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Study of underwater biodiversity in Lake Guerlédan (France) using acoustic systems

A student project at ENSTA Bretagne

An article by IRÈNE MOPIN

Each year since 2016, students of ENSTA Bretagne specialised in hydrography/oceanography and marine robotics participate to a field project on Lake Guerlédan in Brittany (France). One of the subjects they work on is the study of biodiversity in the lake using acoustic systems. In collaboration with research institutes such as Ifremer and directed by their advisor Irène Mopin, they are using professional echo sounders in order to implement analyses of water column echoes in depths up to 40 m. Each year, results of the previous group are used to improve processing techniques and new specificities are added such as the sonification of data.

hydrography education | practical training | water column | fishery acoustics | sonification
Hydrographieausbildung | praktische Übungen | Wassersäule | Fischakustik | Beschallung

Seit 2016 nehmen jedes Jahr Studierende der ENSTA Bretagne, die auf Hydrographie/Ozeanographie und Meeresrobotik spezialisiert sind, an einem Feldprojekt am Guerlédan-See in der Bretagne (Frankreich) teil. Eines der Themen, an denen sie arbeiten, ist die Untersuchung der Artenvielfalt im See mit Hilfe akustischer Systeme. In Zusammenarbeit mit Forschungsinstituten wie Ifremer und unter der Leitung ihrer Beraterin Irène Mopin setzen sie professionelle Echolote ein, um die Echos aus der Wassersäule in Tiefen bis zu 40 m zu analysieren. Jedes Jahr werden die Ergebnisse der vorherigen Gruppe genutzt, um die Verarbeitungstechniken zu verbessern, und es kommen neue Besonderheiten hinzu, wie zum Beispiel die Beschallung der Daten.

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1 Introduction

Each year, almost 50 students of ENSTA Bretagne participate to a field project on Lake Guerlédan in the centre of Brittany (France). They come from two speciality courses of ENSTA Bretagne: hydrography/oceanography and marine robotics. The objective of the project is to apply their technical background on concrete subjects proposed by a team of researchers and engineers from ENSTA Bretagne and external companies or partner research labs. During six months students work in groups of three to five on their subjects. Two weeks in the field are planned in October and February, supplemented by dedicated work-days in between at the lab. Tens of subjects are studied each year, one in particular is discussed in this article: the study of underwater biodiversity of the lake using acoustic systems.

The aim of this subject is to use echo sounders to describe the underwater fauna and flora of the lake. Each year a partnership is made with a research institute (Ifremer, Université de Bretagne Occidentale, IRD France) which gives students the opportunity to discuss any aspect of their subject with expert engineers and researchers specialised in fishery acoustics. This partnership make also available professional fisheries echo sounders and software for the students. At the end of the project, some students have the opportunity to continue their work in some of the partner institute labs, in particular for their internships. In some cases, students can also be hired by the partner institute at the end of their studies.

2 A project in constant change

During the project, students are required to design and prepare the survey (define survey lines, etc.), acquire data in situ and process them using a research methodology and professional software. Acoustic measurements are performed on the lake on the ENSTA Bretagne survey vessel *Panopée* equipped with hydrographic systems (global navigation satellite system, inertial navigation system). An example of survey lines carried out by a group of students and inspired from Simmonds and MacLennan (2008) is given in Fig. 1. Other measurements requiring to stop the vessel (e.g. sound speed profiles) are made at specific locations called stations on the figure.

From one year to another, acoustic systems used were different because of the specificity chosen by the advisor and partners and the availability of the materials. Table 1 shows the different acoustic systems used since 2016 for the project. Each year the Kongsberg EA400 single-beam echo sounder is present. Thanks to the main partner Ifremer, different fishery single-beam echo sounders were available along the years (Simrad EK60 and EK80) which are up-to-date professional echo sounders.

The first years (2016, 2017), the specific objectives were to evaluate the presence of fauna in the lake and its composition. Indeed, the lake was dried up in 2015 in order to repair the dam thus all underwater life decreased severely. It was then re-filled with rain-water during fall and winter 2015. In 2016, 13 tonnes of fish were re-introduced by the fishery federation of the department containing 80 % of roaches, carps, tenches and 20 % of perches, pikeperches, pikes. Measurements with Kongsberg EA400 were therefore made the first years to estimate if fish were still present and where they were located. It also gave the opportunity to demonstrate the ability of this bathymetric echo sounder to provide usable data of the water column.

In addition to acoustic acquisitions, samples of micro-life were taken using a plankton net with a filter of 80 µm. They allow to detect if plankton is present in the lake, as it represents the base of a sustainable underwater life. Also, a fluorometer was used to measure water turbidity and chlorophyll concentration, and water physico-chemical parameters (temperature, sound speed, etc.) were measured with a CTD probe. All these measurements are important to better relate acoustic data to the underwater biodiversity as they give information on the water layers and their compositions.

In the following years, dedicated fishery echo sounders were used to improve the analysis of the water column. Indeed, even if a magnitude calibration of the Kongsberg EA400 was performed based on the method of Foote (1987) and Vagle et al. (1996) on standard sphere, bias on the measurements of fishes acoustic responses (i.e. target strength, TS) still remained because targets cannot be located inside the beam of this echo sounder. This information is provided by Simrad EK60 and EK80 using their split-beam antennae which consequently make the measurements of fishes TS more accurate.

The acoustic response of fish and also of any volume target (e.g. diffusive layers composed of plankton or suspended matter) depends on the frequency of the signal transmitted by the echo sounder. Thus, the use of several frequencies is informative to analyse the underwater biodiversity. That is why different echo sounders at different frequencies were employed each year as mentioned in Table 1. The echo sounder Simrad EK80 was also useful because it can provide wide-band measurements by transmitting frequency modulated (FM) signals. With this single echo sounder, multiple frequency measurements were therefore made in the frequency bands described in Table 1.

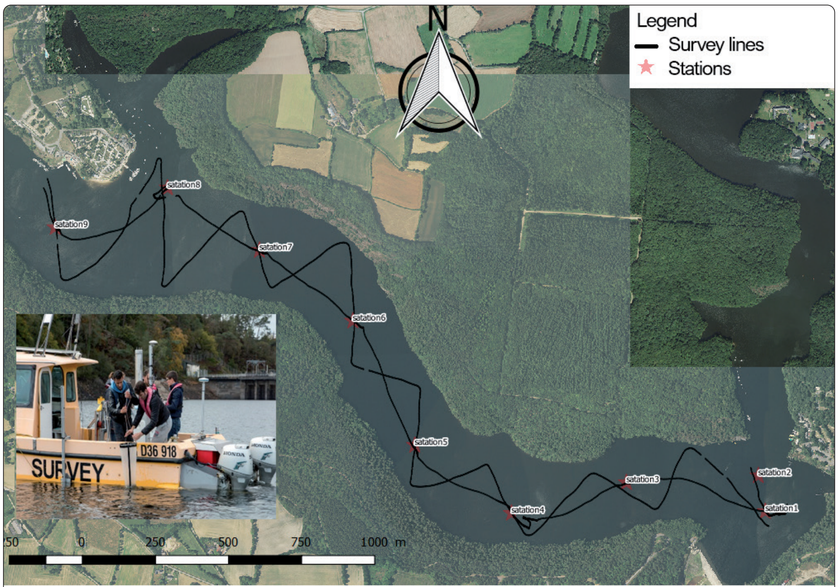

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Fig. 1: Aerial picture of Lake Guerlédan in the centre of Brittany, France. Survey lines and stations carried out by the student group of 2016 and 2017. Photo of the students using the plankton net to sample micro-organisms of the water column (illustration from student report 2016–2017)

3 Results along the years

At the end of their project, students are asked to present their results during an oral presentation to a large panel of scientists. They also discuss their results in a report and through a poster. In the fol-

Year	Echo sounders	Frequencies	Other material
2016–2017	Kongsberg EA400	38 kHz, 200 kHz	CTD Plankton net Fluorometer
2017–2018	Kongsberg EA400	38 kHz, 200 kHz	CTD Plankton net Fluorometer
2018–2019	Kongsberg EA400 Simrad EK80	38 kHz, 200 kHz [45 kHz – 90 kHz], [160 kHz – 260 kHz], [260 kHz – 420 kHz]	CTD Plankton net Fluorometer
2019–2020	Kongsberg EA400 Simrad EK80	38 kHz, 200 kHz [45 kHz – 90 kHz], [160 kHz – 260 kHz]	CTD
2021–2022	Kongsberg EA400 Simrad EK80	38 kHz, 200 kHz 120 kHz	CTD

Table 1: Single-beam echo sounders used by students and their frequencies according to the year of the project

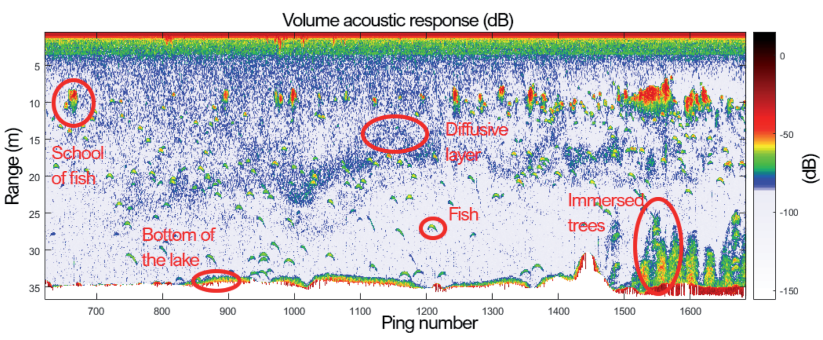

Fig. 2: Echogram of water column data from Kongsberg EA400 at 38 kHz acquired in February 2018 (from student report 2017–2018)

lowing some of their results are presented and illustrated.

3.1 Fishery acoustics

Echo sounder data are at first analysed as images called echograms such as Fig. 2. The vertical axis corresponds to the range, i.e. the distance between the echo sounder and the target (fish, lakebed, etc.). The horizontal axis corresponds to the vessel progression, i.e. the distance travelled by the vessel. Colours describe the acoustic response of the targets in decibels, i.e. the ability of targets to backscatter an incident acoustic energy. Targets in the echogram of Fig. 2 are supposed volumetric thus the response depicted in colour is a volume target strength also noted S_V in decibels (MacLennan et al. 2002).

On the echogram at 38 kHz of Fig. 2 we can observe school of fish, individual fish, diffusive layers

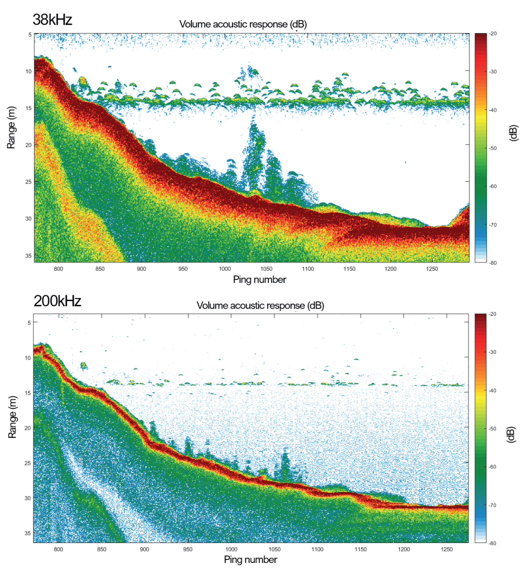

Fig. 3: Echograms of water column data from Kongsberg EA400 at 38 kHz and 200 kHz simultaneously acquired in October 2016. Pulse lengths at 38 kHz and 200 kHz respectively 128 µs and 256 µs. Beam apertures respectively 21° × 13° and 7° × 7° (from student report 2016–2017)

that can be composed of plankton or suspended matter, and vegetation on the lake bottom including trees. Indeed, trees and old structures built before the dam was erected are still standing in the bottom of the lake. This immersed vegetation is also seen on Fig. 3 which illustrates the difference of echogram that can be derived from measurements at different frequencies. Targets like fish and trees are less visible at 200 kHz whereas they are perfectly observable at 38 kHz. This effect is due to the difference of transmitted signal length between the two frequencies, the different beam apertures of the echo sounders, and also to the specificities of the acoustic responses of the targets.

A particular observation was made every year from echograms such as Fig. 2 and Fig. 3: in February fish are found everywhere in the water column whereas in October they are mostly located in a specific layer between 10 and 15 m deep. By measuring the temperature of the water column, the depth limit where the fishes always regroup in fall was observed to be a strong thermocline present in October. Indeed, in October the water mass is highly stratified with an upper layer around 17 °C and a lower layer around 9 °C (see Fig. 4 where an example of representative temperature profiles of October and February is presented). In February, this stratification disappeared and the temperature is homogeneous in the whole water column. In that case, fishes are sparse. The analysis can not be pushed further without any more information, however some useful indications were given using the plankton net and the fluorometer. In October, when the water column is stratified, the concentration in chlorophyll-a is higher in the upper layer than in the lower layer. In addition, the upper layer was observed to contain a higher concentration of plankton than the lower layer, in particular copepods and daphnia. Fig. 5 shows a picture taken by a student during the analysis of plankton net samples.

Because most of the fishes in the lake seem to travel alone, it makes possible to analyse their

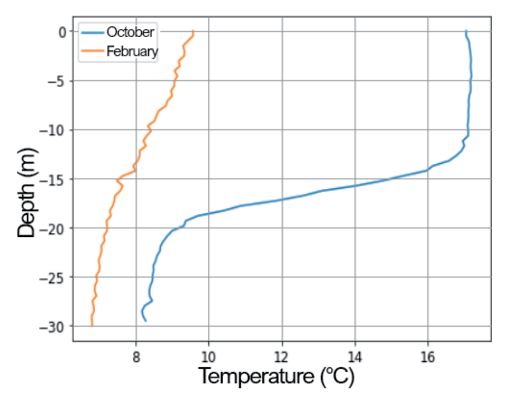

Fig. 4: Temperature profiles measured in October 2019 and February 2020 (from student report 2019–2020)

acoustic responses TS individually. An algorithm to detect the fishes was developed by the students in addition to their calculus of TS using the sonar equation. Resulting fishes responses were then plotted as histogram such as example of Fig. 6 at 120 kHz. On that example we can observe two main modes in the histogram. We can make the assumption that they are related to two different species of fishes. On the echogram on the right of the figure are plotted the fishes which TS being part of one or the other mode to study their location in the water column. A specific behaviour has not been specifically brought to the fore except their aggregation in the thermocline thickness.

Using the echo sounders Simrad EK60 and EK80, it was also possible to track one fish inside the beam of the echo sounder. Once the trajectory of the fish is detected, the incidence angle of the transmitted signal on the fish can be derived. In addition, when using Simrad EK80, the frequency response TS(f) of the fish is also available. Consequently, for a given target detected on echograms, we can derive its acoustic response according to frequency f and incidence angle Θ. An example of track of a target (supposed a fish) is given in Fig. 7 with its frequency response for [45 kHz – 90 kHz]. An example of frequency response TS(f, Θ) is given in Fig. 8 where two echo sounders are used to derived frequencies at [45 kHz – 90 kHz] and [160 kHz – 260 kHz]. On this figure some resonances seem to appear, mostly at high frequencies. This effect could be due to the scattering of the fish bones as observed by Nesse et al. (2009) or other effect of resonance of the target itself.

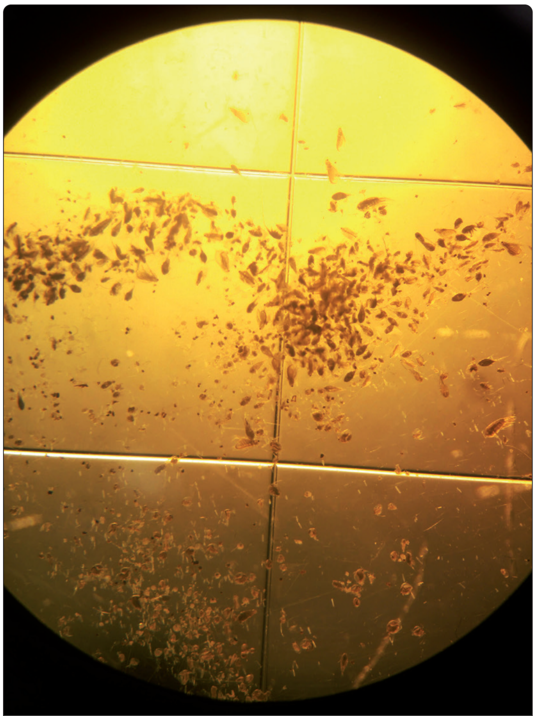

Fig. 5: Picture of a sample taken with the plankton net in Lake Guerlédan (from student report 2018–2019)

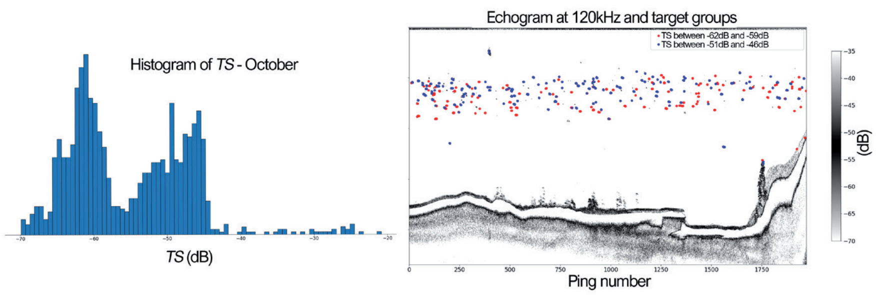

Fig. 6: Histogram of fish acoustic responses TS at 120 kHz and their locations in the echogram in October 2021 (from student report 2021–2022)

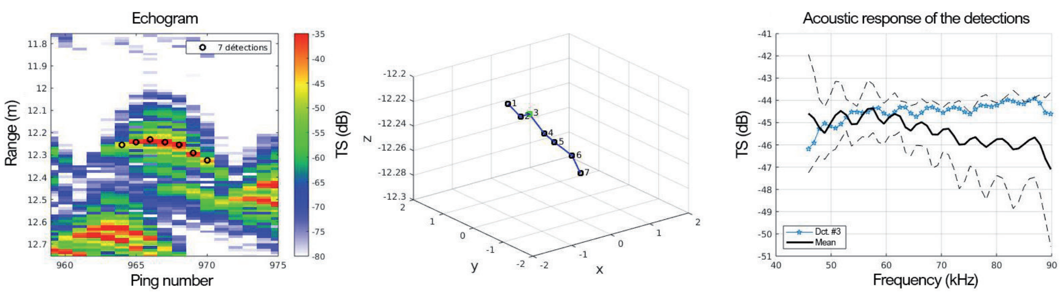

Fig. 7: Tracking of one target (supposed a fish). Left: Detection of the target on the echogram. Centre: Trajectory of the target in the echo sounder beam. Right: Frequency response of the target; blue curve: frequency response of one detection; black curve: mean of target strengths of the different detections of the target; dash curve: standard deviation (from student report 2019–2020)

3.2 Sonification

In 2021, a specific objective of the project was to demonstrate the ability of the human ear to discriminate different underwater targets echoes. Because the echo sounders use ultrasounds for measurements, data had to be transposed into the audible band before performing listening tests (on a panel of 30 persons). This step was fulfilled by re-generating the real acoustic signal based on its envelop provided by the echo sounders, and then translating this signal in the audible band. Three types of targets were studied: individual fishes, school of fishes and the lake bed. Their echoes were all transposed and three tests were performed in order to distinguish between fishes versus lake bed, individual fishes versus school of fishes, and hard lake bed versus soft lake bed. The question asked to the listeners were to classify the sounds from a list of eight in two categories. They had no information on the content. Conclusive results were obtained which are promising for other experiences in classification of ultrasound echoes with human ear.

Besides these scientific objectives, an artistic goal was proposed to the student during the project 2021–2022. The aim was to create a musical piece based on one of their echograms and on the knowledge they learnt in the scientific part of the project. For example, that year they used the fishes detections to generate music notes tuned according to their depth, the fishes TS controlling the magnitude of the notes. At the end of the project, the students creation was performed at two Science & Art festivals in Brest (France): festival RESSAC and Les Art'Pulseurs. It can still be heard on Youtube (youtu.be/s-VfAiiaTn4 with details on the project at youtu.be/GOPh15y5Yiw).

4 Conclusion and feedback

In conclusion, during the several occurrences of the project, students brought into light diverse information on the underwater biodiversity of the Lake Guerlédan. The presence of different species of fishes and plankton was demonstrated. Terrestrial vegetation was also found on the bottom of the lake (shrubs and trees). An interesting result was that between October and February the water mass characteristics change and so is the fauna and flora behaviour. In October the water column is stratified with two layers: a surface layer of higher temperature and containing more plankton concentration than the lower layer. In that period, fishes are found located in the highly marked thermocline which is generally between 10 m and 15 m depth. On the contrary, in February the water mass in homogeneous and fishes are found sparse in the water column. When fishes of the lake were travelling individually their echoes were analysed and their acoustic responses TS studied according to frequency and incident angles.

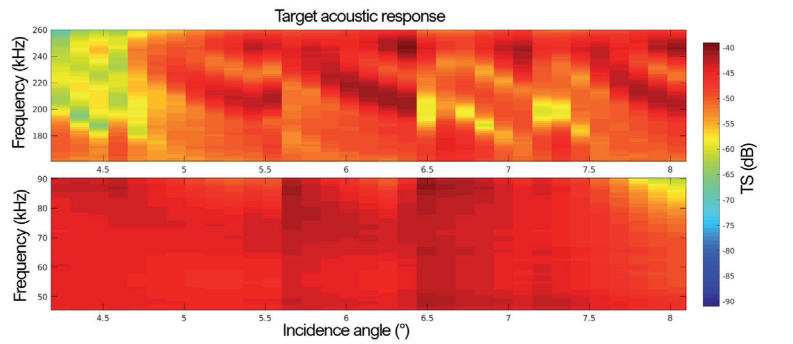

Fig. 8: Frequency response TS(f, Θ) of one target (supposed a fish) according to frequency and incidence angle on the target (from student report 2018–2019)

Echo sounder data were also analysed in order to classify echoes from the different underwater target. The method used was the sonification, i.e., the listening of data with the human ear. Data were therefore transposed in the audible band and submit to a panel of 30 persons to evaluate the ability of human ear to distinguish echoes from fishes, school of fishes and lake bed. In addition, students composed a sound creation based on the echo sounder echograms they acquired. The piece of music was performed at two Science & Art festivals in Brest (France).

The very large majority of students that had chosen the project presented in this article mentioned that they were glad to participate. In addition to their motivation originating from the group work and the practical aspects of the survey, their feedback was excellent and they appreciated to discover new domains of acoustics and underwater acoustics. Years later, satisfying feedback also comes from alumni students that made their internship in fishery acoustics in one of the partner lab such as Dung at Ifremer in 2018:

»The project at Lake Guerlédan was very useful for my internship at Ifremer. I learnt how to calibrate an echo sounder using a standard target. I had also the opportunity to study theory and practice of the sound wave backscattered by the sphere. I appreciated working in group and in autonomy. All of this helped me a lot in my internship which subject was the calibration of a wide-band fishery echo sounder on standard target.«

And also Marie who is now full time employee in the same partner lab:

»The project essentially gave me the opportunity to discover and develop my interest in underwater acoustics, a field in which I am now working full time at Ifremer. More concretely, though the project I learnt a lot about fishery echo sounders: how to install them, to acquire and process data for a concrete scientific purpose. These are tools and knowledge that I still use daily. It was also a privileged way to meet and exchange with scientists from different institutes, some of whom are now my colleagues.«

5 Acknowledgement

The author would like to thank all the students who participated to the project, and also the partners: Ifremer for their participation and the loan of acoustics systems along the years, Université de Bretagne Occidentale/Image & Son Brest for their help and support with the sound creation, IRD France, festival RESSAC and festival Art-Pulseurs.

All projects at Lake Guerlédan are support by ENSTA Bretagne, EDF, ISblue and Association Francophone d'Hydrographie (AFHy). More information on guerledan.ensta-bretagne.fr. //

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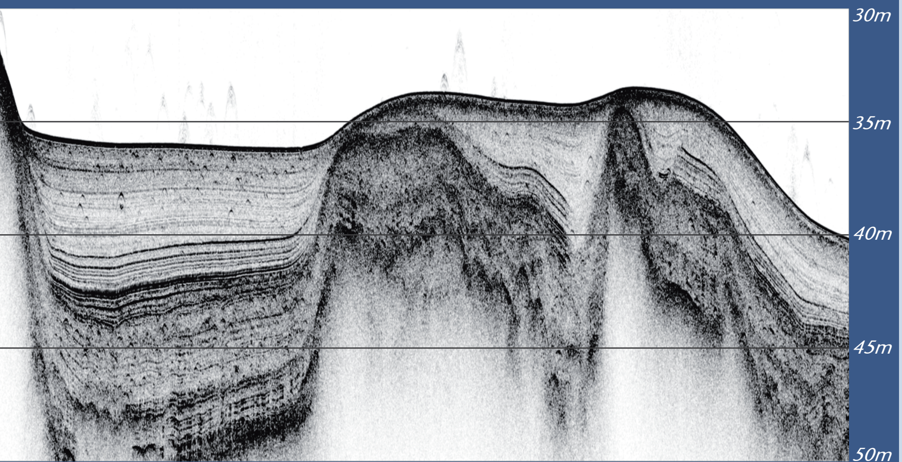

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