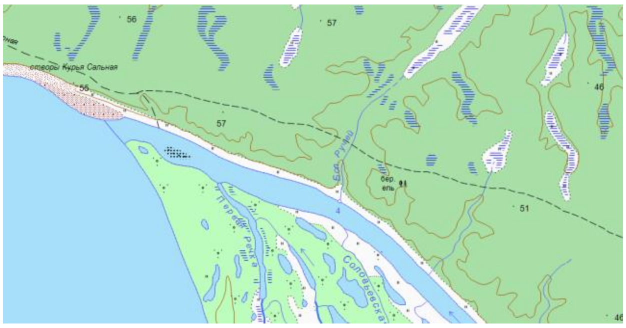

**Figure 8.** Recent Russian topographical map providing inaccurate information on Sal'naia Kur'ia river.

## 4. Conclusion

In conclusion it is necessary to say that less sophisticated methods employing simpler active sonars such as fishfinders may find limited application for underwater archeology. Naturally, more advanced equipment such the side-scanning sonar is preferable to use for detecting submerged objects of heritage and performing early research. Despite the vast assortment of side-scanning sonars available on the market, it is preferable to use less energy-consuming and higher frequency devices as they provide better visibility on small depths, which are predominant on the Yenisei; besides they are more mobile and allow investigating lesser uncharted river channels. If, due to a shortage of funds, the researcher is reduced to using simpler sonar technology, such as two-dimensional fishfinders it is possible to use the obtained data to construct topographic models of the riverbed using various software, provided that the area of interest has been divided into equal spaces with depths determined for each space. This can be done easier by affixing the data to the geographic coordinates system through GPS/GLONASS.

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