Bathymetry and lakebed mapping of Lake Altaussee using Multibeam Echo Sounding, UAV photogrammetry and underwater ROV imagery

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Key words: bathymetry, lake, multibeam echo sounding, ROV, UAV, Structure from Motion

SUMMARY

As part of an international research cooperation, Lake Altaussee - located in the Styrian Salzkammergut in Austria - is being surveyed using state-of-the-art hydroacoustic measuring methods and investigated hydro-geologically. With the help of a high-resolution multibeam echo sounder (MBES), a precise 3D model of the lake basin was created. It is highly detailed and shows sediment formations, larger rocks, cracks, cables and water supply pipelines at the lake bottom as well as submarine spring pits of varying extent and depth. Additionally, water column information as well as backscatter data of the multibeam echo sounder were used to classify zones of different sediments of the lakebed, and to detect objects of interest, such as gas plumes or submarine spring discharges.

An unmanned aerial vehicle (UAV) with RTK-GNSS positioning provided high-resolution multi-view stereo imagery from the 5 km long shoreline. Structure from Motion photogrammetry (SfM) delivered the topographic information of the shallow water zones and its adjacent land zone. Water refraction models were applied to the SfM results to correctly map the lakebed topography of the water-covered areas. Due to a water transparency value (Secchi depth) of 10 m it was possible to map shallow water zones of up to 2 m water depth.

A remotely operated underwater vehicle (ROV) with a manipulator arm was used to investigate the geological situation of the karst springs located at a depth of 70 m and to map further interesting geomorphological lakebed structures located nearby. Furthermore, the ROV video-imagery was used for validating and classifying even small objects of this high-resolution and detailed topographic 3D model of Lake Altaussee.

Based on this lake model, a first web map application was developed for the local rescue organizations to support them in their operations on the lake.

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1 INTRODUCTION AND OBJECTIVES

1.1 Walter Munk – Einstein of the oceans

The world-renowned ocean explorer Walter Munk initiated a comprehensive exploration of Lake Altaussee, when he returned to the lake of his childhood in the summer of 2018.

Walter Munk dedicated 70 years of his life to oceanographic research resulting in countless highly renowned awards and memberships (see Day, 2005). In later years, he became increasingly involved in research on human impacts on oceans and aquatic ecosystems.

1.2 Conception and objectives of the project "Lake Altaussee"

In autumn 2018 the research goal, the framework for the participation of international scientists, but also the funding were jointly defined between the Walter Munk Foundation for the Ocean (WMFO), La Jolla, California and the University for Natural Resources and Life Sciences (BOKU), Vienna. Walter Munk's focus was on a detailed investigation the geological structure, the hydrogeologic system and the biology of the lake of his native country. Communicating the results to the local residents was a central concern for him, especially to the youth. In particular, to increase the awareness of the importance of water bodies for the future of the society.

The overall or long-term goal was finally defined as the creation of a multidimensional digital representation of Lake Altaussee. The content should be contributed from all water-related scientific disciplines by integrating international institutions.

1.3 Geographical and geological key data

Lake Altaussee is located in a blind valley in the Northern Limestone High Alps, east of the village of Altaussee at 712 m above sea level (Fig. 1). The lake basin is bordered by the Loser (1837 m) in the north, the Tressenstein (1201 m) in the south and the Trisselwand (1754 m) in the east. The shores of Lake Altaussee are relatively unobstructed except for a small bay in the northeast. East of this bay is the small Ostersee.

The catchment area of Lake Altaussee is part of the karst mountain range of Totes Gebirge. Geologically, Plassenkalk, Tressensteinkalk and Dachsteinkalk dominate thisKarst landscape.

To the west of the lake an open moraine landscape with the villages of Fischerndorf and Altaussee spreads out. The lake outlet, the river Altausseer Traun, has an average water flow of 3.8 m/s. The lake itself receives its water inflow from submarine springs and a few tributaries. According to Zötl (1961), there are only small tributaries on the shores of the lake, whereas the most significant discharges only 15 l/s (Riedl et al., 2008).

1.4 Previous mapping activities and resulting research questions

In the early 1990s, G. Schaeffer realized a series of comprehensive research activities regarding submerged trees in the lakes of the Salzkammergut region in Austria (Scheaffer, 1994). In Lake Altaussee he encountered 57 trees applying single beam echo sounding with a Lowrance Mach 1 fish finder sonar. Radiocarbon dating of two of these trees indicated an age of 1300 years (700 AD ± 50).

In fall of 2010, W. Gasperl, head of the water service of the Altaussee volunteer fire department, discovered a previously unknown funnel-shaped depression at the flat lake bottom observing the depth measurements of his boat echo sounder.

In 2011, a first hydrographic survey was undertaken using single-beam echo sounding along predefined survey lines by the company ICRA, Salzburg, on behalf of the government of Styria. The resulting depth map shows the position and shape of a submarine spring pit (funnel-shaped crater of a karst spring) with a diameter of 70 m, but other shallower or smaller spring pits are not recognizable due to the horizontal resolution/ footprint size of 6 m at 50 m water depth and the survey line distance of 20 m.

However, a comprehensive hydrological and isotopic hydrological investigation by Harum et al. (2014) showed that the available information on submarine karst springs is not sufficient to provide reliable information about their discharge. Furthermore, it remains uncertain how many other submarine spring pits exist besides from the known one (see also Zötl, 1961), and how much they contribute to the lake water balance.

Digital terrain models (DTM) as well as digital surface models (DSM) acquired by Airborne Laser Scanning (ALS) with a point density of about 10 pts/m² and a vertical root mean square error (RMSE) of 0.15 m are provided by the state government for the surrounding area of the lake.

2 MULTIBEAM ECHOSOUNDER - BATHYMETRY

2.1 System equipment and calibration

On May 15 and 16, 2019 a high-resolution and detailed mapping of the seafloor was performed using a survey grade multibeam echosounder (MBES). The survey boat Epsilon of viaDonau weas used for this purpose (Fig. 2). It is equipped with a Kongsberg EM2040 dual transducer system and configured for high-precision surveying of inland waters. Accordingly, it is equipped with high-quality complementary sensors. These include the high-performance iXblue Hydrins inertial navigation system, Valeport sound velocity profiler (SVP) and a Leica GS25 RTK GNSS system for positioning. Patch test at the beginning of each measurement mission is used for the determination of angular offsets in both the transducers of the dual head system as well as the motion sensor (roll, pitch, heading) and the latency remaining between the reception of the GNSS fix and its integration by the acquisition system. Inaccurate values would introduce bias when computing the 3D geographic location of the lakebed (Gueriot et al., 2000). Sound velocity probe (SVP) profiles were measured several times a day at representative locations in the lake to properly account for the influence of the sound velocity on the MBES measurements.

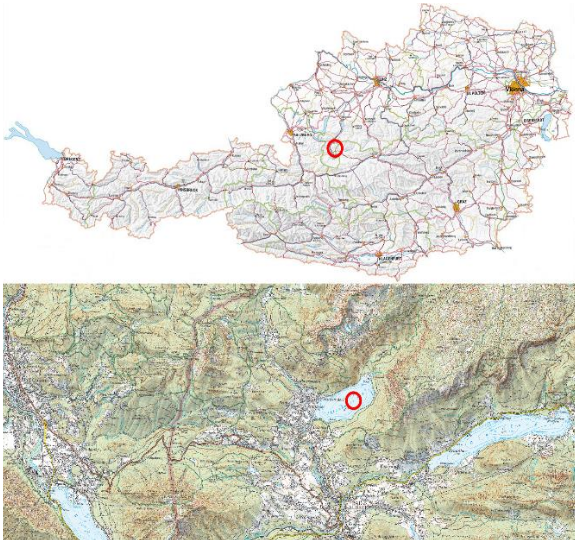

Fig. 1: Location of Lake Altaussee. (Source: Austrian Map; BEV - Bundesamt für Eich- und Vermessungswesen)

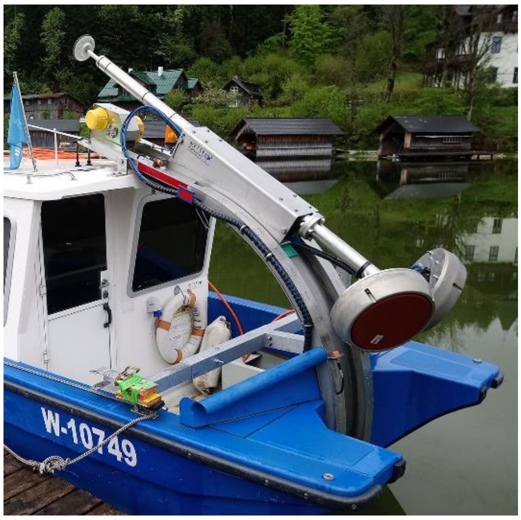

Fig. 2: Survey vessel with Kongsberg EM2040 multibeam echosounder dual head

2.2 MBES surveying mode

The multibeam measurements were performed with an echo sounder frequency of 400 kHz and in two different measurement modes. The central area of the lake with its only slightly sloping bottom was recorded with the mode “equidistant distribution of fan points”. The very steep shore zones, on the other hand, were recorded in “equiangle mode” to guarantee dense and accurate soundings (Fig. 3).

The dual head transducer system enables a higher point density and a larger measurement width than a single head transducer system. Furthermore, the inclined arrangement of the transducers offers the possibility to record steep banks up to a few decimeters below the water level. The large measurement width (swath width) of the system proved to be an advantage in terms of measurement times as well as safety (risk of collision between the measuring boat and boulders), especially when recording the heavily blocked northeastern shallow water zone.

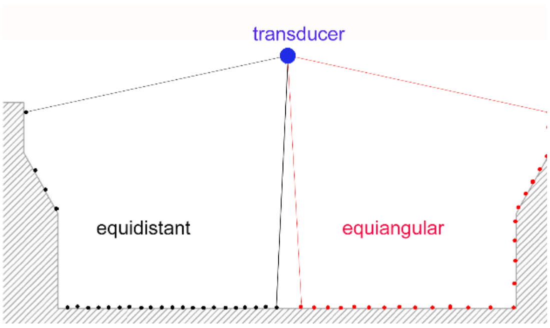

Fig. 3: Distribution of fan points resulting from different measurement modes (left: equidistant; right: equiangular)

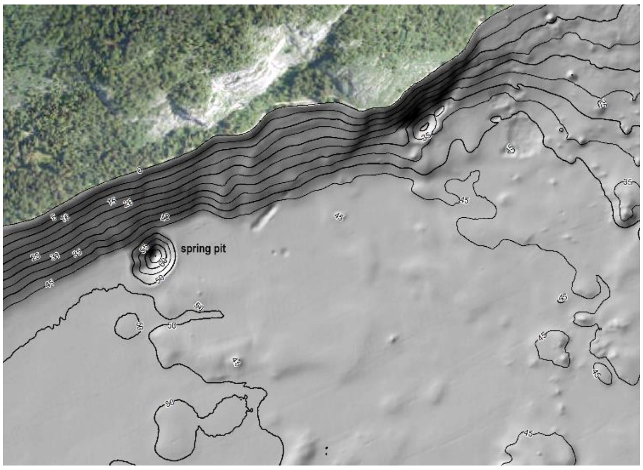

Fig. 4: High-resolution bathymetry of the submarine spring area (see also Chapter 4). Shaded relief of the lakebed DTM (0,5m x 0, 5m)

2.3 Additional data for bottom classification and object detection

However, survey grade multibeam echo sounders of this generation not only provide precise depth data (Fig. 4), but the recorded "backscatter" strength (backscattering energy) provides additional information about the structure of the seafloor (Fig. 12). Four acoustic classes ranging from lowest backscatters to highest values will be used to classify the sediment coverage of the lakebed, determined and verified with grab samples based on the Folk sediment classification with four classes plus an additional class “rock and boulders” (Miller et al., 2013; Amiri et al., 2019). Further input data delivers the ROV imagery taken at characteristic lakebed zones.

For the detection of near-bottom single objects, like sunken barrels or wooden piles the multi-detection functionality of the MBES measurement systems is a particularly interesting option. Here, not only one point from the last and strongest backscattered signal (i.e., lakebed) is detected from the reflections from a ping, but several points in the respective area of interest, e.g., pile surface and lakebed (Heine, 2017).

Furthermore, the ability of water column imaging (WCI) by MBES was used to detect potential areas of interest where objects such as gas plumes (methane gas seeps), submarine spring discharges or submerged trees.

For processing the WCI data, the post-processing software packages for hydrographic and fishery applications FMMidwater from QPS was used. Preliminary tests were realized in the area of submerged trees already described by Schäffer (1994), which is located close to southwestern shore. The interpretation of the water column images were realized using the so called fan view representation of the data (Fig. 5), where even singular objects can be traced through the water column (Deimling & Weinrebe, 2014). The fan image in Fig. 5 shows a submerged tree rising from 18 m deep lake bottom (Fig. 6).

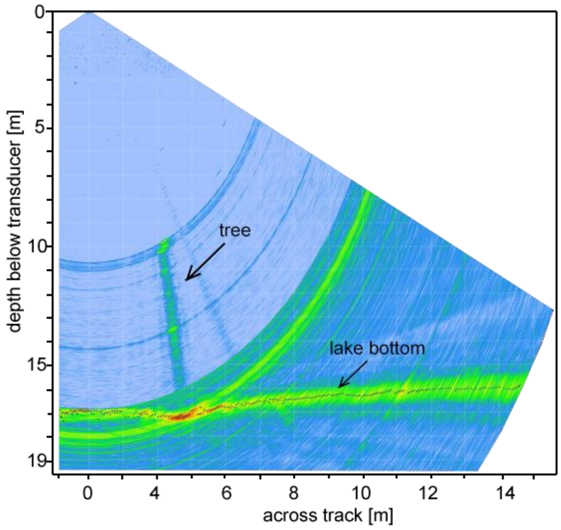

Fig. 5: MBES WCI data showing a 7 m high submerged tree at 18 m water depth

Fig. 6: Photo of a submerged tree taken by a remotely operated underwater vehicle (ROV) (see also chapter 4)

3 UAV PHOTOGRAMMETRY OF SHALLOW WATER AND SHORE ZONES

Shallow water zones with water depths less than 1.5 m and the steep shore zones with water depths less than 1 m could not be reliably detected with the MBES. Furthermore, the landside of the extremely steeply sloping shore zones are not described in sufficient detail in the existing governmental airborne laser scanning (ALS) datasets. Further, a clear delineation between land and water zones (land-water boundary) is not possible for the shallow shore zones based on the ALS data.

For these reasons, the shore zone was flown with an unmanned aerial vehicle (UAV) on November 21 and 22, 2019. The UAV (quadro-copter DJI Phantom 4 RTK) is equipped with a multi-frequency GNSS receiver with RTK functionality and a digital camera with a 1-inch CMOS sensor with 20 megapixel. The necessary correction data for RTK GNSS positioning was obtained via mobile internet connection from the GNSS service of the Austrian Federal Office of Metrology and Surveying. The survey was carried out with a longitudinal coverage of 80% and a transverse coverage of 70%. The entire lakeside of about 5 km length was flown in three strips: dry land; shore zone (land / water) and water area with a flight altitude of 65 m

(Fig. 7). This results in an effective ground resolving distance (GRD) of 3 cm for the 1" COMS camera sensor at 65 m flight altitude (Cramer et al., 2020). To obtain the best possible fit of this extremely narrow strip of overlapping images (5 km long and only 150 m wide), more than 50 control points were measured along the shore using RTK GNSS. In a first approach the Structure from Motion (SfM) software package Agisoft Photoscan Professional (Agisoft LLC, 2018) was used as a photogrammetric method for creating three-dimensional models of the topography from the overlapping photographs.

The evaluation of the UAV point cloud quality of the dry land was done by comparing it to points acquired by RTK GNSS with an accuracy of 3 cm. Approximately 350 points were surveyed along the shore. 20% of them were used as ground control points in the SfM process for creating the three-dimensional model of the topography. Based on the remaining GNSS points, an RMSE (3D) of 8 cm was determined.

Due to the good water clarity of almost 10 m (Secchi depth), a photogrammetric restitution of the lakebed of shallow water zones of up to 2.5 m water depth was possible.
Different approaches were chosen for the SfM processing of the images with land and water areas or images of water-only areas.
For the first case, masking of the water areas was performed in Agisoft Photoscan for an accurate determination of the photogrammetric model parameter, like orientation parameter determination. The resulting 3D model itself includes again the entire shore zone, land and water areas (Fig. 8).

Contrary to the dry land topography, the underwater object points had to be corrected due to the light refraction at the air-water interface. An empirical correction factor (CF) was utilized to convert the apparent water depth into a refraction-corrected (real-scale) water depth. (Partama et al., 2017). To determine the best fitting CF, the resulting 3D model of the lakebed as well as the 3D position of individual features were compared with 3D data received from the MBES survey at overlapping areas.

Both, the multibeam and the UAV photogrammetric survey data have a horizon in the point clouds representing the surface with a mean point density of 12 points per square-meter.

In a first step, the height difference between the lake bottom data from the UAV and the MBES points was calculated by comparing the individual UAV points with the average height of its neighboring multibeam points. By linear regression, a correction equation was built and applied to all underwater UAV points. Finally, a difference model was calculated based on the corrected UAV data and the MBES data, which showed a standard deviation (SD) of 25 cm for the overlapping area (1 m to 2 m water depth).

The first results with the SfM application for the hydrographic software package Qimera (QPS, 2020) are promising, too. This software package is based on the Dietrich Method for refraction correction (Dietrich, 2017 and Woodget et al., 2019). The comparison of the corrected final

UAV depths with MBES measured depths showed a standard deviation (SD) of 0.15 m for the overlapping shallow water zone of 1 m to 2 m water depth. When assessing these results, it must be taken into account that the resulting SD values are only of relative value due to the uncertainty of the MBES survey of about 0.1 m.

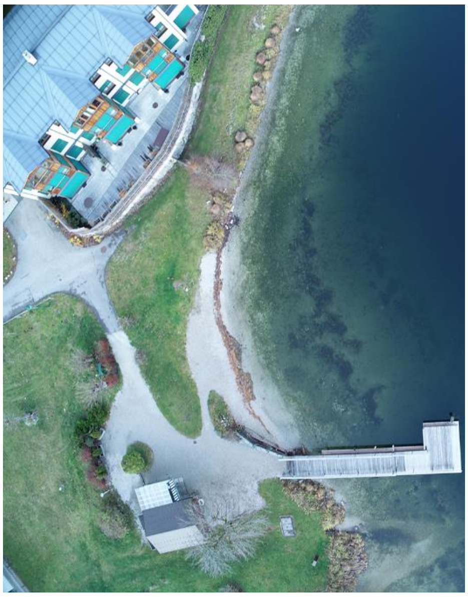

Fig. 7: UAV aerial image of the shore

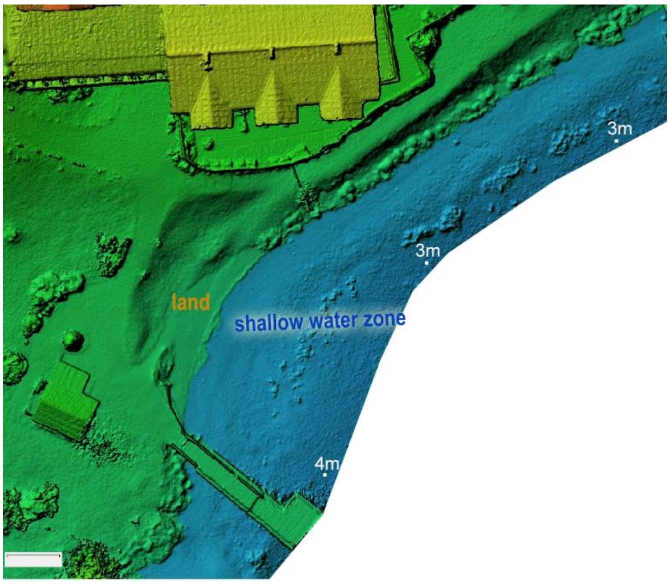

Fig. 8: DTM from photogrammetric restitution (SfM) of the shore (dry land) and shallow water zone

4 OBJECT VERIFICATION AND MAPPING USING UNDERWATER ROV

The primary motivation for using a remotely operated underwater vehicle (ROV) was the intention to investigate the submerged trees and the huge spring pit at the lake bottom in detail. An initial dive to this submarine karst spring was conducted on October 2 and 3, 2012 by M. Schafheutle and G. Derler, who also documented this dive on film (Harum et al., 2014). The diving depth of 70 m requires special diving equipment and the narrow bottom of the pit with obstacles, like branches and cables require experienced professional divers. Thus, a detailed investigation of the spring pit with repeated dives and the periodic dives during the following long term monitoring period results in very complex and costly mission. The selected ROV DTG3 from Deep Trekker, Canada is a proven, durable and portable remotely operated vehicle (Fig. 9). Its compact shape (30 x 25 x 25 cm), robust construction (lightweight die-cast shell), movable manipulator arm for water and sediment sampling and a maximum diving depth of 300 m characterize it.

4.1 Submarine spring pit

The submarine spring pit is located at the flat lake bottom area near the northwestern shore at 50 m water depth. The funnel-shaped karst spring has a diameter of 70 m at the rim and only a few meters at its narrow end at 72 m water depth. In 2019 and 2020, several ROV dives were conducted to the spring pit, which were documented using a 4K UHD video camera and LED spotlight. These recordings provide additional information for mapping the pit structure, like type and distribution of sediments in the different areas of the pit. The narrow end of the funnel is blocked by tree trunks and stone blocks (Fig. 10).

Fig. 9: ROV DGT3 from Deep Trekker

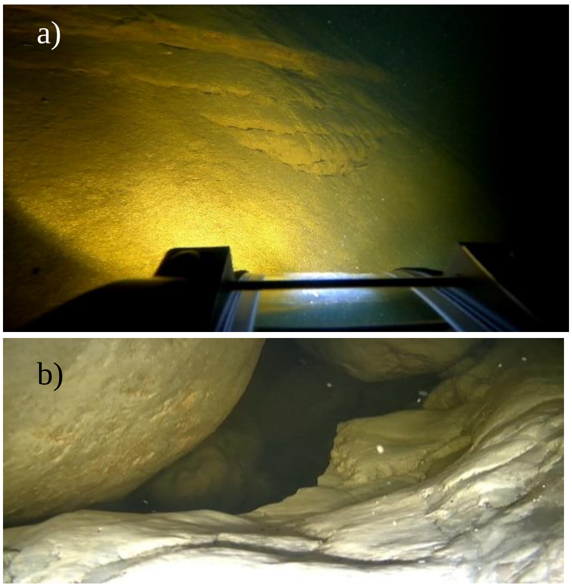

Fig. 10: ROV images: a) slope of the spring pit, b) blocked discharge zone at 72 m depth

Several dives along as well as across the rim document in detail the uplifted structure and the irregularities of its shape. At the western section, a submerged bundle of waste water pipes and power lines of the tavern on the lake meadow crosses the spring pit (Fig. 11). The location of these pipelines were detected already during the MBES survey, but the ROV video shows in detail the different slack of the pipes of the bundle when crossing the water body of the spring pit (Fig. 11 & Fig. 12).

4.2 Craters of other possible submarine springs

North of the spring pit are several cratered structures that are shallow in depth and covered with rocks and fine sand. A ROV dive, which was conducted immediately after a rainy period, showed a strong turbidity of the otherwise crystal-clear water in two of the craters at 40 m water depth. Unfortunately, the prevailing turbidity at this time made it impossible to observe the crater floor and its water body regarding the discharge of spring water. Anyway, ROV video sequences taken a few days later show individual accumulations of fine sediments indicating strong currents at these zones.

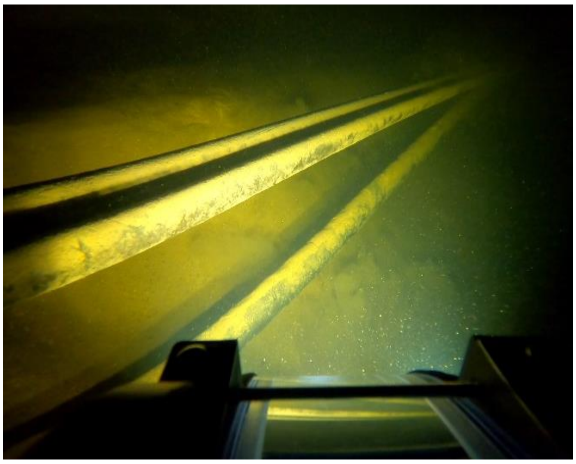

Fig. 11: ROV image of a pipeline crossing the spring pit

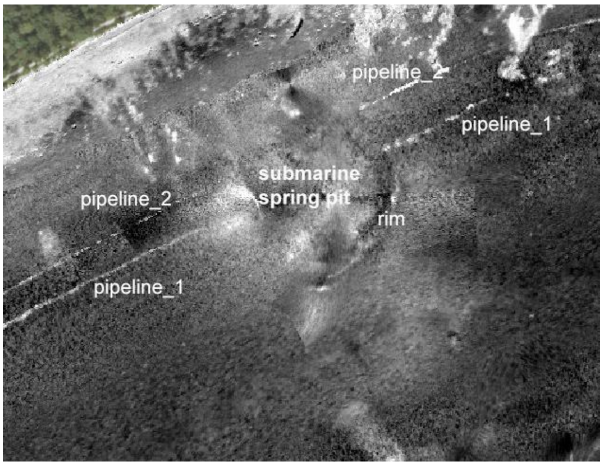

Fig. 12: Backscatter image of the spring pit showing pipeline routes

4.3 Verification of lake bottom structures and submerged trees

In the multibeam echo sounder data of the western shore area, several small-scale lake bottom structures appear, which significantly differs from the surrounding morphology. In order to clarify the type, dimension and shape of the objects, several dives with the ROV were carried out in this area at a depth of between 35 and 45 m. The ROV was used to determine the shape of the objects. One of these objects turned out to be an enormous karst boulder lying on a steep slope and being partly embedded in the lakebed sediment. The ROV video sequences show further, that the surface of this boulder is composed of small hallows (Fig. 13). This is particularly impressive, because this surface structure and its development is associated with the melt-water and sheet water of snow patches (Veress, 2019).

Special attention was given to the verification and documentation of submerged trees, which had been identified using backscatter and WCI data from the multibeam echo sounding (see chapter 2.3). This was done by recording video sequences of the entire tree-trunk, its rhizome zone and the surrounding lake bottom.
The challenging part of this mission is to bring the ROV to the predetermined position, due to the leak of navigation systems for subsea positioning. Thus, the ROV had to be carried on board of a GNSS guided boat to the assumed position of the tree, where it was dropped into the water. The ROV immediately initiated its dive to the tree, as fast and as vertical as possible, to reach the bottom at the preplanned position. Even weak currents produced displacements of the ROV of more than 10 meters on his way to the lake bottom at 50 m. Thus, the trees often could not be found due to the poor underwater visibility, and the dives had to be repeated.

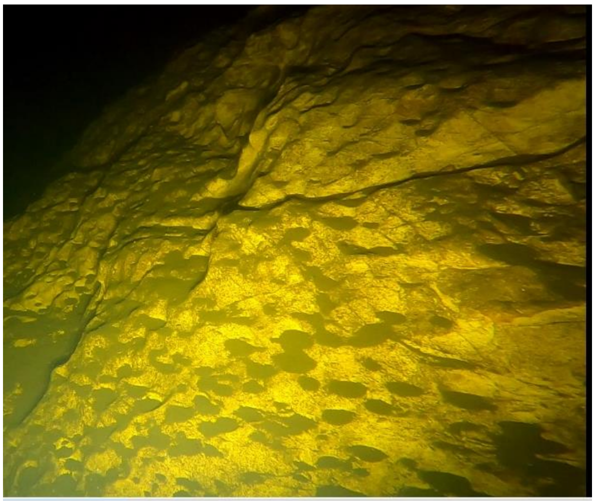

Fig. 13: ROV image of karst boulder at 40 m water depth

Fig. 14: ROV image of two submerged trees at 44 m water depth

5 RESULTS - BATHYMETRIC MAP OF LAKE ALTAUSSEE

The primary result of this project phase is the high-resolution and detailed topographic 3D model of Lake Altaussee (Fig. 15). Based on multibeam echo sounder measurements, photogrammetric restitution of UAV images and underwater ROV video recordings, this model represents a comprehensive and precise information source of the lake basin.

Previously unknown submarine crater formations indicate the importance of karst springs and its discharge, which have been suspected since the 1960s but were unknown until now. Thus enable more precise statements to be made about the hydrobiology, water quality and water exchange in the lake with the surrounding karst system.

However, derivations from this digital model also represent a targeted and profound source of information for a wide variety of user groups from the scientific community but also the local population. In this connection, a webmap application was developed for the fire department of the municipality of Altaussee, which has been supporting its water rescue unit in operations and diving training since 2020.

6 OUTLOOK AND FURTHER RESEARCH

In September 2020 the second phase of the Walter Munk project "Lake Altaussee" started with the focus on the geological formation and the development history of the lake, based on the new high-resolution bathymetry map combined with reflection seismic and sedimentary core analyses.

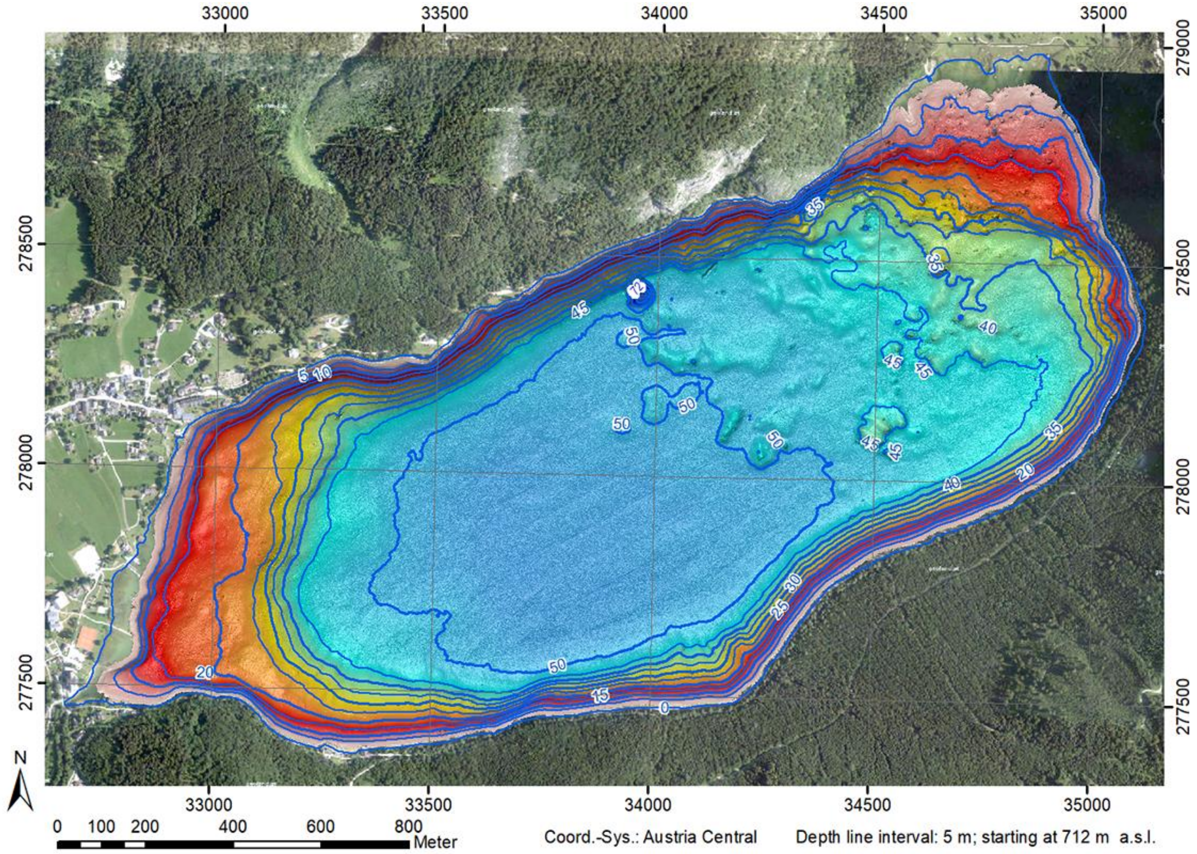

Fig. 15: High-resolution bathymetric map of Lake Altaussee

Glacial geological questions on the formation of the lake basin as well as the inclusion of the widely ramified cave system of the surrounding karst mountains in the hydrogeological investigations are just as much a part of this as the detailed recording and analysis of the sedimentary body of the lake. For the investigation of the latter, a research cooperation between BOKU and the University of Innsbruck has been established, where the focus is on the recording of the internal structure of the upper sediment layers. To record these layers, measurements were carried out in 2019 and 2020 using different marine sub-bottom systems: Innomar SES-2000 compact & iXblue Echo 1000 (see also Jouve et al., 2019) and Kongsberg GEOPULSE pinger. The measured data from these sub-bottom profilers represent the individual reflection horizons of the seafloor subsurface in so-called echograms.

To realize a correlation between the reflection horizons of the sub-bottom measurements and the sediment structure, more than 30 sediment cores distributed over the lake were taken from the lake bottom in September 2020. The cores are now being analyzed in the laboratory of the Sediment Geology laboratory at the University of Innsbruck and correlated with the geophysical measurement data. These data will be used to detect events with hydrodynamic sediment transport in the past, which may indicate an earthquake or an extreme hydrodynamic event (e.g., seiche, tsunami) that did affect the entire lake (Moernaut et al., 2021).

PROJECT SPONSOR AND ACKNOWLEDGEMENTS

It is due to the spirit and enthusiasm of Walter Munk that this project was started.

Walter Munk was born in Vienna in 1917 and spent every summer and winter of his childhood in Altaussee before his family sent him to live with relatives in the United States when he was 15. After years of training as a banker, he changed his plans and studied physics under Beno Gutenberg at the California Institute of Technology. After graduation, he became a staff member of the Scripps Institution of Oceanography, La Jolla, where he pursued his Ph.D. studies under the direction of the distinguished Norwegian oceanographer Harald Ulrik Sverdrup, graduating in 1947. This was followed by 70 years of oceanographic research (Fig. 16). In 2010, Munk received the Crafoord Prize of the Royal Swedish Academy of Sciences for Geosciences "for his pioneering and fundamental contributions to the understanding of ocean currents, tides and waves, and their role in Earth dynamics".

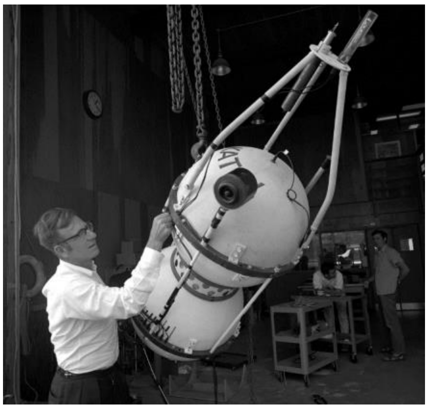

Fig. 16: Walter Munk in 1963 with a tide capsule (Photo by Ansel Adams, University of California)

The successful continuation of this project is due to the Walter Munk Foundation for the Oceans (WMFO), La Jolla, California, and its president Mary Munk. This constellation and objective of the project inspired the CHEOPS Private Foundation Vienna, under the direction of Johannes Baum-Koller, to agree to financially support this project. I would like to express my sincere thanks for this.

I would like to recognize the invaluable assistance of Sebastian Wagner in this project.

I’d also like to thank Walter Held and Werner Loibl, via donau - Österreichische Wasserstraßen, Olaf Lautenschläger, Kongsberg Maritim, Hamburg and Christian Stäuble, VERBUND, Vienna for their great cooperation in the measurement campaign.

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REFERENCES

AGISOFT LLC, (2018): Agisoft PhotoScan User Manual: Professional Edition, Version 1.4 Online available at https://www.agisoft.com/pdf/photoscan-pro_1_4_en.pdf

AMIRI-SIMKOOEI, A.R.; KOOP, L.; VAN DER REIJDEN, K.J.; SNELLEN, M.; SIMONS, D.G. (2019): Seafloor Characterization Using Multibeam Echosounder Backscatter Data: Methodology and Results in the North Sea. Geosciences 2019, 9, 292.

CRAMER, M.; ZHANG, S.; MEIßNER, H.; REULKE, R. (2020): Quality assessment of high-resolution UAV imagery and products. 40. Wissenschaftlich-Technische Jahrestagung der DGPF in Stuttgart – Publikationen der DGPF, Band 29, 2020, pp. 33-46. URL: https://www.dgpf.de/src/tagung/jt2020/proceedings/proceedings/papers/07_DGPF2020_Cramer_et_al.pdf

DAY, D. (2005): Walter Heinrich Munk Biography. Scripps Institution of Oceanography Archives, La Jolla, California.

DIETRICH, J. T. (2017) Bathymetric Structure-from-Motion: extracting shallow stream bathymetry from multi-view stereo photogrammetry. Earth Surf. Process. Landforms, 42: 355–364. doi: 10.1002/esp.4060.

GUÉRIOT, D.; CHÈDRU, J.; DANIEL, S.; MAILLARD, E.; 2000. The patch test: a comprehensive calibration tool for multibeam echosounders. In: Proceedings of OCEANS 2000 MTS/IEEE Conference pp. 1655–1661 vol.3. https://doi.org/10.1109/OCEANS.2000.882178

HARUM, T.; LEIS, A.; RESZLER, CH.; DALLA-VIA, A.; STADLER, H. (2014): Hydrologische Untersuchungen des Altausseer See. Endbericht des Joanneum Research - Forschungsgesellschaft. Durchgeführt im Auftrag des Amtes der Steiermärkischen Landesregierung, Abteilung 15.

HEINE, E. (2017): Multi-transducer sediment echo sounder for 3D documentation of submerged archaeological sites - a case study at a prehistoric pile dwelling at Lake Mondsee (Austria). In: FIG - International Federation of Surveyors, Proceedings of FIG Working Week 2017; ISBN: ISBN 978-87-92853-61

JOUVE, G.; BOUCHARD, A.; LELOUP, D.; ALAIN, P.; CHAPRON, E.; HEINE, E. (2019): High-resolution seismic reflection in Lake Altaussee (Salzkammergut, Austrian Alps): Preliminary results and implication for paleoenvironmental reconstructions. In: Extended abstracts AGU Fall Meeting 2019, San Fransico, USA. https://agu.confex.com/agu/fm19/meetingapp.cgi/Paper/491346 Online-Zugriff: 30.03.2020

MILLER, H., BULL, J.M., COTTERILL, C.J., DIX, J.K., WINFIELD, I.J., KEMP, A.E.S., PEARCE, R.B. (2013): Lake bed geomorphology and sedimentary processes in glacial lake Windermere, UK. Journal of Maps 9, 299–312. https://doi.org/10.1080/17445647.2013.780986

MOERNAUT, J.; WAGNER, S.; RECHENMACHE, J.; FIEBIG, M.; ORTLER, M.; FABBRI, S.; STRASSER, M. &, HEINE, E. (2021): A late Holocene Record of sediment dynamics obtained from Lake Altaussee (Salzkammergut, Austria). In: European Geosciences Union General Assembly, Vienna, April 28, 2021, EGU2021-1963.

PARTAMA, I.G.Y.; KANNO, A.; AKAMATSU, Y.; INUI, R.; GOTO, M.; SEKINE, M. (2017): A Simple and Empirical Refraction Correction Method for UAV-Based Shallow-Water Photogrammetry. International Journal of Geological and Environmental Engineering 11, 295–302.

QPS, 2020: How-to Qimera - Structure from Motion (SfM) Version 2.3. https://confluence.qps.nl/qimera/latest/en/how-to-qimera-structure-from-motion-sfm-182618055.html (last access: 7th of January, 2021)

RIEDL, R.; FRIEHS, B.; HOCHREITER, M. & ELLINGER, A.; 2008: 1. Steirischer Seenbericht. Ergebnisse der limnologischen Untersuchungen von 1999–2007 unter Berücksichtigung früherer Veröffentlichungen. Gewässeraufsicht, Abt 17C, Steiermärkische Landesregierung, Graz, 151 S.
http://www.verwaltung.steiermark.at/cms/beitrag/11839112/74838052/

SCHAEFFER, G.; 1994: Integrative Erfassung von Georisken in alpinen Gebieten: im Zeitraum von Juli 1990 bis September 1994. In: IDNDR-Aktivitäten der geologischen Bundesanstalt im Zeitraum von VII/190 bis IX/1994. 461 S., 99 Abb., 8 Beil., Wien.

VERESS, M., 2019. The KARREN and KARREN formation of bare slopes. Earth-Science Reviews 188, 272–290. https://doi.org/10.1016/j.earscirev.2018.11.006

WOODGET, A.S.; DIETRICH, J.T.; WILSON, R.T. (2019): Quantifying Below-Water Fluvial Geomorphic Change: The Implications of Refraction Correction, Water Surface Elevations, and Spatially Variable Error. Remote Sens. 2019, 11, 2415.

ZÖTL, J. (1961): Die Hydrographie des nordostalpinen Karstes.- Steir. Beitrag zur Hydrogeologie, Jg 1960/61, Heft 2, 183 S, Graz.

BIOGRAPHICAL NOTES

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