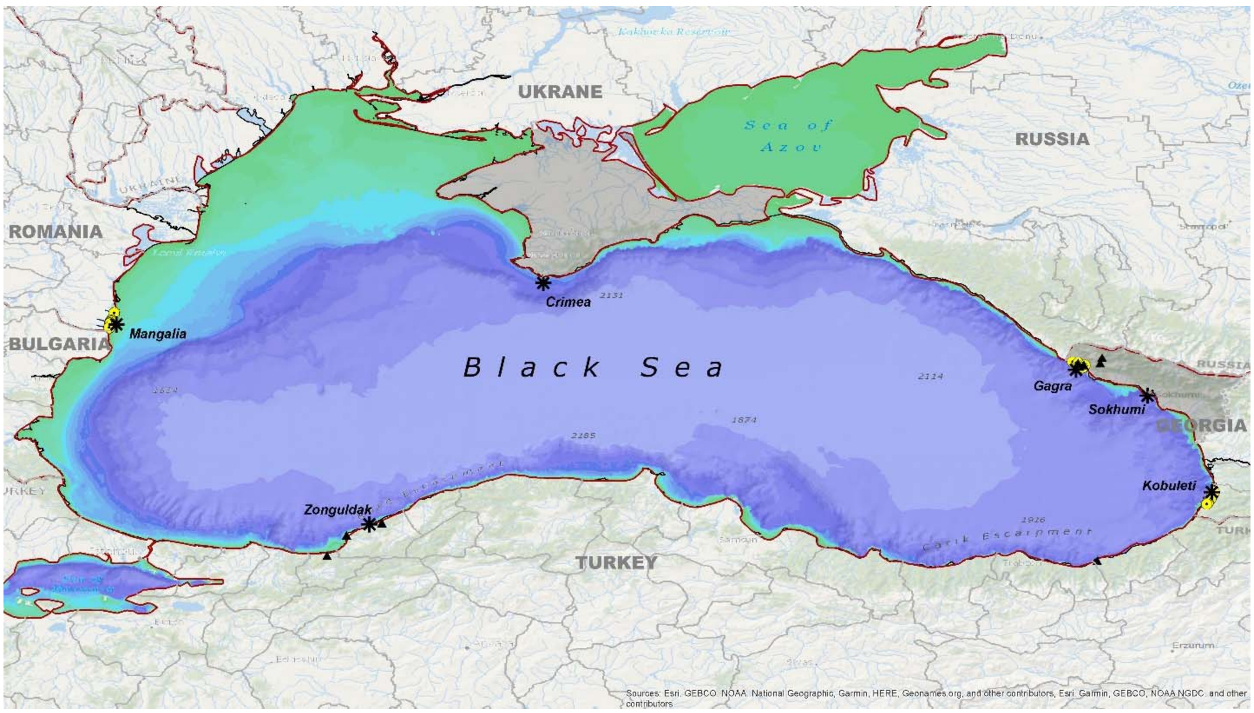
Search for Submarine Springs & Caves in the Black Sea - 2019



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Executive Summary

GeoHydros, LLC was contracted by Halcyon Manufacturing to develop and join a reconnaissance of the coastal Black Sea to search for potential locations of submarine springs and caves. A review of published literature revealed six areas in which hydrogeologic conditions favor the existence of submarine springs: karstic carbonate rocks, minimal overburden cover, and anecdotal or published references to submarine springs. The identified target areas include (clockwise from the west): Mangaila Romania, Foros Crimea, Gagra Georgia, Sokhumi Georgia, Kobuleti Georgia, and Zongdulak Turkey.

Email communications were sent to researchers in Romania, Turkey, and Georgia associated with published research on springs and/or caves in the region. Communications were established with two researchers: Dr. George Melikadze, Director of the Institute of Geophysics at the Tbilisi State University in Georgia, and Dr. Serdar Bayari, Professor of Hydrogeology at the Hacettepe University in Ankara Turkey. Dr. Melikadze provided useful information to help identify the target area in Kobuleti and attempted to meet the expedition onsite to provide further assistance though scheduling ultimately prohibited an in-person meeting. Dr. Bayari indicated that there is a low probability of significant submarine groundwater discharge off the coast of Turkey.

A 2-week diving expedition was organized to investigate two of the six areas, Mangalia and Kobuleti. The areas in Georgia and the Crimea were omitted due to security concerns stemming from their status as Russian occupied territories. The area in Turkey was omitted due to unexpected time constraints. The expedition leveraged a 29-meter liveaboard motor yacht to carry five divers and equipment to the target areas. The expedition left from Varna, Bulgaria and followed a route to Mangalia, Romania across the Black Sea to Batumi, Georgia, and back to Varna along the Turkish coast. The vessel suffered damage to the prop in the Mangalia harbor resulting in slower transits and an associated loss of two diving days.

Underwater investigations focused on visual inspections of the target areas as well as CTD (conductivity, temperature, and depth) profiling. Two dive teams were fielded in each area. Each team conducted transect surveys along multiple depth contours leveraging diver propulsion vehicles to cover as much ground as possible, double tanks or rebreathers to permit bottom times in excess of one hour, video cameras to record notable features, and a CTD sonde set to record continuously during each dive. Six dives were planned however only three were performed due to the slower than anticipated transits.

The area investigated off of Kobuleti Georgia contained promising bathymetric features: pronounced canyons and rock outcrops extending from approximately 40 to >85 meters water depth. Conductivity profiles recorded from that area revealed fresher than expected water as compared to published salinity profiles. No springs or caves were identified, however the observed features are suggestive of the presence of significant groundwater discharge, which would be consistent with published expectations. No evidence of springs was observed off the coast of Mangalia though only a short dive was conducted within a limited portion of the target area.

Results of the reconnaissance can not conclusively prove or disprove the existence of submarine springs or caves in either of the two investigated areas. Observed conditions do indicate that the presence of springs and/or caves is more likely in the Kobuleti area than in the Mangalia area. Future investigations would benefit from:

- continued and expanded communication and collaboration with local experts including Dr. Melikadze;
- detailed bathymetric profiling in advance of diving efforts and targeting areas characterized by steep slopes, canyons, and probable hard substrate;
- CTD profiling of the upper 100 meters of the water column along the transits across the Black Sea to establish baselines for comparison to the profiles collected from the target areas;
- use of better lighting with the video and still cameras and configuration of the lights to work better in high particulate water; and
- longer bottom times or more diving days such that more territory can be covered during the onsite investigations.

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1. Overview

GeoHydros, LLC was contracted by Halcyon Manufacturing to develop and join a reconnaissance of the coastal Black Sea to search for potential locations of submarine springs and caves that may exist in the upper 100 meters of water depth. For the purpose of the reconnaissance, GeoHydros defined areas with characteristics associated with submarine groundwater discharge (SGD) in the form of discrete spring vents and caves as:

- published descriptions of SGD and/or springs or caves within the upper 100 meters of water depth;
- karstic or fractured carbonate or fractured volcanic or plutonic bedrock exposed at or near the surface offshore and/or nearshore;
- substantial onshore catchment area;
- evidence of spring discharge onshore within the target or adjacent catchments; and/or
- apparent or probable imbalance between recharge and river outflow to the Black Sea within the target catchment.

1.1. Objectives

The reconnaissance included the following seven tasks.

1. Compilation of reports from previous investigations that describe the locations and magnitudes of SGD along the perimeter of the Black Sea.
2. Attempted correspondence with researchers in Romania, Turkey, and Georgia associated with published research on springs and/or caves in the region.
3. Identification of target areas that have the characteristics associated with SGD in the form of discrete spring vents.
4. Compilation and analysis of detailed bathymetric maps covering the target areas to identify specific target sites for investigation.
5. Survey of a subset of the target sites deemed most likely to encompass SGD using divers equipped with video, temperature, and salinity recorders along transects following depth contours identified from the bathymetric surveys.
6. Detailed documentation of any groundwater discharge features identified in the surveys.
7. Compilation of this report including recommendations for future surveys.

1.2. Benefits

Identifying and quantifying SGD in the Black Sea, particularly spring discharges, will significantly benefit three areas of societal concern and interest.

First, in many areas of the world including the Black Sea nations, submarine groundwater discharge presents an untapped or largely untapped freshwater resource. Identifying spring locations and quantifying discharge will provide necessary information for the development and calibration of groundwater flow models used to manage groundwater resources; and potentially provide local water supplies; see Gilli and Cavalera (2009).

Second, SGD is known to be a substantial vector for contaminant transport to the Black Sea. Contaminants include both point and non-point source constituents including the nutrient loading known to be contributing to the ongoing eutrophication problem in the Black Sea (Talley and Swift, 2011). Identifying spring locations and quantifying discharge will provide necessary information for the development and calibration of groundwater flow models and contaminant transport models used to rank contaminant sources in terms of their contributions to pollutant discharge; and provide water resource managers with the information needed to justify political and regulatory actions aimed at contaminant reduction.

Finally, springs have and continue to be locations around which communities develop and are sustained. The identification of springs in the upper 100 meters of water in the Black Sea will provide targets for future archeological and anthropological investigations of ancient civilizations in the Black Sea area.

2. Previous Investigations

GeoHydros conducted an Internet search for published research related to the existence of submarine springs in the Black Sea. Three documents were identified, studied, and used as the basis for the development of the reconnaissance effort. Those documents include:

- Buachidze (2007) who described the occurrence of SGD as a function of riverine discharge to the Black Sea in the coastal waters off of northwestern and southwestern Georgia as well as the probable existence of SGD in the coastal waters on northern Turkey;
- Klimchouk (2012) who described cave and karst development in the Arabika region of northwestern Georgia and the connection between deep dry cave systems in the mountains to coastal and submarine springs in the vicinity of the Arabika Submarine Depression; and
- Schubert and others (2017) who conducted a series of geochemical investigations that identified the approximate locations and magnitudes of SGD in the Mangalia region of eastern Romania, and the Adjara region of southwestern Georgia.

In addition to reviewing these documents, GeoHydros sent email correspondence to researchers in Romania, Turkey, and Georgia associated with published research described above. Communications were established with two researchers: Dr. George Melikadze, Director of the Institute of Geophysics at the Tbilisi State University in Georgia, and Dr. Serdar Bayari, Professor of Hydrogeology at the Hacettepe University in Ankara Turkey. Dr. Melikadze provided useful information to help identify the target area in Kobuleti and attempted to meet the expedition onsite to provide further assistance though scheduling ultimately prohibited an in-person meeting. Dr. Bayari indicated that there is a low probability of significant submarine groundwater discharge off the coast of Turkey. Appendices I and II provide copies of the email correspondence to and from researchers related to collaboration on the identification of SGD in the Black Sea.

3. Target Areas

GeoHydros identified six areas in which hydrogeologic conditions favor the existence of submarine springs. Bathymetric analyses were performed using GIS data obtained from the European Marine Observation and Data Network (EMODnet, 2019). Figure 1 and Appendix III provide a bathymetric map of the Black Sea identifying the target areas relative to surrounding topographic and political features.

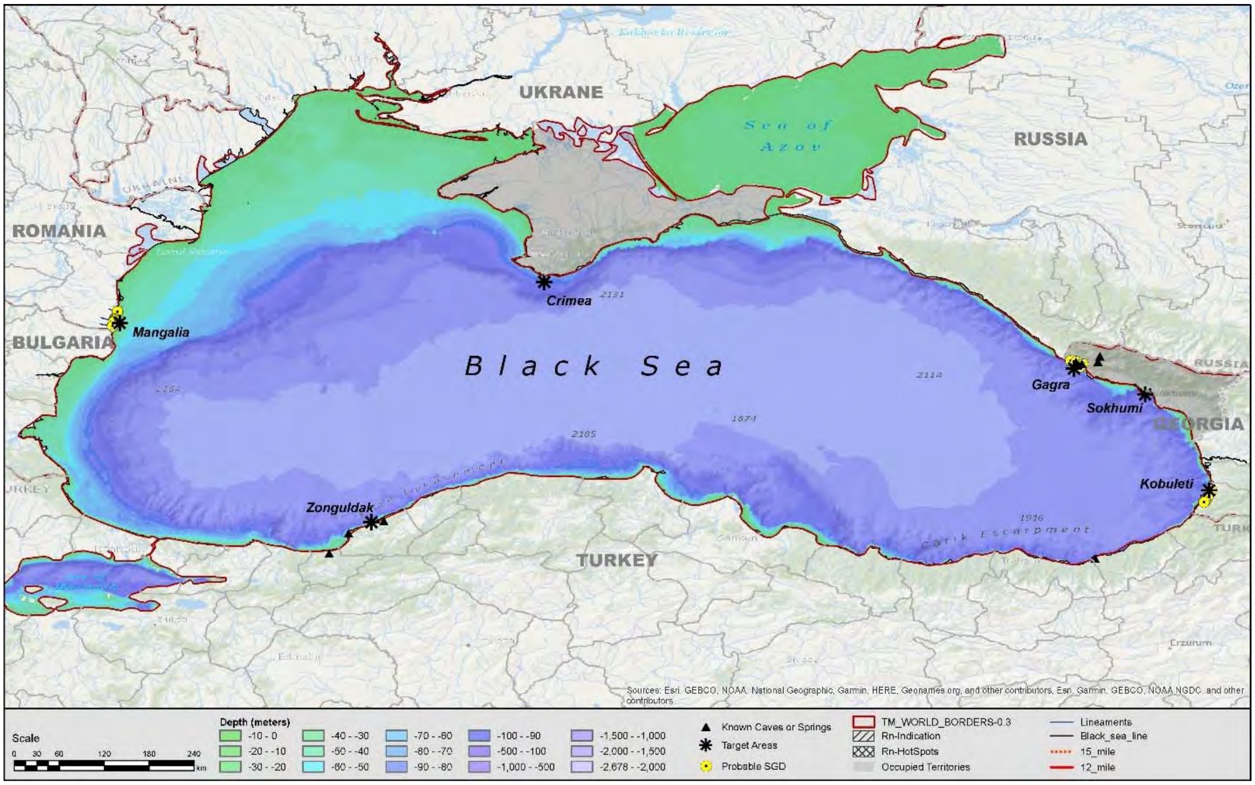

Figure 1. Map of the Black Sea showing bathymetric contours (EMODnet, 2019) emphasizing the upper 50 and 100 meters of water depth, and the locations of target areas that meet two or more criteria for the likely presence of submarine springs and/or caves as determined through a review of published literature.

3.1. Arabika Submarine Depression (northwestern Georgia)

The Arabika Submarine Depression (ASD) is situated immediately offshore of the Arabika and Bzubsky Massifs, part of the Caucasus Mountains, near the town of Gagra in the Abkhazia region of northwest Georgia. This is the only area of the Black Sea coast in which discrete springs have been described in the reviewed literature. The onshore region is extensively karstified containing numerous deep caves open at high elevations in the Ortobalagan Valley including the deepest known caves in the world, Krubera / Voronja caves. Klimchouk (2005) reports numerous onshore springs in the region that discharge between 1.0 and 2.5 m^3s^{-1}, fresh water encountered in boreholes drilled along the shore at elevations of -40 to -280 meters; several submarine springs in depths of 5 to 7 meters; an unspecified number of submarine springs at depths of between 25 and 30 meters; and hydrochemical indications of SGD within the ASD down to the bottom of the depression at nearly 400 meters below sea level.

The EMODnet bathymetric data (EMODnet, 2019) shows steep contours from the Black Sea shore to depths in excess of 100 meters indicating the predominance of steep rocky walls in the region. Buachidze (2007) classifies the Black Sea shelf is this region as *Karst*. Klimchouk (2005) provides a map graphic (that depicts more detailed bathymetric contours than those depicted by the EMODnet data that show the ASD and the locations of submarine springs. The locations of springs reported in the Klimchouk study were digitized and included on the map provided as Figure 1 and Appendix III.

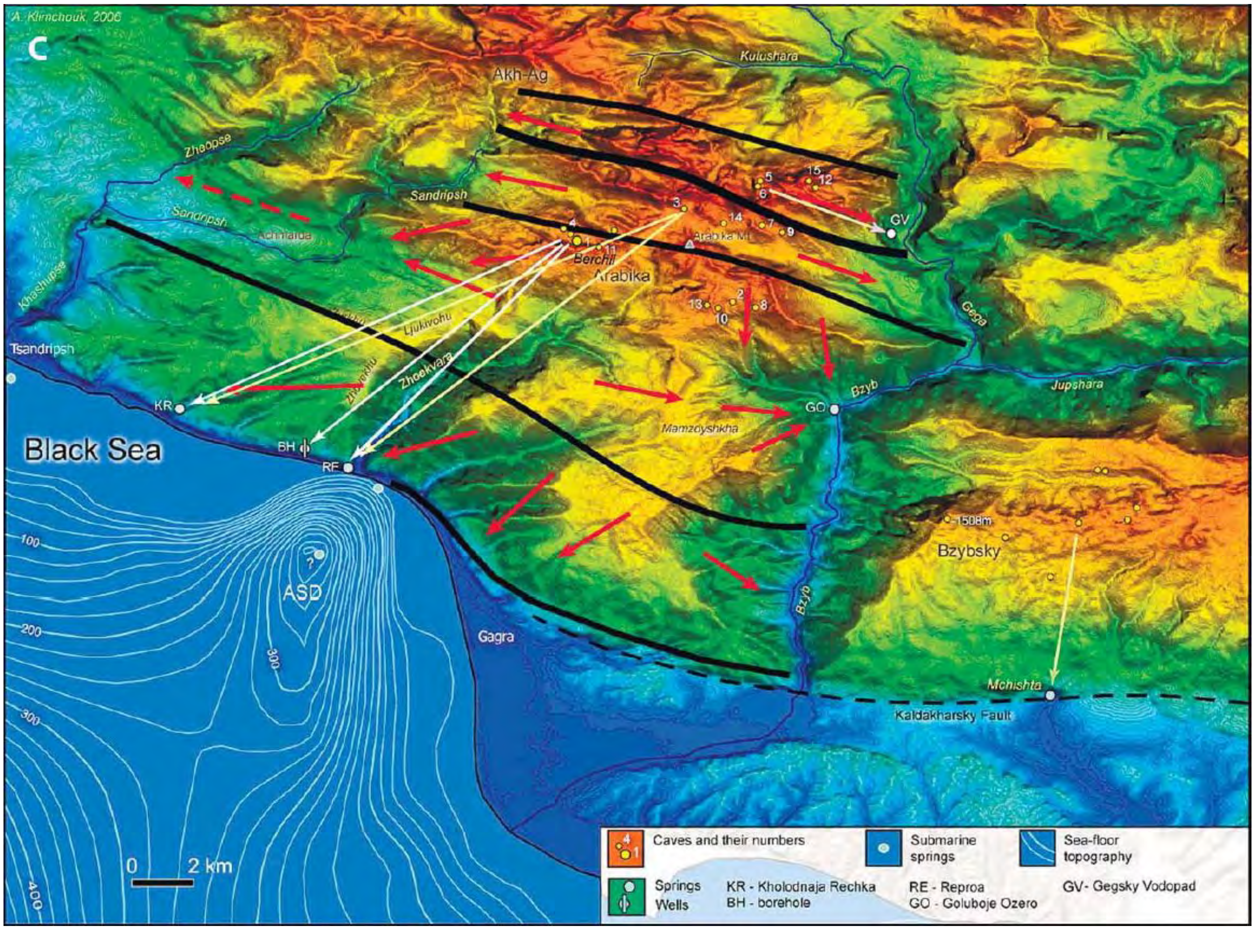

Figure 2. Map of the Arabika region of northwest Georgia reproduced from Klimchouk (2005) that shows the locations of verified onshore and offshore springs and postulated submarine springs associated with the Arabika Submarine Depression.

3.2. Adjara Region (southwestern Georgia)

The Adjara region of southwestern Georgia was studied by Schubert and others (2017) in their investigations of SGD in the Black Sea. The Schubert team identified three areas of probable SGD in this region between the town of Batumi in the south and the Natanebi River at the border between the Ajara and Guria provinces in the north on the basis of Radon-222, sea surface temperatures (SST), and physical hydrogeological characteristics. Six specific locations were identified as probable locations of SGD, which they describe as potential springs associated with fissures/faults in volcanic rocks. They report that previous investigations have estimated SGD in this area as being as high as 30% of river discharge to the sea. The area specified as highest probability of large-magnitude SGD is near the town of Kobuleti continuing along the town beach and south of it for about 7 km.

The EMODnet bathymetric data (EMODnet, 2019) show steep contours from the Black Sea shore to depths in excess of 100 meters as well as canyons that descend substantially deeper indicating the predominance of steep rocky walls in the region. Buachidze (2007) classifies the Black Sea shelf is this region as *Volcanic*. The regions and locations of probable SGD reported in the Schubert study were digitized and included on a map provided as Figure 3 and in Appendix III.

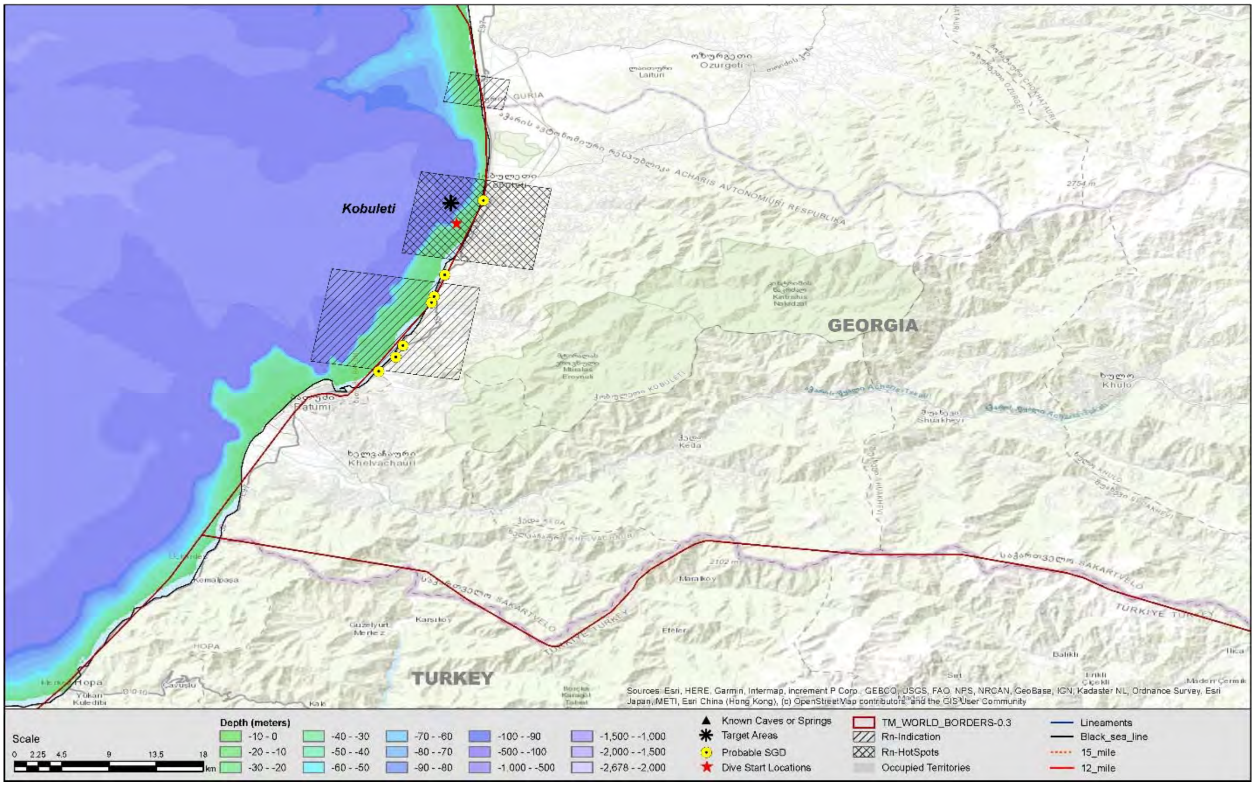

Figure 3. Map showing the location of the Kobuleti target area relative to the Adjara region of southwest Georgia and bathymetric contours (EMODnet, 2019) highlighting water depths down to -50 and -100 meters, and the locations of probable SGD as reported by Schubert and others (2017).

3.3. Sokhumi Region (western Georgia)

Buachidze (2007) describes potential SGD in this region but provides no supporting evidence other than the region is underlain by karstified carbonate rocks comprising the Caucasus Mountains. This target zone is identified on the basis of shelf type and bathymetric contours. The EMODnet bathymetric data (EMODnet, 2019) show very steep contours from the Black Sea shore to depths in excess of 100 meters indicating the predominance of steep rocky walls in the region. Buachidze (2007) classifies the Black Sea shelf is this region as *Karst*. Figure 4 and Appendix III provide a map of the Sokhumi target area showing bathymetric contours that highlight water depths down to 50 and 100 meters.

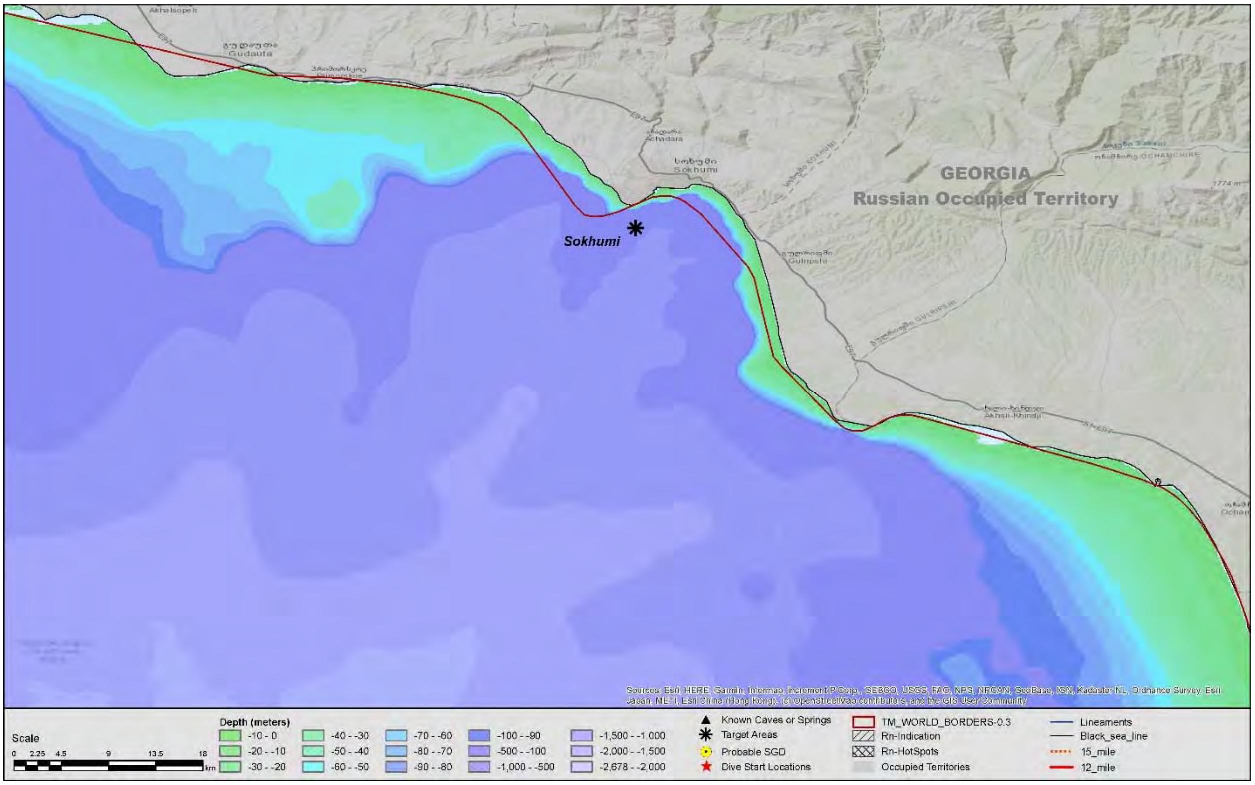

Figure 4. Map showing the location of the Sokhumi target area relative to the Adjara region of southwest Georgia and bathymetric contours (EMODnet, 2019) highlighting water depths down to -50 and -100 meters.

3.4. Southeastern Romania

The southeastern region of Romania was studied by Schubert and others (2017) in their investigations of SGD in the Black Sea. The Schubert team identified three areas of probable SGD in this region between the Bulgaria/Romania border in the south and Techirghiol Bay, south of Constanta in the north on the basis of Radon-222, sea surface temperatures (SST), and physical hydrogeological characteristics. Fourteen specific locations were identified as probable locations of SGD. Ten of the locations were associated with regions of very high Radon-222.

The EMODnet bathymetric data (EMODnet, 2019) show broad contours from the Black Sea shore to depths in excess of 100 meters. Buachidze (2007) classifies the Black Sea shelf is this region as *Stable-Wide*. Both of these conditions indicate that SGD, if it occurs, is likely shallow and disperse rather than associated with spring vents. The area remains worthy of investigation because of the SGD indications and because similar characteristics would be ascribed to the Spring Creek region of South Florida USA, which research has verified as containing numerous discrete, large magnitude springs.

The regions and locations of probable SGD reported in the Schubert study were digitized and included on a map provided as Figure 5 and in Appendix III.

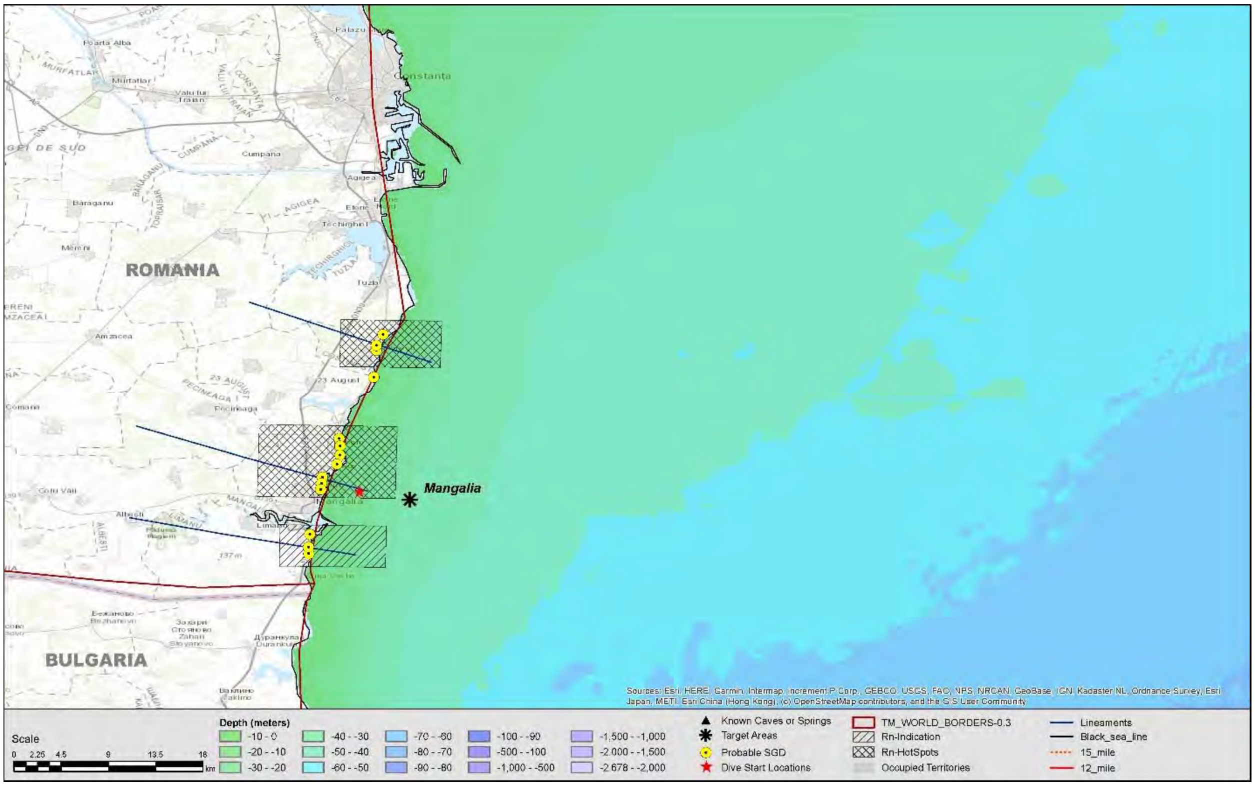

Figure 5. Map showing the location of the Mangalia target area relative to eastern Romania and Bulgaria, bathymetric contours (EMODnet, 2019) highlighting water depths down to -50 and -100 meters, and the locations of probable SGD as reported by Schubert and others (2017).

3.5. South Coast Crimea

No published discussion or reference to known or suspected SGD has been identified. This target zone is identified on the basis of shelf type and bathymetric contours. The EMODnet bathymetric data (EMODnet, 2019) show very steep contours from the Black Sea shore to depths in excess of 100 meters indicating the predominance of steep rocky walls in the region. Buachidze (2007) classifies the Black Sea shelf is this region as *Karst*. The Crimea coast was considered a lower priority target area because no specific sites of probable springs, caves, or SGD could be identified. Figure 6 and Appendix III provide a map of the Crimea target area showing bathymetric contours that highlight water depths down to 50 and 100 meters.

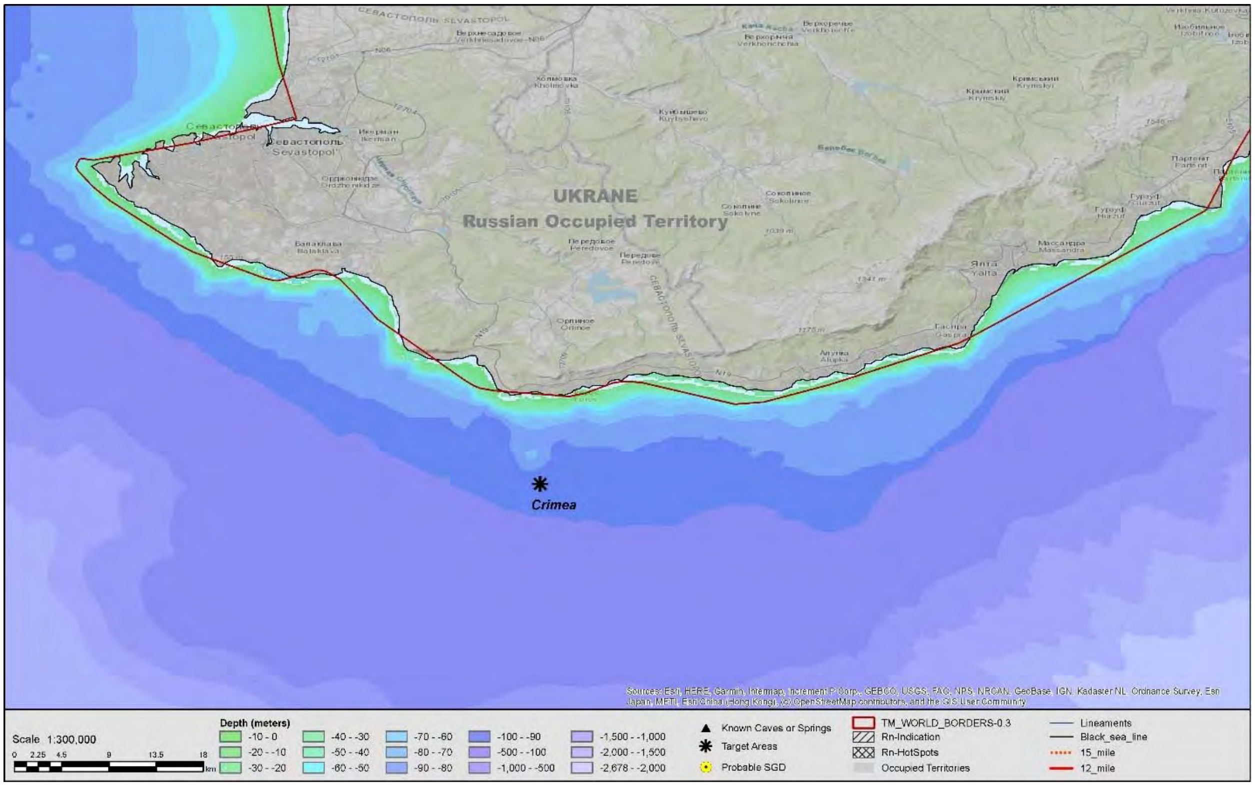

Figure 6. Map showing the location of the Crimea target area relative to the Sevastopol region of the Crimean peninsula and bathymetric contours (EMODnet, 2019) highlighting water depths down to -50 and -100 meters.

3.6. Zonguldak Region - West, Turkey

No published discussion or reference to known or suspected SGD has been identified. This target zone is identified on the basis of shelf type and bathymetric contours. The EMODnet bathymetric data (EMODnet, 2019) show very steep contours from the Black Sea shore to depths in excess of 100 meters indicating the predominance of steep rocky walls in the region. Buachidze (2007) classifies the Black Sea shelf is this region as *Karst*. Several dry caves exist in this region of Turkey and within five km of the Black Sea coast. Location and background information for two of these is available online: Cehennemagzi Caves, and Gokgol Magarasi. The Zonguldak region was considered a lower priority target area because no specific sites of probable springs, caves, or SGD could be identified. Figure 7 and Appendix III provide a map of the Zonguldak target area showing bathymetric contours that highlight water depths down to 50 and 100 meters.

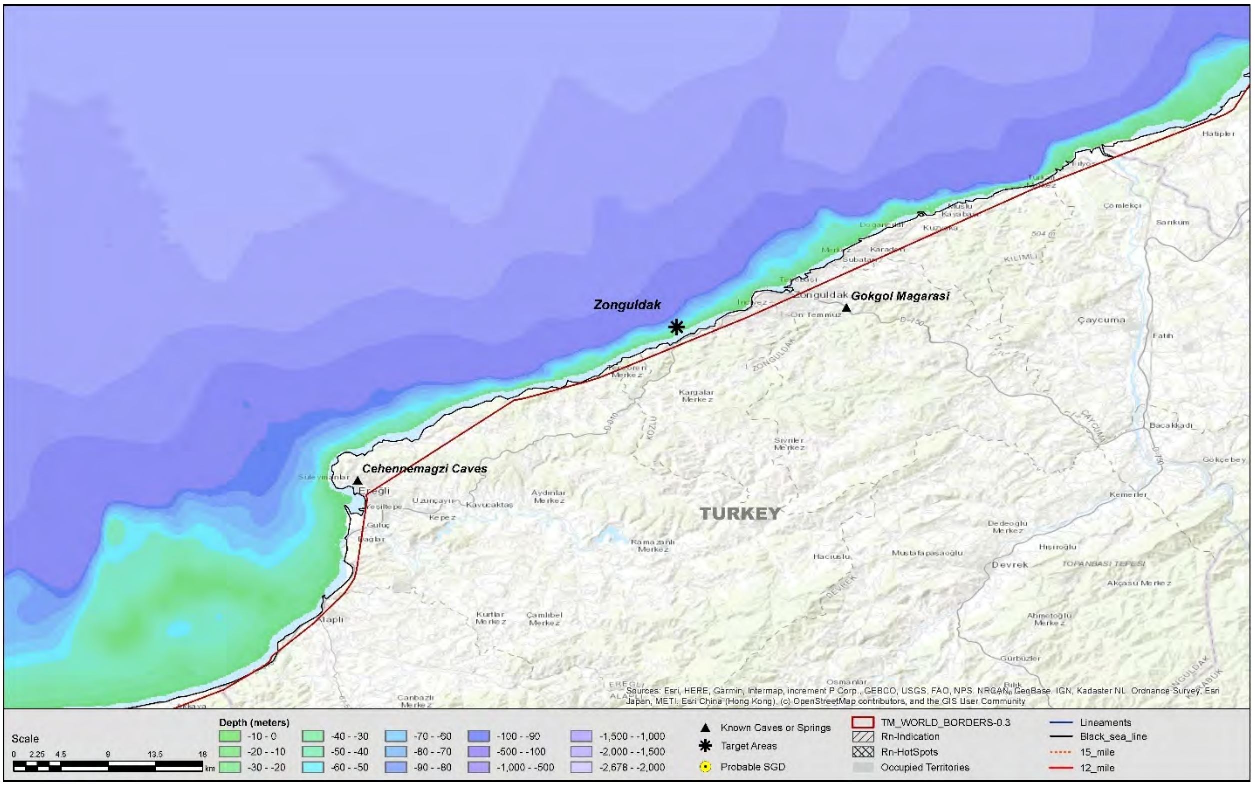

Figure 7. Map showing the location of the Zonguldak target area relative to the north coast of Turkey, location of dry caves described in literature available online, and bathymetric contours (EMODnet, 2019) highlighting water depths down to -50 and -100 meters.

4. Direct Observations

A 2-week diving expedition was organized to investigate two of the six areas, Mangalia and Kobuleti. The expedition leveraged a 29-meter liveaboard motor yacht to carry five divers and equipment to the target areas. The expedition left from Varna, Bulgaria and followed a route to Mangalia, Romania across the Black Sea to Batumi, Georgia, and back to Varna along the Turkish coast.

The areas in Georgia and the Crimea were omitted due to security concerns stemming from their status as Russian occupied territories. The area in Turkey was considered a lower priority and ultimately not investigated due to time constraints stemming from damage to one of the vessel’s props suffered in the Mangalia harbor, which resulted in slower transits across the Black Sea and an associated loss of two diving days.

Target sites were chosen in the Kobuleti and Mangalia target areas (Figure 3 and Figure 5) based on inspection of the bathymetric contours, description of probable SGD reported by Schubert and others (2017), and, at Mangalia, proximity to mapped fault structure.

Underwater investigations focused on visual inspections of the target sites as well as CTD (conductivity, temperature, and depth) profiling. Two dive teams were fielded in each area. Each team conducted transect surveys along multiple depth contours leveraging diver propulsion vehicles to cover as much ground as possible, double tanks or rebreathers to permit bottom times in excess of one hour, video cameras to record notable features, and a CTD sonde set to record continuously during each dive. CTD data was processed two ways: one in which the data from each entire dive was downloaded, processed in MS Excel to calculate depth, specific conductivity, and salinity from the raw pressure, temperature, and conductivity measurements; and another in which the device processed the data into a single parameter vs. depth profile. Both sets of resulting profiles are presented.

4.1. Kobuleti

Two sites were investigated off of Kobuleti Georgia by two dive teams and four dives to depths between 40 and 85 meters. All dives were initiated from the same location (Figure 3). Two dives were conducted on 8/24/2019. Both targeted a variably steep slope trending north-northwest away from the initiation point reaching a maximum depth of approximately 42 meters. The other two dives were conducted on 8/25/2019. Both targeted a steeper slope trending to the west-northwest from the initiation point and reached a maximum depth of approximately 85 meters.

The western site was characterized by promising bathymetric features including pronounced canyons and rock outcrops extending from approximately 40 to >85 meters water depth. Conductivity profiles recorded from both sites revealed fresher than expected water as compared to published salinity profiles. No springs or caves were identified however the observed features are suggestive of the presence of significant groundwater discharge, which would be consistent with published expectations.

Figure 8 and Figure 9 show the temperature, conductivity, specific conductance vs. depth profiles processed from the raw data for the four dives. Figure 10 compares the raw and device-processed parameter vs. depth curves for all four dives. Appendix IV provides dive profiles relating depth and parameter values to dive time along the transects.

Figure 11 and Figure 12 provide pictures exported from video collected by divers during the transect surveys at the two Kobuleti target sites. The video and pictures are unfortunately of poor quality due to particulates in the water and insufficient video lighting. The pictures in Figure 11 do however provide a visual depiction of the rock outcrops encountered along the steepest portion of the western slope while the pictures in Figure 12 provide depictions of the slopes and initial rock outcrops encountered along both the northern and western slopes.

4.2. Mangalia

Only two short dives were conducted within a limited portion of the Mangalia target area. Figure 5 shows the location of the dive site relative to indications of SGD reported by Schubert and others (2017). Rocky substrate characterized by small ledges was encountered on both dives but no evidence of springs was observed.

Three CTD profiles were collected by casting the device off of the boat at the dive site. The raw data exported from each of those profiles as well as the aggregate data processed by the device are presented in Figure 13. CTD profiles from the two dives could not be plotted because the CTD profiler was improperly configured when deployed for the dives.

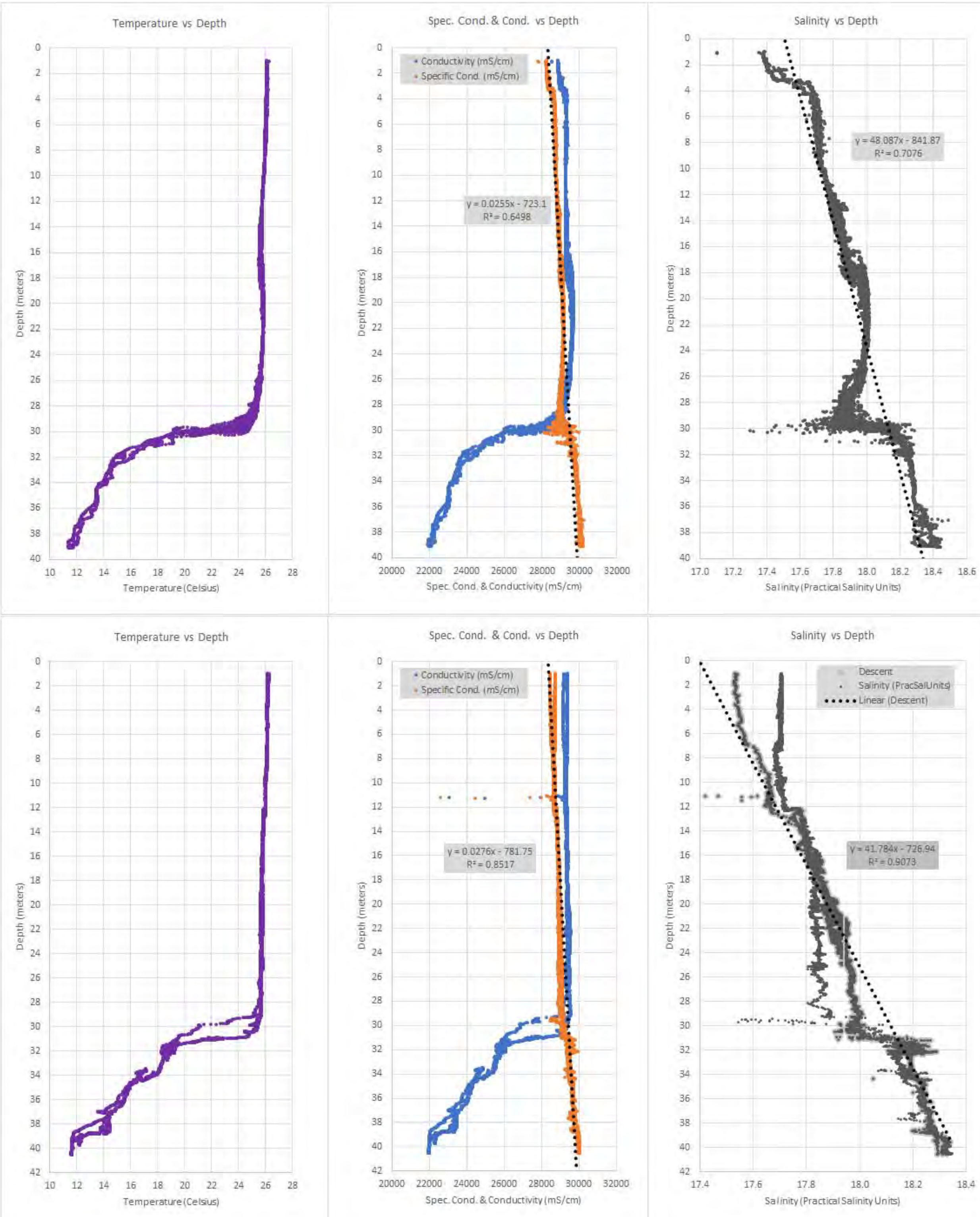

Figure 8. Temperature, specific conductance, and salinity vs. depth profiles processed in MS Excel from the raw data downloaded from two dives conducted on 8/24/2019 along a variably steep slope oriented north-northwest from the dive initiation point shown on Figure 3.

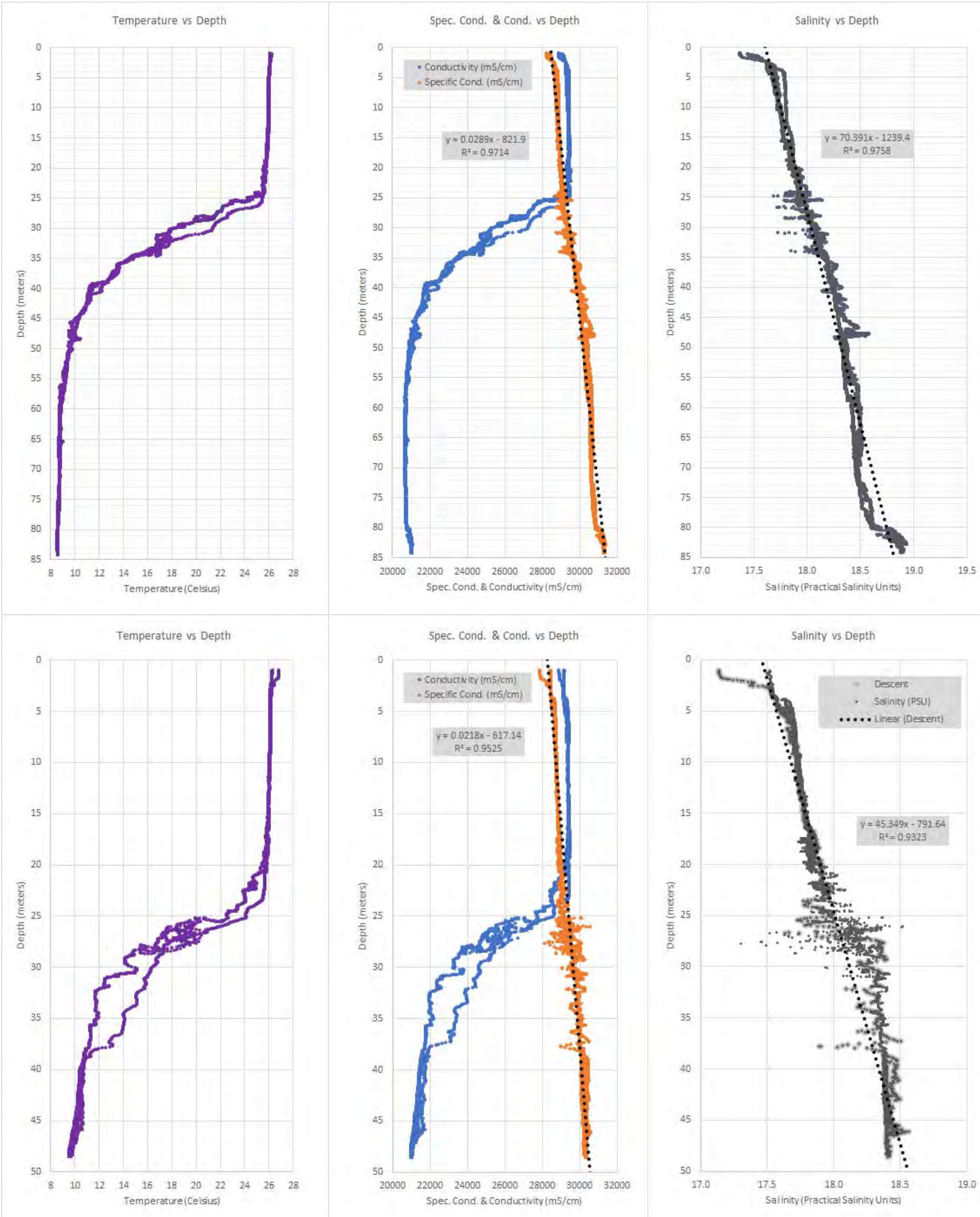

Figure 9. Temperature, specific conductance, and salinity vs. depth profiles processed in MS Excel from the raw data downloaded from two dives conducted on 8/25/2019 along a steep slope oriented west-northwest from the dive initiation point shown on Figure 3.

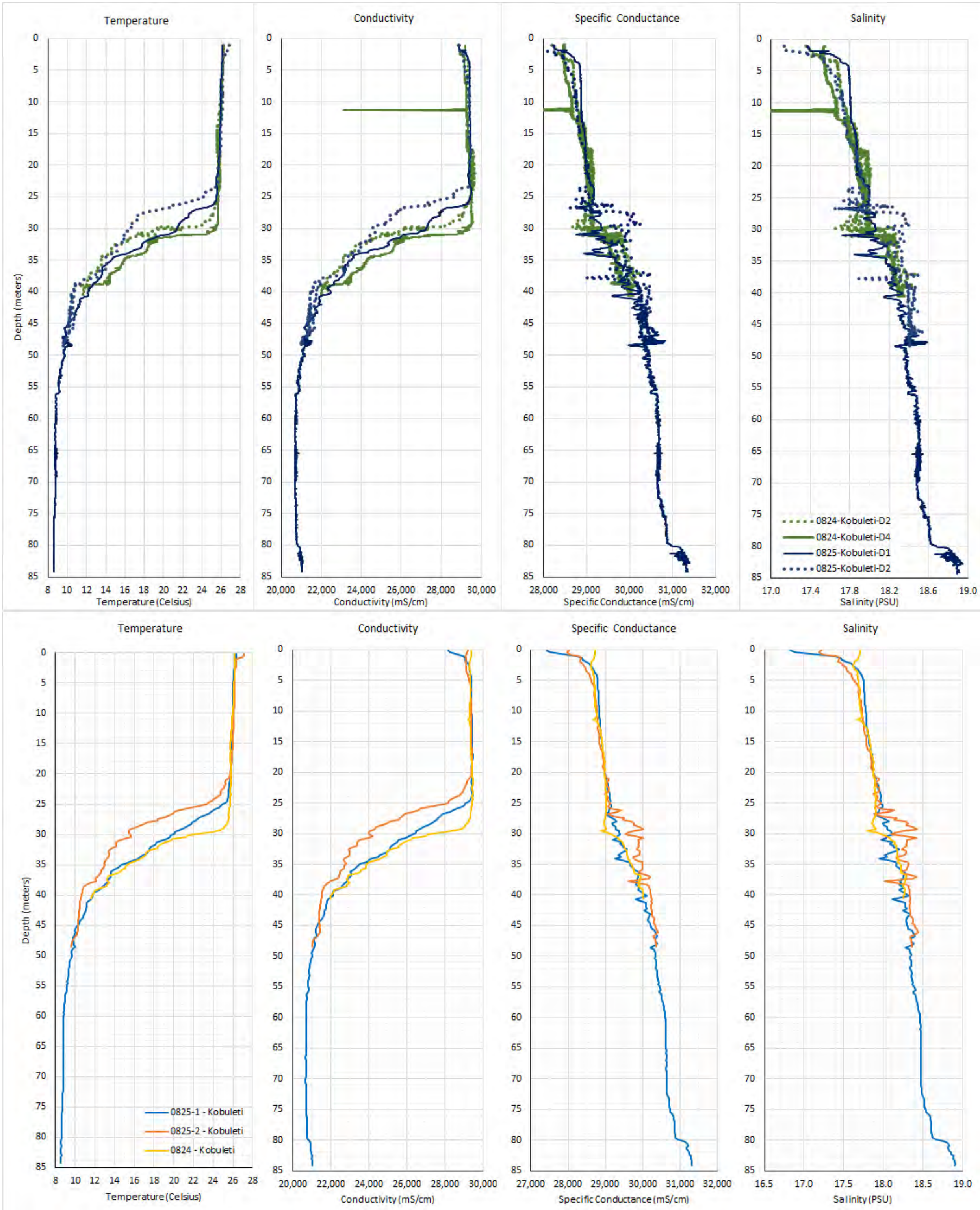

Figure 10. Comparison of parameter vs. depth profiles using all of the raw data collected on each of the four Kobuleti area dives (top) and using the form of the data processed by the CTD device (bottom). Note that the device-processed data consolidated the two dives conducted on 8/24/2019 into a single curve.

Figure 11. Pictures exported from video collected from the dive over the western slope at the Kobuleti target area on 8/25/2019 showing outcrops encountered along the steepest portion of the slope in water depths between 220 and 250 feet.

Figure 12. Pictures exported from video collected from the dives over the northwestern and western slopes at the Kobuleti target area on 8/24/2019 and 8/25/2019 showing the substrate along the slope and small outcrops encountered along the upper portion of the western slope in water depths between 120 and 152 feet.

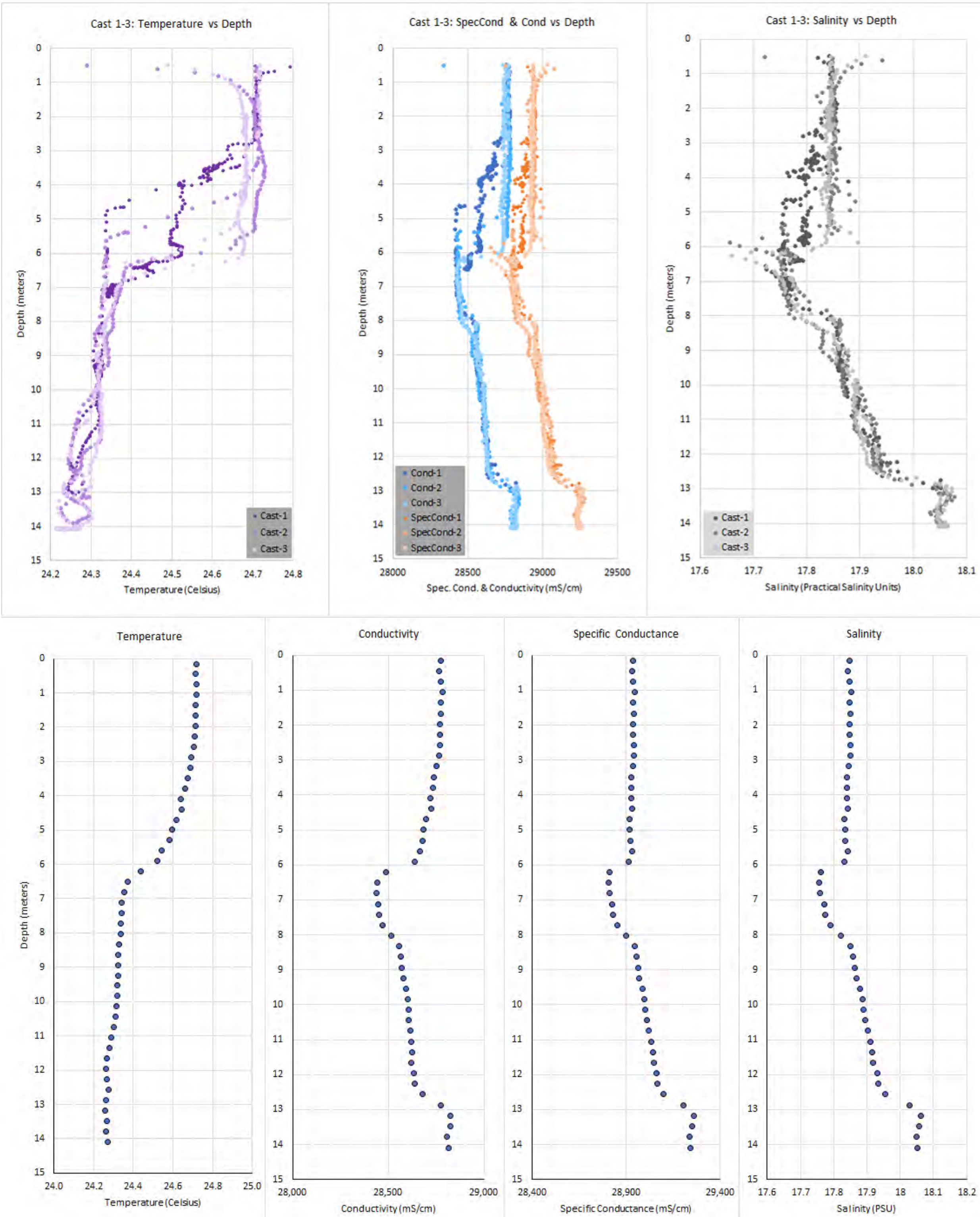

Figure 13. Comparison of parameter vs. depth profiles using the raw data collected on each of three casts (top) and the aggregate data processed by the CTD device (bottom) performed from the boat the Mangalia target site (Figure 5).

5. Discussion

Neither spring vents or caves were observed during the reconnaissance dives at Mangalia or Kobuleti. The salinity profile recorded on the deepest dive at Kobuleti does however indicate freshwater influence at depth. Figure 14 compares the device-processed temperature and salinity vs. depth profiles for all dives. Overall, each profile demonstrates an increase in salinity with depth, which is generally consistent with published profiles for the Black Sea (Figure 15). The profile generated from the deepest dive denotes one zone between approximately 60 and 72 meters depth that displays a near constant salinity and therefore a deviation from the expectation. Table 1 compares salinity values recorded during the reconnaissance dives with values interpreted from published profiles (MISIS, 2014; Maderich et al., 2015; Capet et al., 2016). Salinity values are generally consistent with the average of the published values, though lower by between 0.02 and 0.19 PSU, down to 60 meters depth where the deviation increases to between 0.5 and 0.67 PSU.

Though the data are not definitive, we interpret the deviation between observed and expected salinity in the waters off Kobuleti, Georgia at depths between 60 and 72 meters as indicative of SGD. The geomorphology of the slope in this region further indicates that there may be discrete spring vents and caves in the area that were not observed during the dives.

Table 1. Comparison of observed and published salinity values by depth in the Black Sea.

Depth (m)	OBS Kobuleti	OBS Mangalia	MISIS-RO	MISIS-BG	MISIS-TK	Maderich-Central	Capet-Central	Avg-Rep	δ Kob-Avg
10	17.75	17.88	18.00	18.15	17.50	17.75	18.00	17.88	-0.13
20	17.90	nr	18.05	18.15	17.95	18.10	18.20	18.09	-0.19
30	18.10	nr	18.13	18.25	18.30	18.45	nr	18.28	-0.18
40	18.30	nr	18.20	18.30	18.35	18.45	nr	18.33	-0.02
50	18.35	nr	18.30	18.40	18.40	18.55	18.50	18.43	-0.08
60	18.45	nr	18.40	18.75	18.50	18.70	18.60	18.59	-0.14
70	18.45	nr	18.65	19.20	19.10	19.10	18.70	18.95	-0.50
75	18.50	nr	18.75	19.50	19.30	19.40	18.90	19.17	-0.67
100	*19.50**	nr	19.35	20.15	20.30	20.00	20.00	19.96	-0.46

<u>Notes</u>

OBS = observed values
* = projected value based on linear regression of values measured below 81 meters depth
nr = not recorded or interpreted
MISIS-RO = Romanian coastal waters from MISIS (2014)
MISIS-BG = Bulgarian coastal waters from MISIS (2014)
Maderich = central Black Sea waters from Maderich and others (2015)
Capet-Central = central Black Sea waters from Capet and others (2016)
Avg-Rep = average of the values interpreted from the listed published curves
δ Kob-Avg = difference between the observed value at Kobuleti and the average of the published values

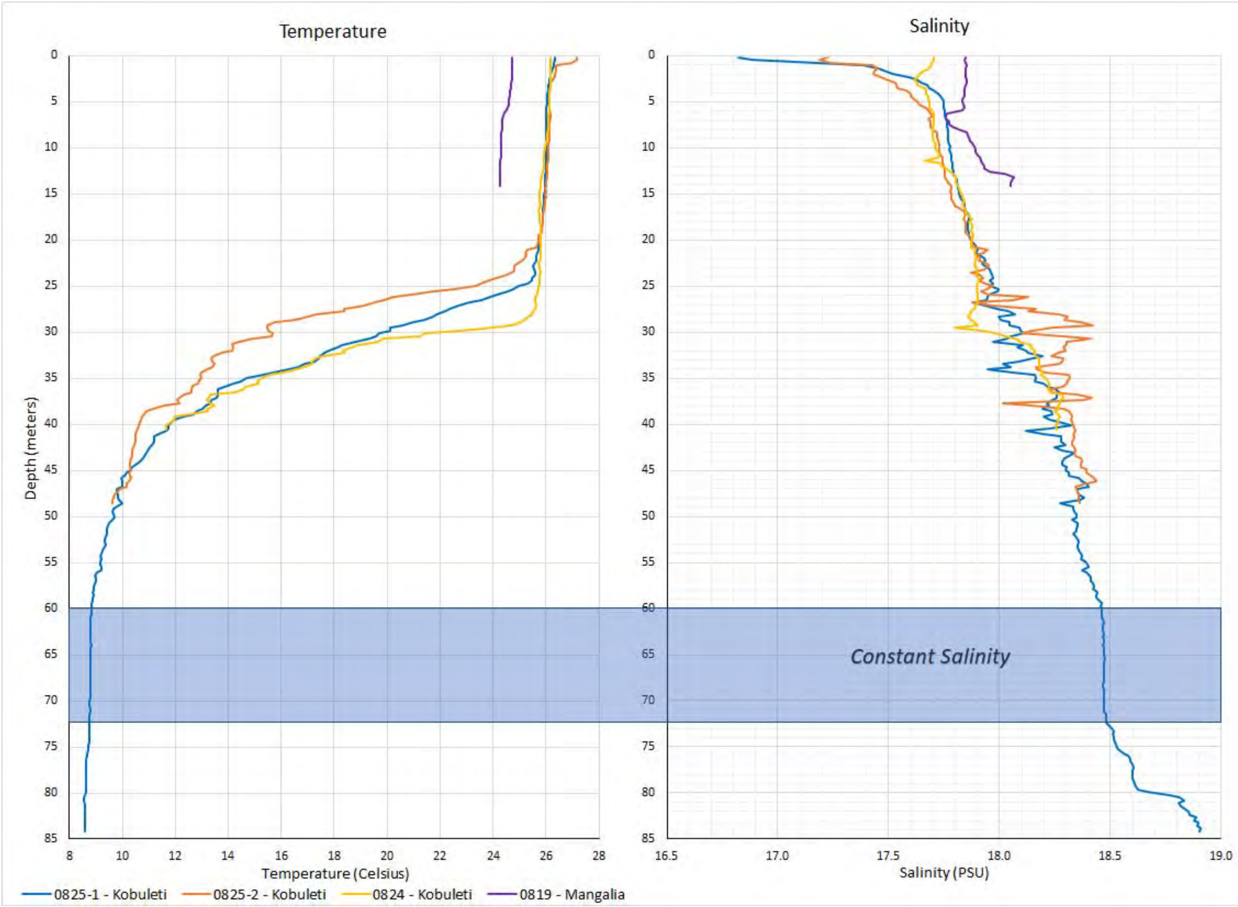

Figure 14. Device-processed temperature and salinity vs. depth profiles recorded in the waters off of Mangalia Romania and Kobuleti Georgia showing a trend of generally increasing salinity with depth except in the depths between 60 and 72 meters off of Kobuleti.

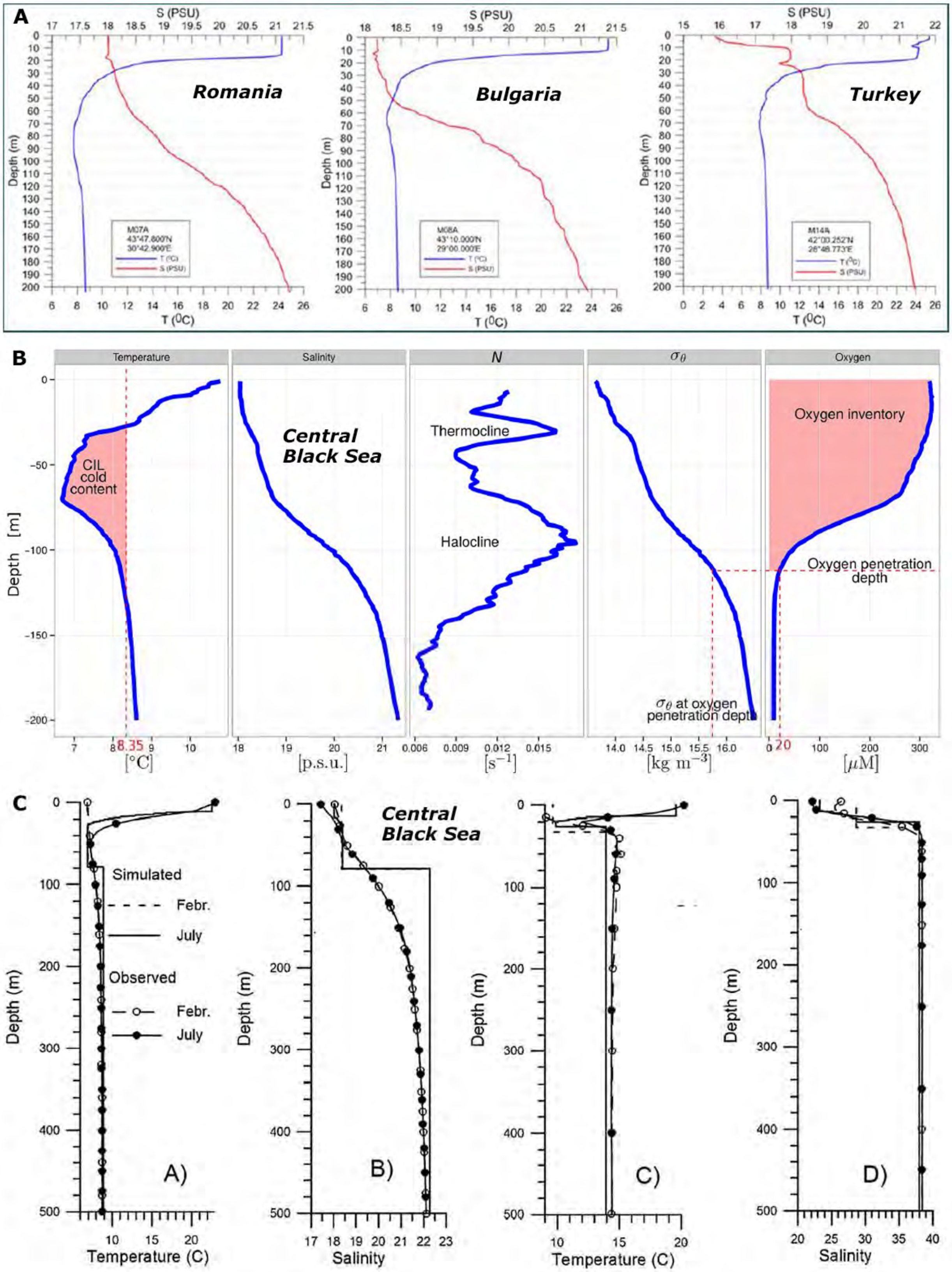

Figure 15. Comparison of published salinity vs. depth profiles for the Black Sea in the western and southern coastal waters (A - MISIS, 2014) and central waters (B – Capet et al., 2016 & C – Maderich, et al., 2015).

6. Recommendations

The salinity profiles and geomorphology of the slope off of Kobuleti Georgia are sufficiently indicative of SGD and possibly discrete spring vents to warrant further investigation. We therefore recommend a second mission to physically observe conditions and record CTD profiles in the coastal waters off of southwestern Georgia, focused particularly on the Kobuleti region. A return to Mangalia is also warranted due to the limited time available at that location during the August 2019 mission. It would however be appropriate to dedicate the majority of effort associated with a return mission to the Kobuleti target area. The following recommendations are intended to render such a mission as productive as possible.

1. Provide added bottom time at each location through longer bottom times and additional scheduled diving days. Water temperatures and currents encountered during the August 2019 mission were permissive of longer bottom times. Four-five hour dives using rebreathers should be achievable within reasonable margins of safety, which would permit between 50 and 60 minutes of bottom time in the 60-72 meter depth range. Adding two diving days should also be feasible even holding to a ~14-day total schedule assuming faster transits across the Black Sea.
2. Perform detailed bathymetric surveying prior to diving. Use of a multi-beam profiler or a similar device would enable to the development of detailed bathymetric maps and profiles in the targeted areas, which would greatly enhance the ability to choose favorable sites for exploration. In addition to their value in site selection, multi-beam bathymetric profiles would be a valuable independent deliverable from the mission.
3. Perform CTD profiling in concert with the bathymetric surveys. The CTD devices that have been purchased for this project can be dropped “cast” from the boat down to 100 meters depth. Each cast and retrieval should take less than 5 minutes. The resulting data would further enhance site selection and also provide another set of independent deliverables.
4. Perform CTD profiling of the upper 100 meters of water column while in transit across the Black Sea to establish baselines for comparison to the profiles collected from the target areas. Performing these profiles would require halting progress and remaining nearly stationary for approximately 5-minutes per profile. Approximately 15 profiles distributed roughly evenly across the northern and southern transits and the eastern transit to Batumi would provide reasonable data to describe the variation in salinity presumably associated with waters not influenced by SGD.
5. Video lights situated away from the video cameras should be used to provide better lighting at depth for the video surveys.
6. Continue and expand communication and collaboration with local experts, particularly Dr. Melikadze in Georgia. The goal of collaboration would continue to focus on the identification of target sites based on local knowledge and experience.

7. References

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8. Contacts

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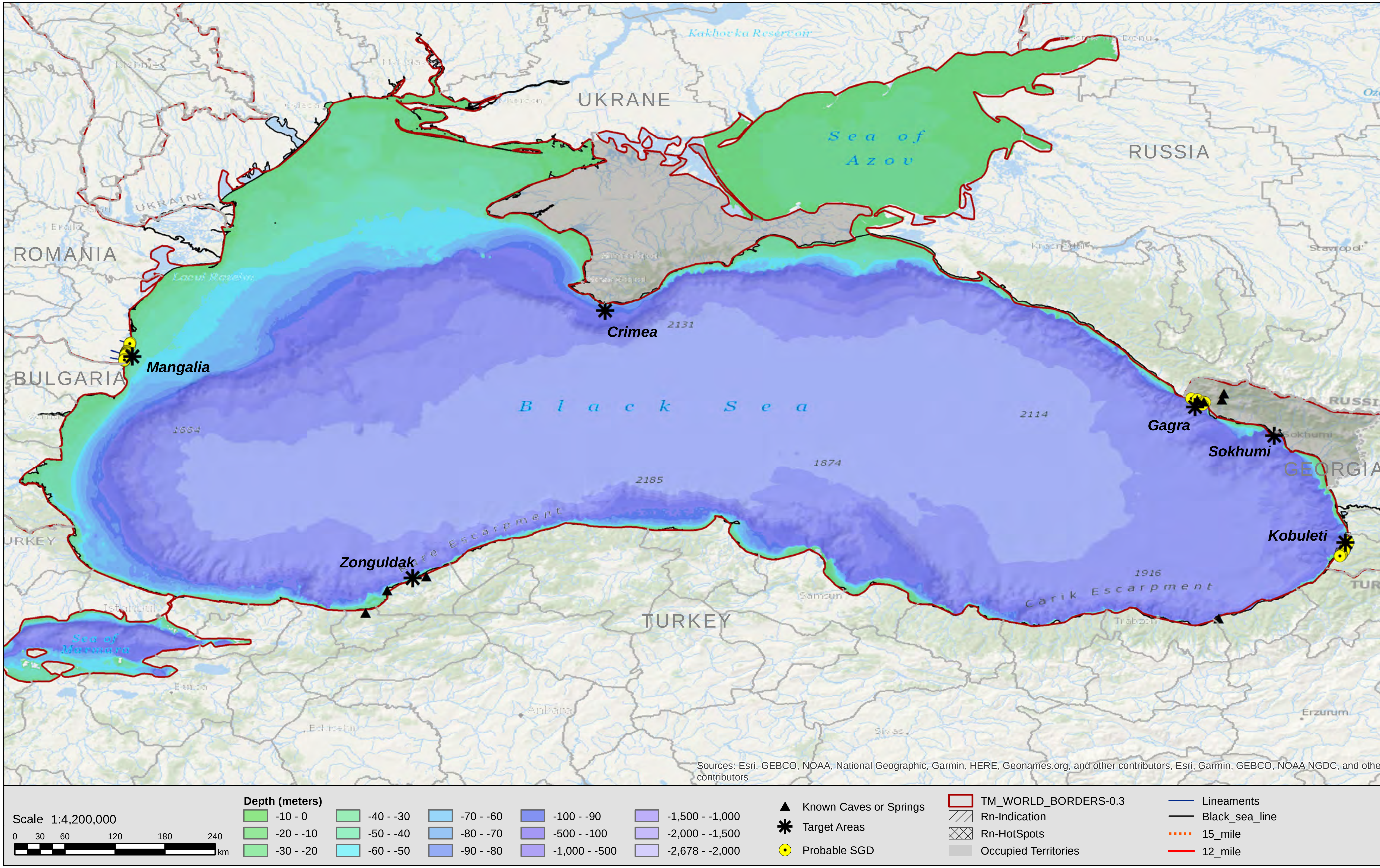
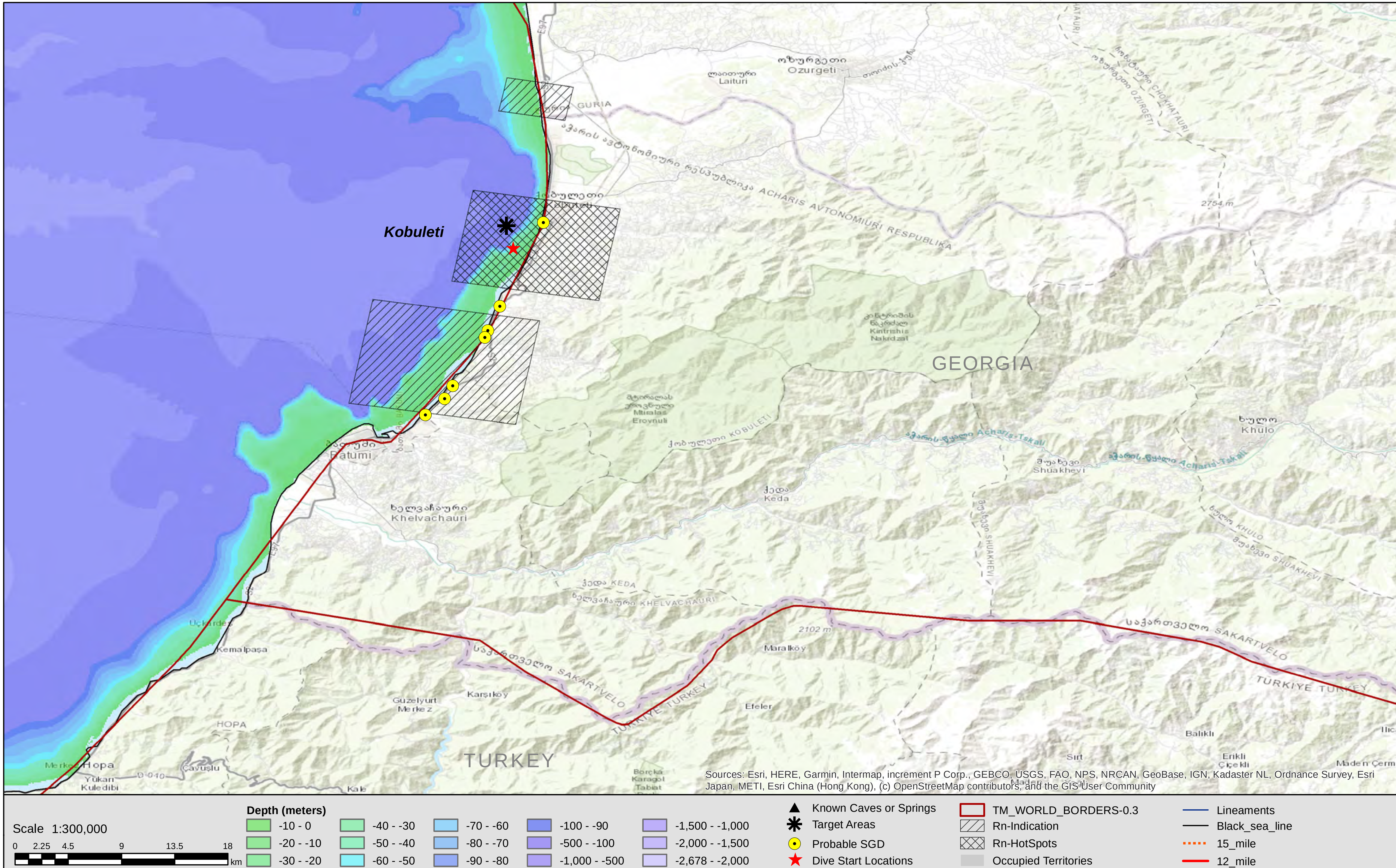
Appendix I
Maps

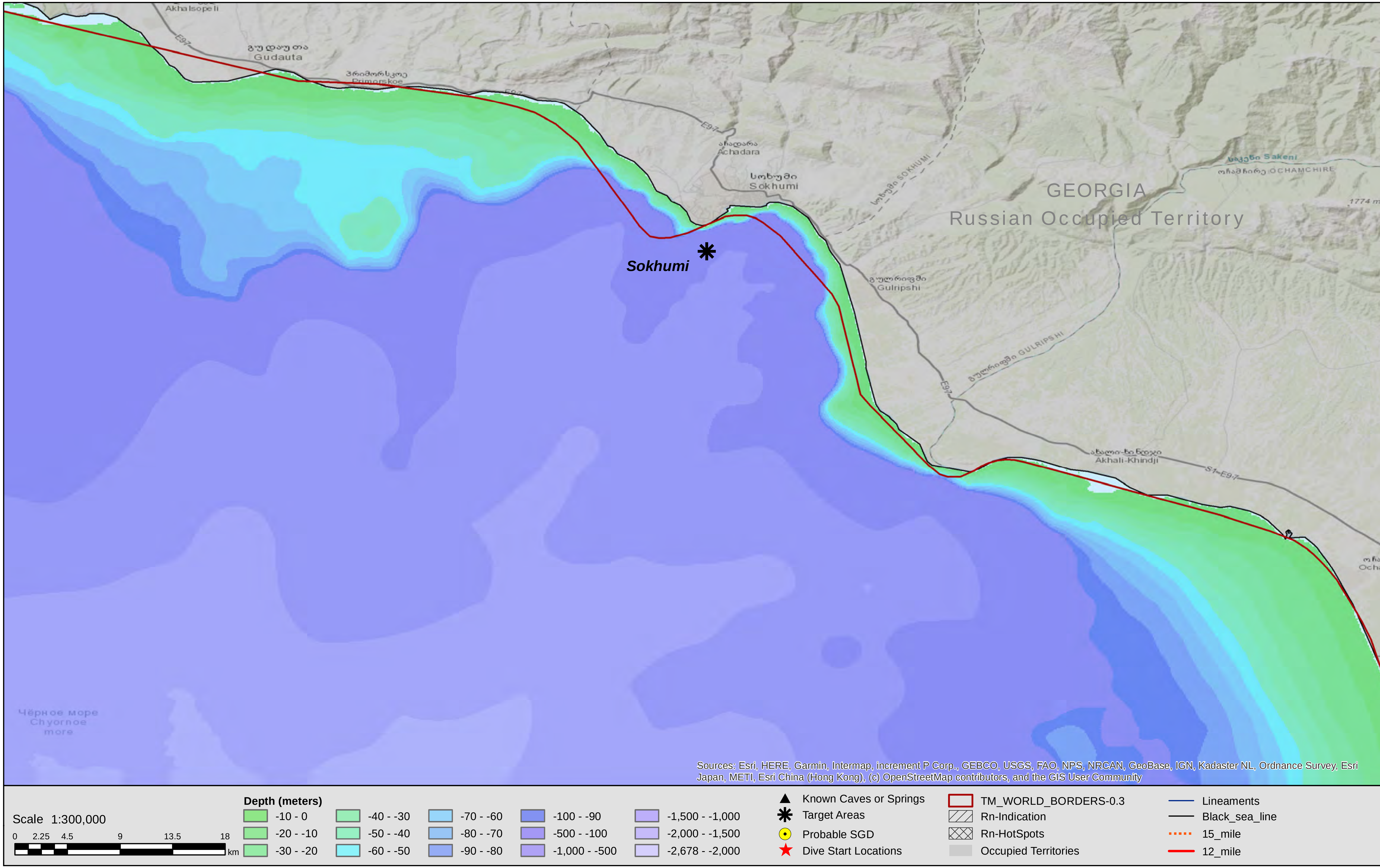
Search for Submarine Springs & Caves in the Black Sea



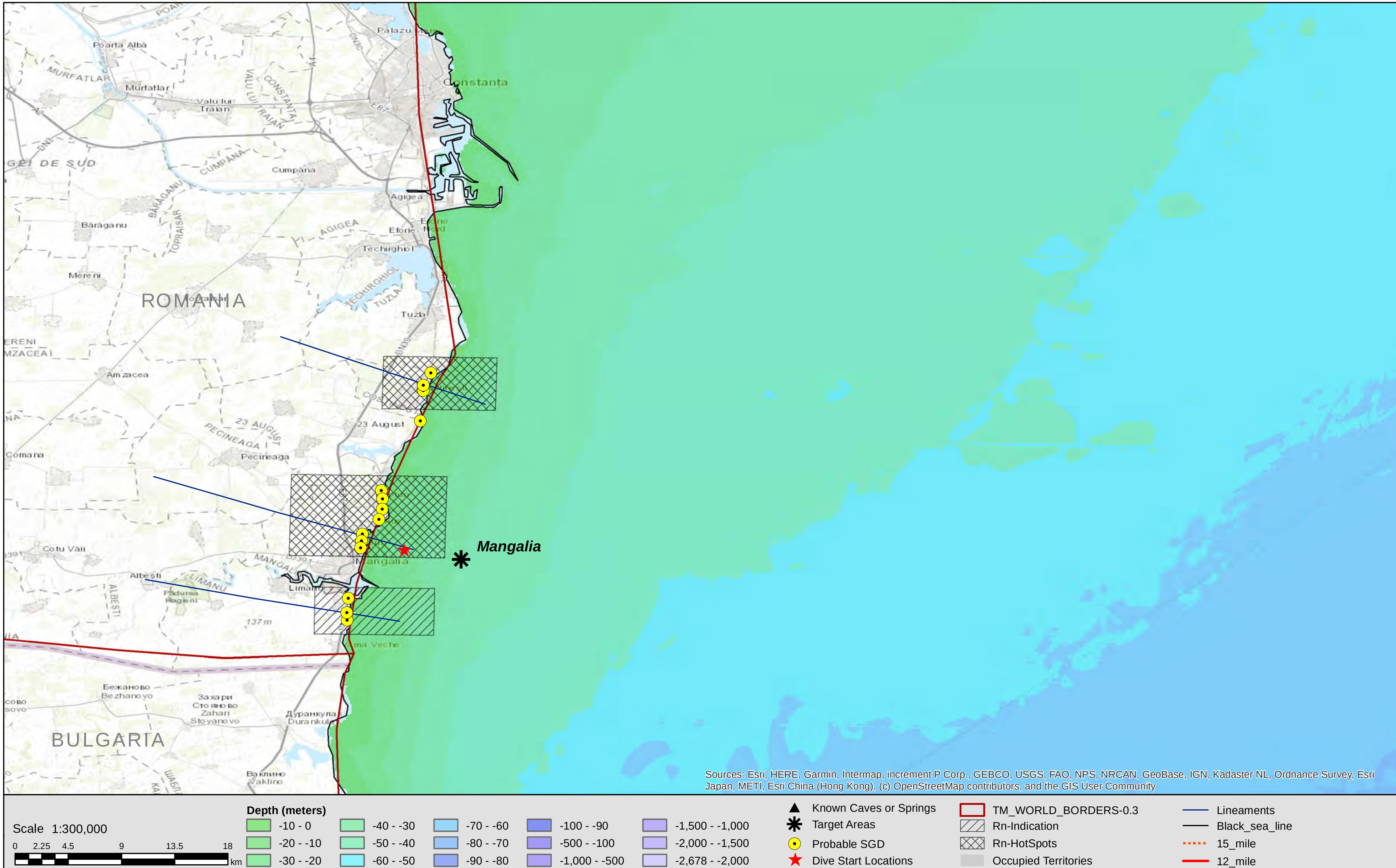
Search for Submarine Springs & Caves in the Black Sea: Kobuleti Target Area



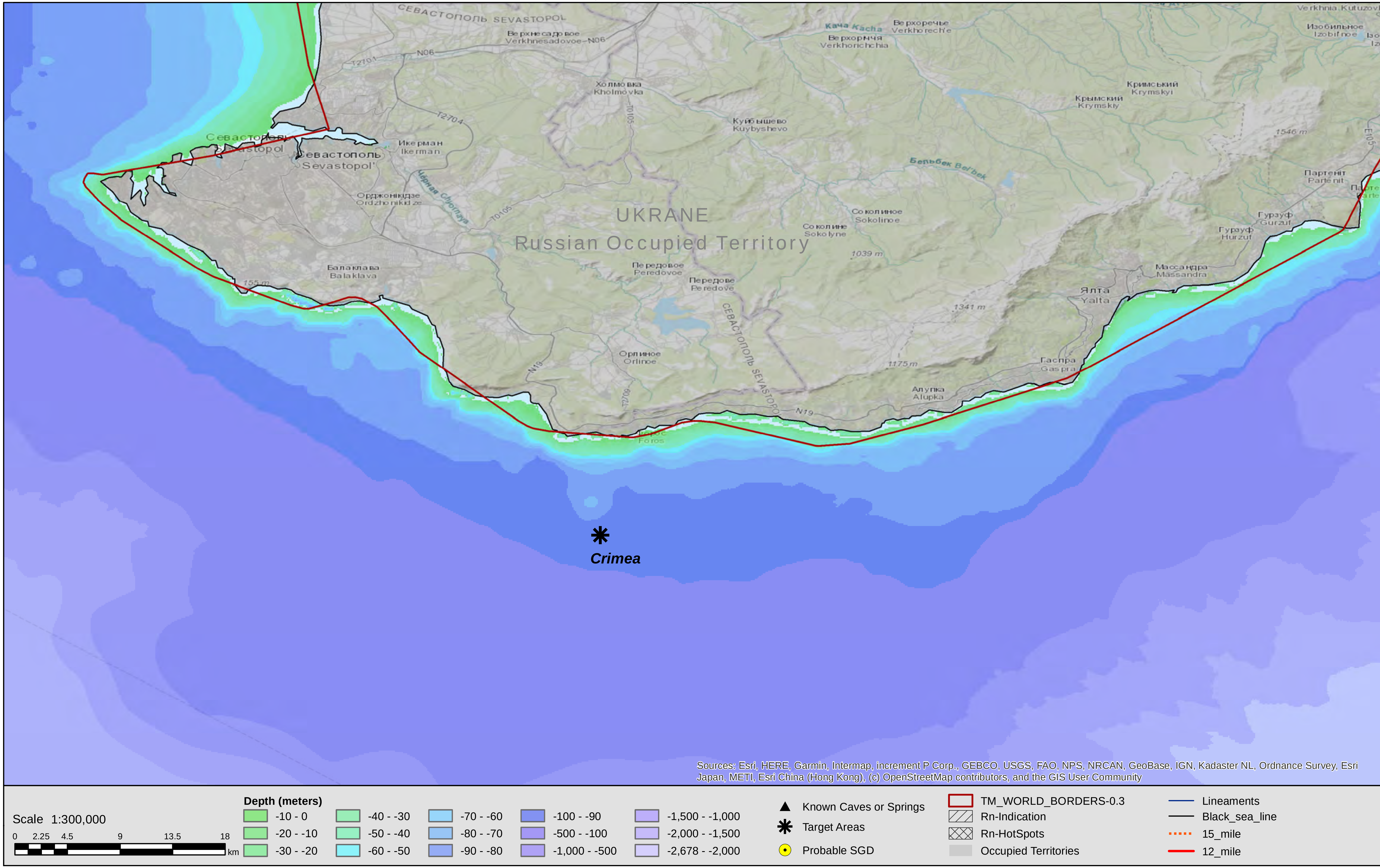
Search for Submarine Springs & Caves in the Black Sea: Sokhumi Target Area



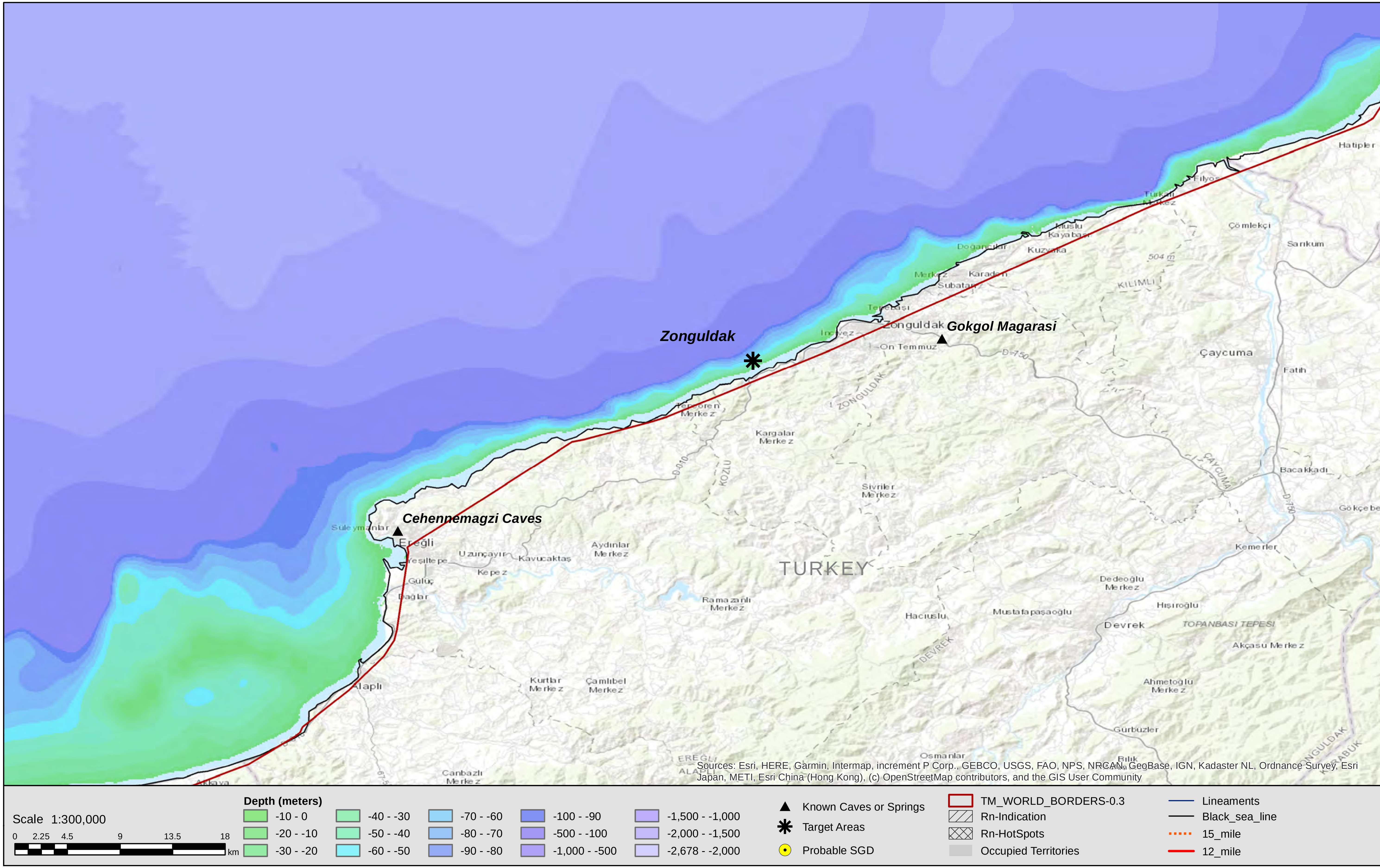
Search for Submarine Springs & Caves in the Black Sea: Mangalia Target Area



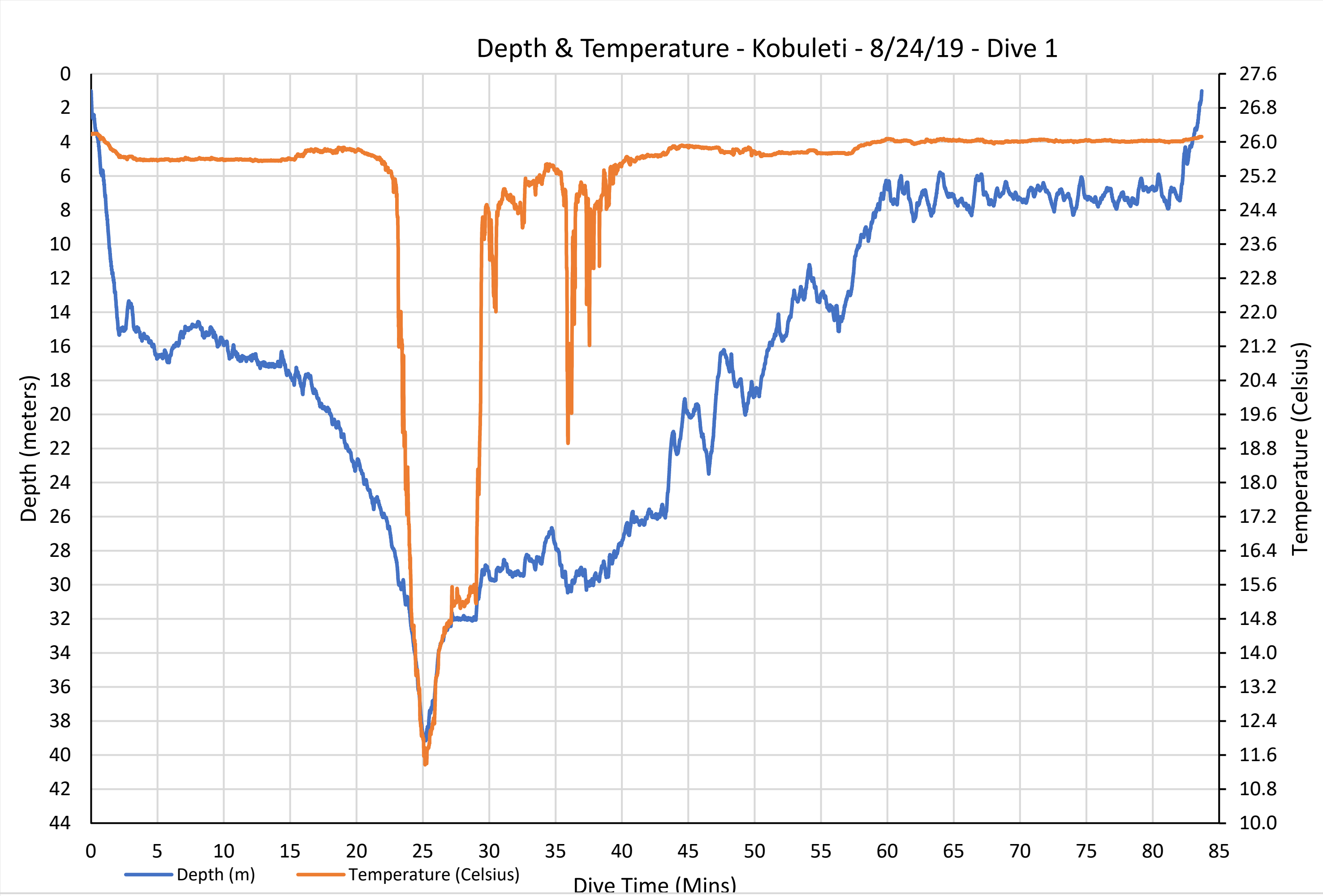
Search for Submarine Springs & Caves in the Black Sea: Crimea Target Area

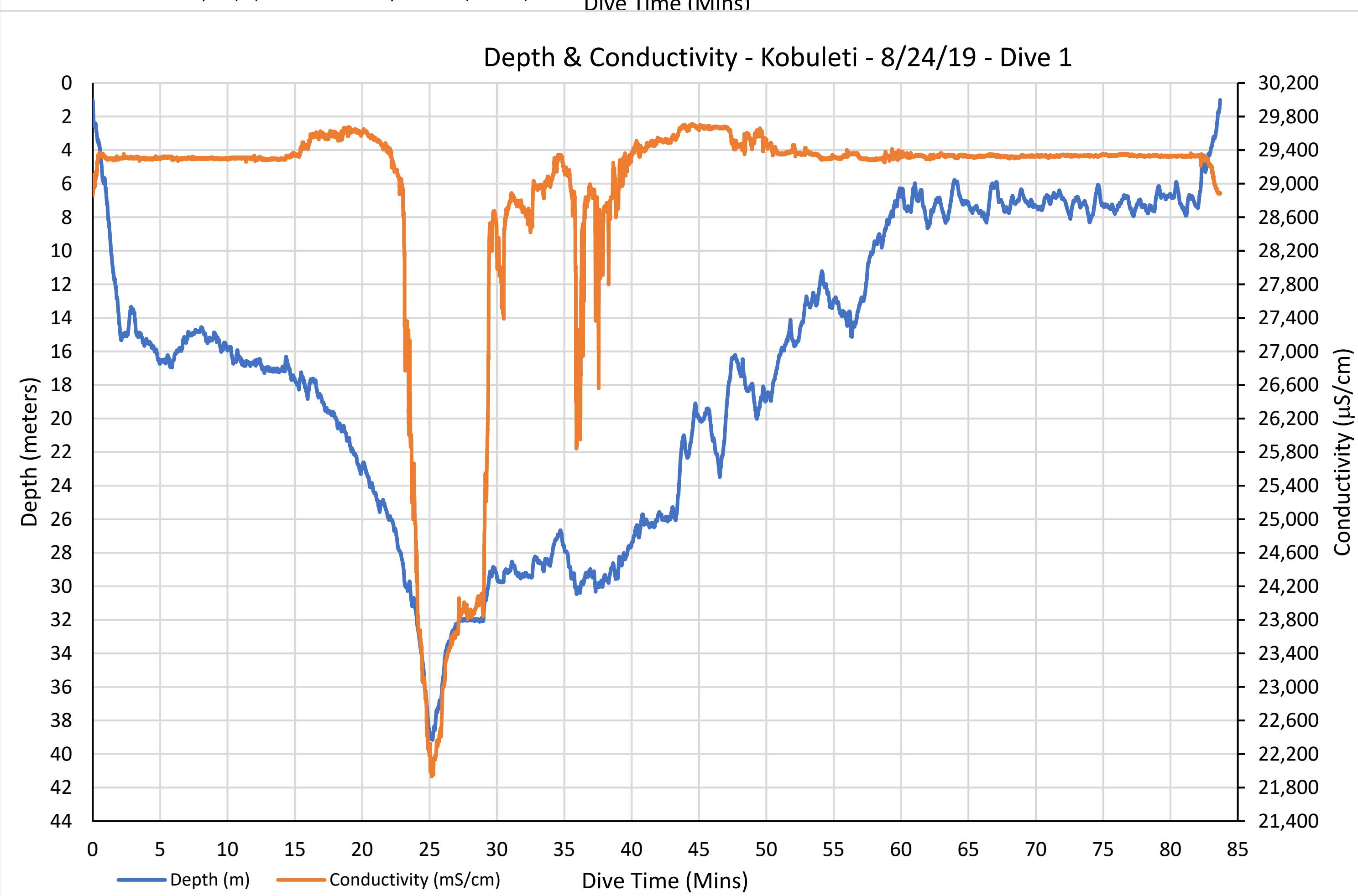


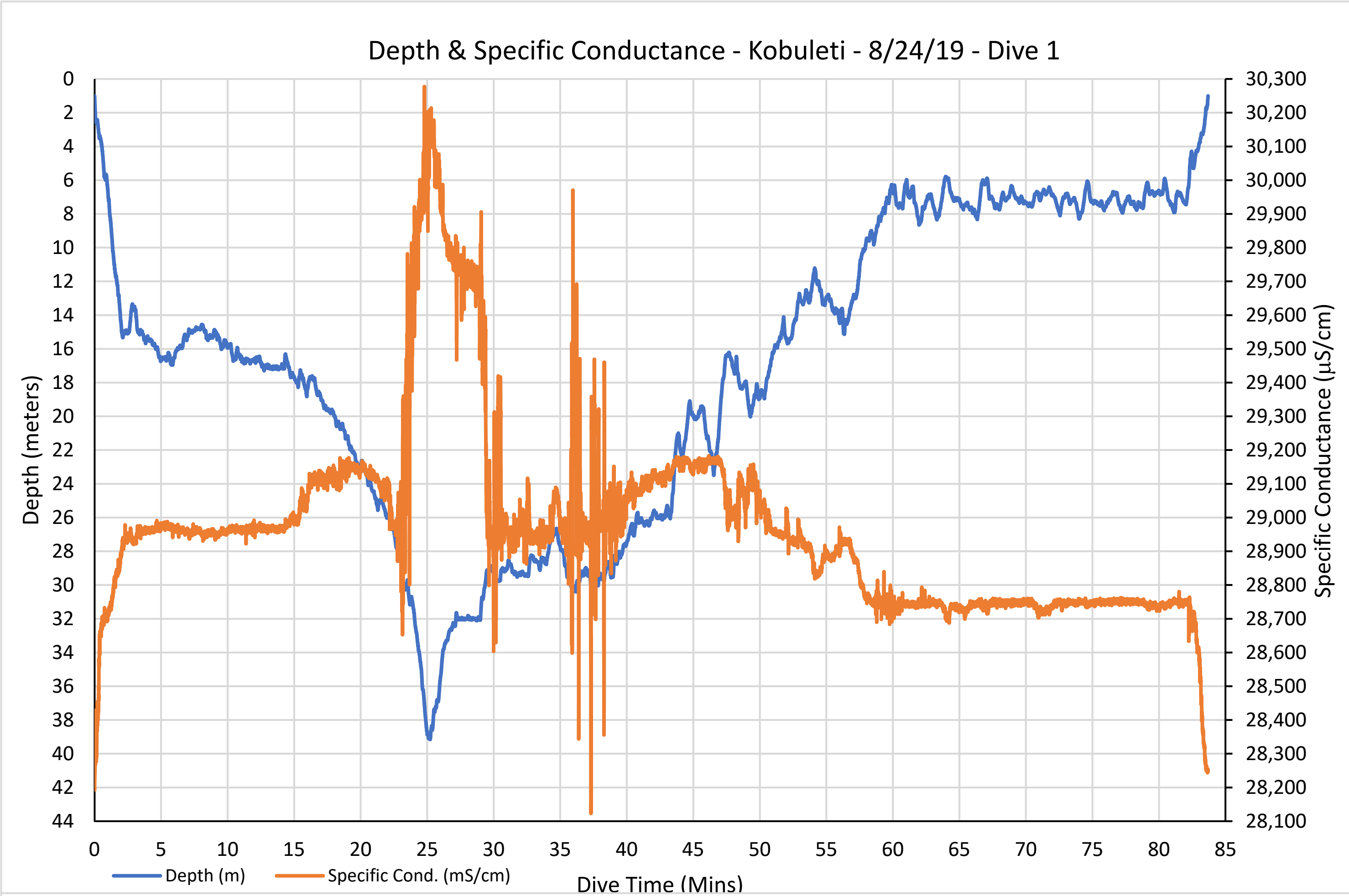
Search for Submarine Springs & Caves in the Black Sea: Zonguldak Target Area



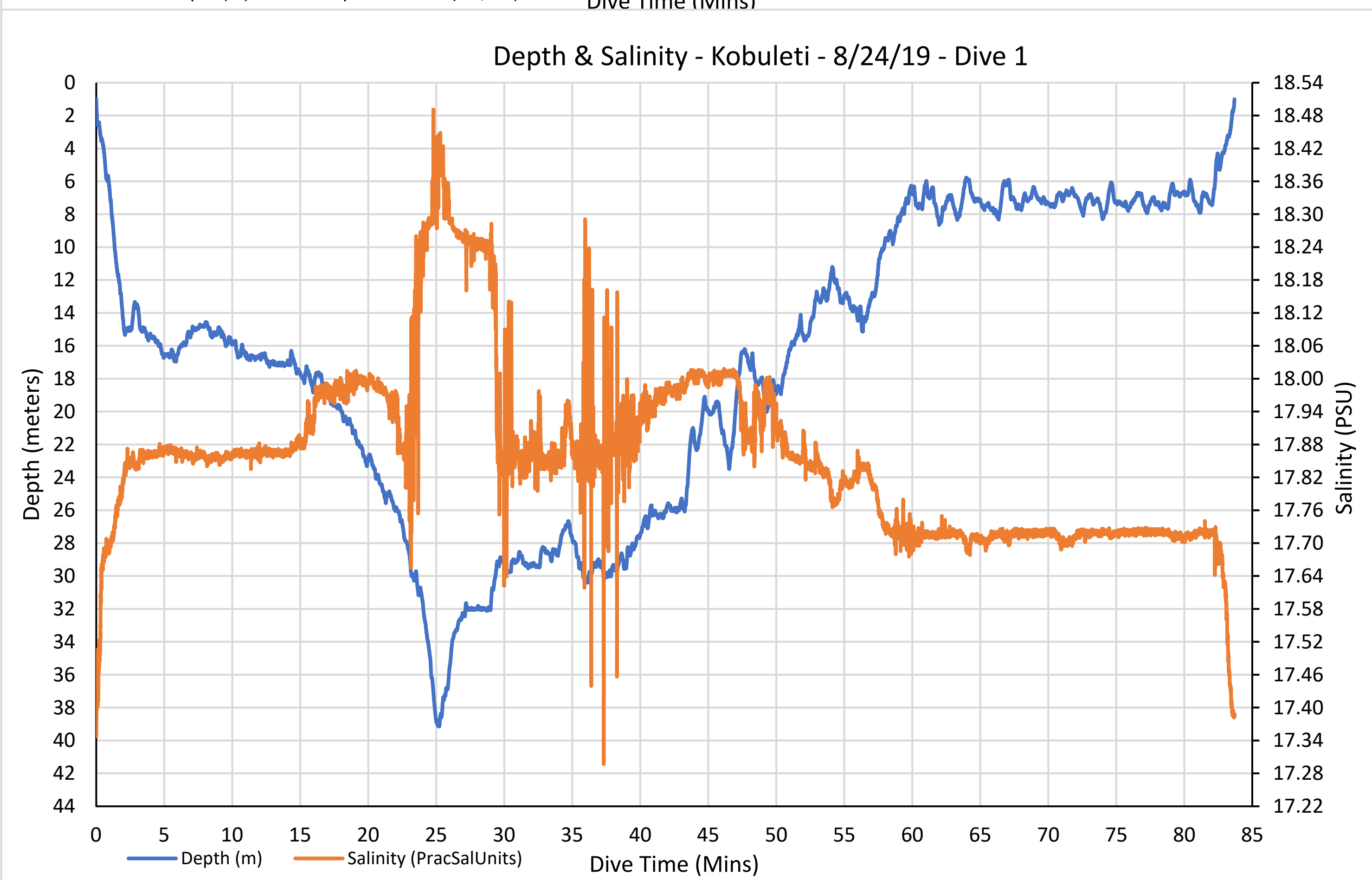
Appendix II
Dive & Parameter Profiles


Depth & Temperature - Kobuleti - 8/24/19 - Dive 1
Depth (meters)
Temperature (Celsius)
Dive Time (Mins)
Depth (m)
Temperature (Celsius)

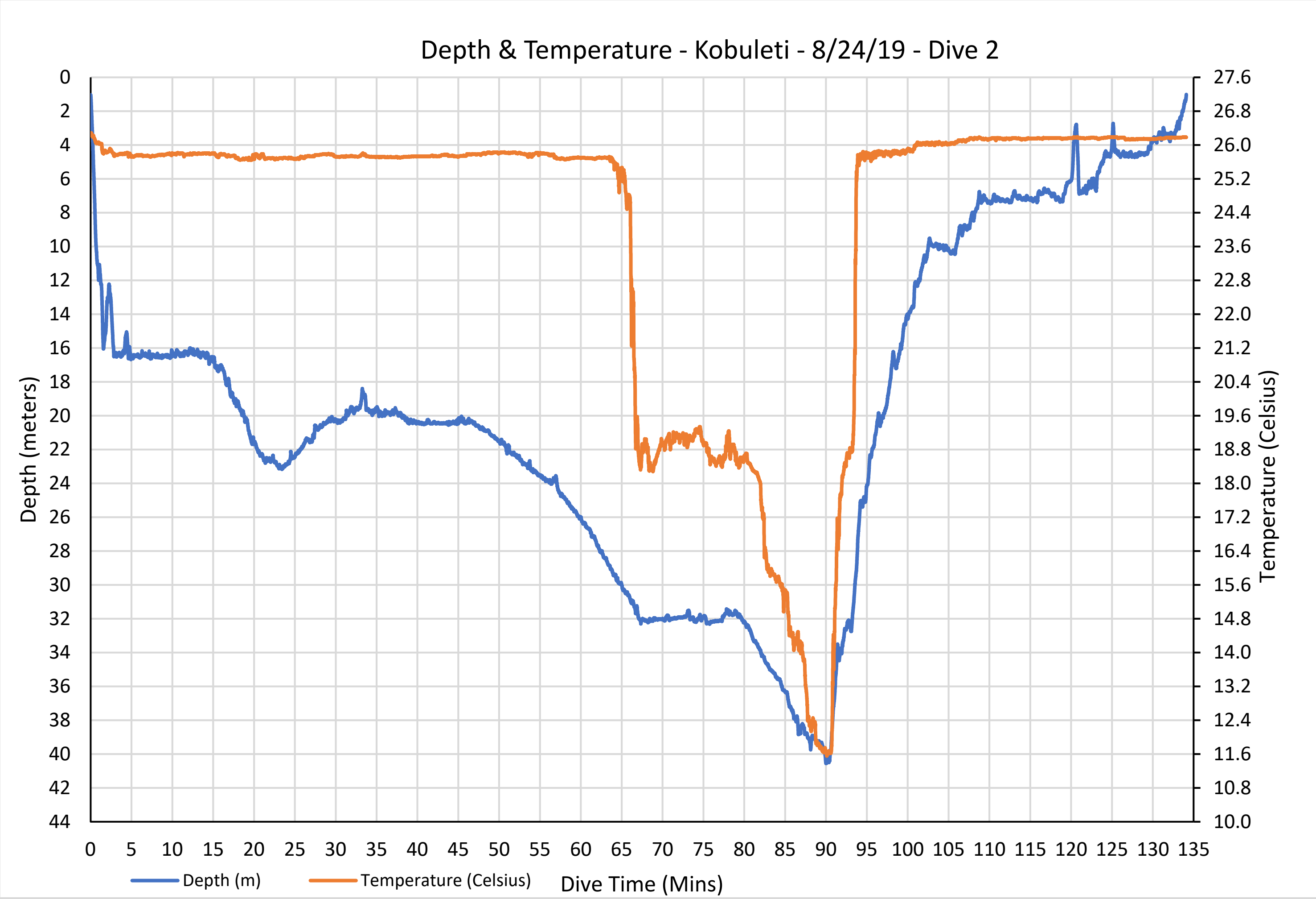

Depth & Conductivity - Kobuleti - 8/24/19 - Dive 1
Depth (meters)
Conductivity (µS/cm)
Dive Time (Mins)
Depth (m)
Conductivity (mS/cm)



Depth & Specific Conductance - Kobuleti - 8/24/19 - Dive 1
Depth (meters)
Specific Conductance (µS/cm)
Dive Time (Mins)
Depth (m)
Specific Cond. (mS/cm)



Depth & Salinity - Kobuleti - 8/24/19 - Dive 1
Depth (meters)
Salinity (PSU)
Dive Time (Mins)
Depth (m)
Salinity (PracSalUnits)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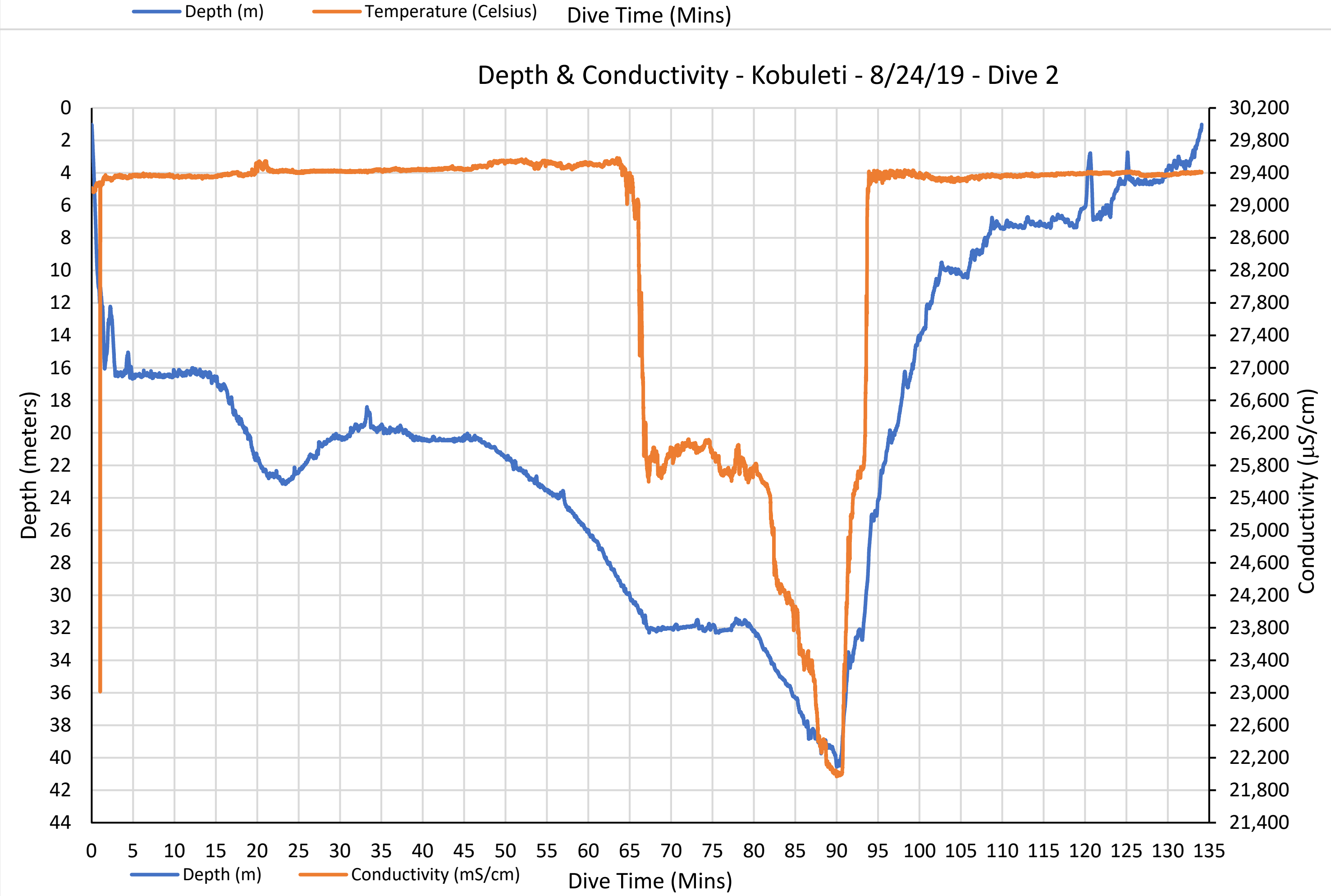
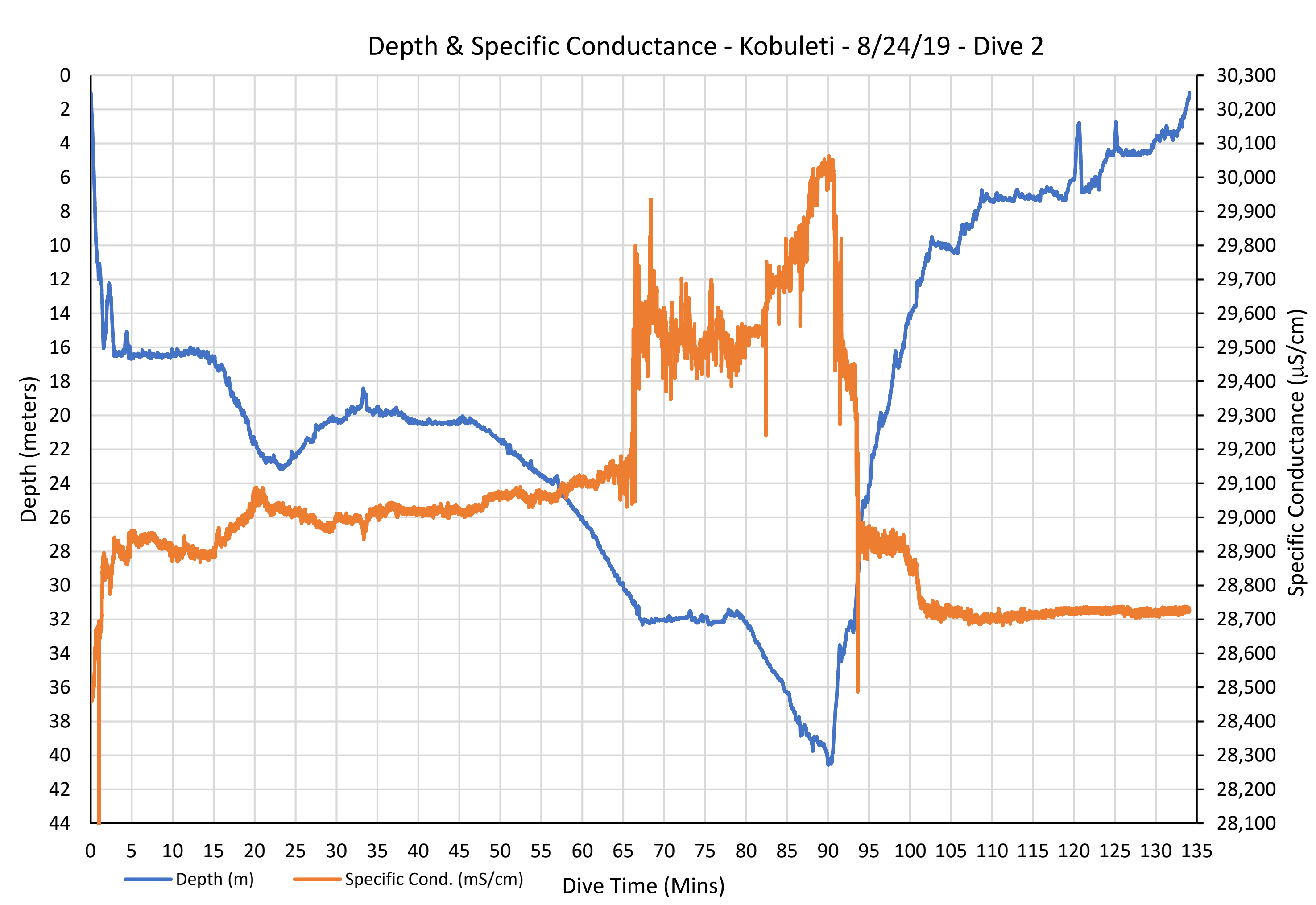
Depth (meters)
Temperature (Celsius)
Dive Time (Mins)
Depth (m)
Temperature (Celsius)


Depth & Conductivity - Kobuleti - 8/24/19 - Dive 2
Depth (meters)
Conductivity (µS/cm)
Dive Time (Mins)
Depth (m)
Conductivity (mS/cm)


Depth & Specific Conductance - Kobuleti - 8/24/19 - Dive 2
Depth (meters)
Specific Conductance (µS/cm)
Dive Time (Mins)
Depth (m)
Specific Cond. (mS/cm)
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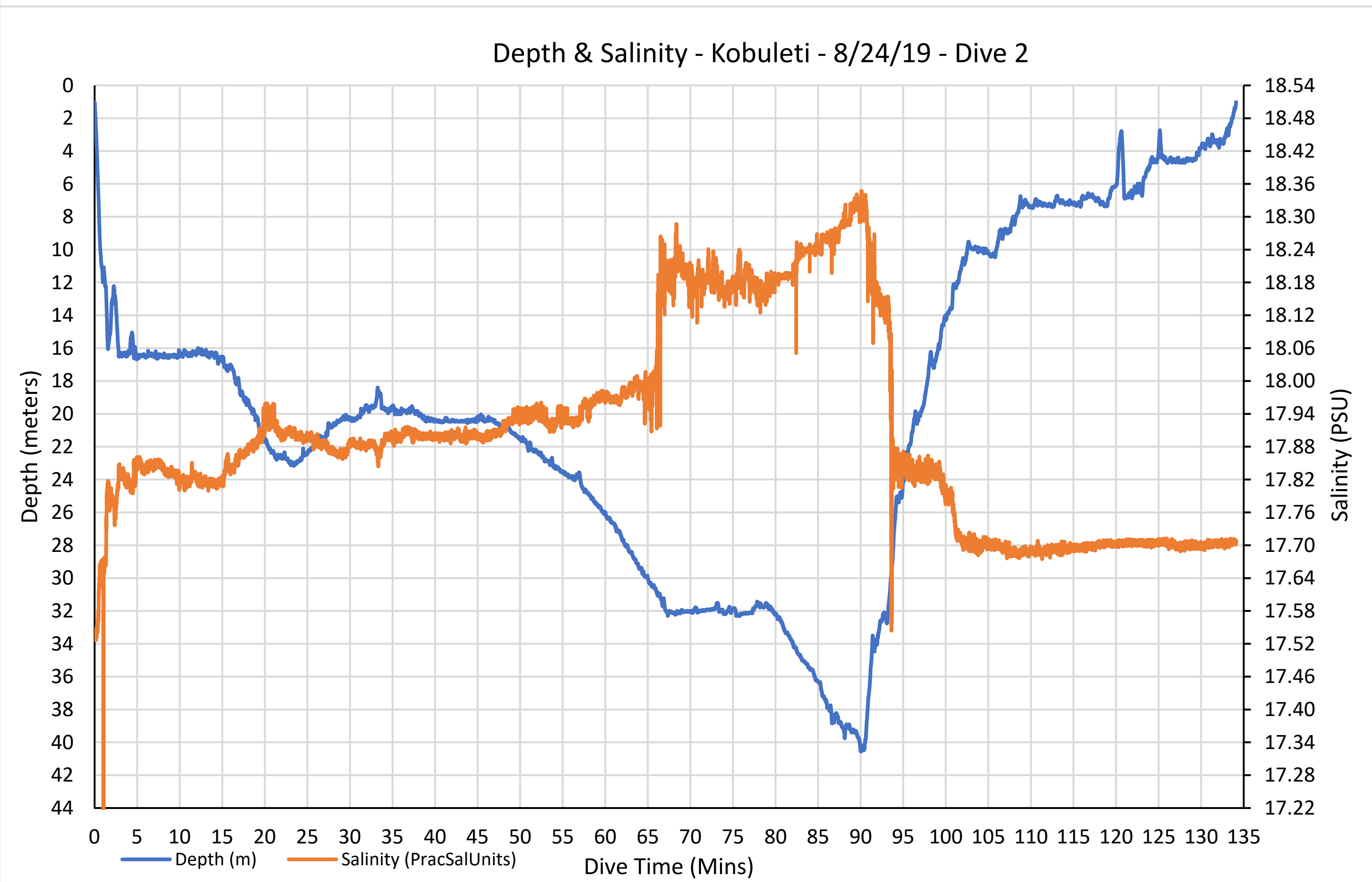
Depth & Salinity - Kobuleti - 8/24/19 - Dive 2
Depth (meters)
Salinity (PSU)
Dive Time (Mins)
Depth (m)
Salinity (PracSalUnits)
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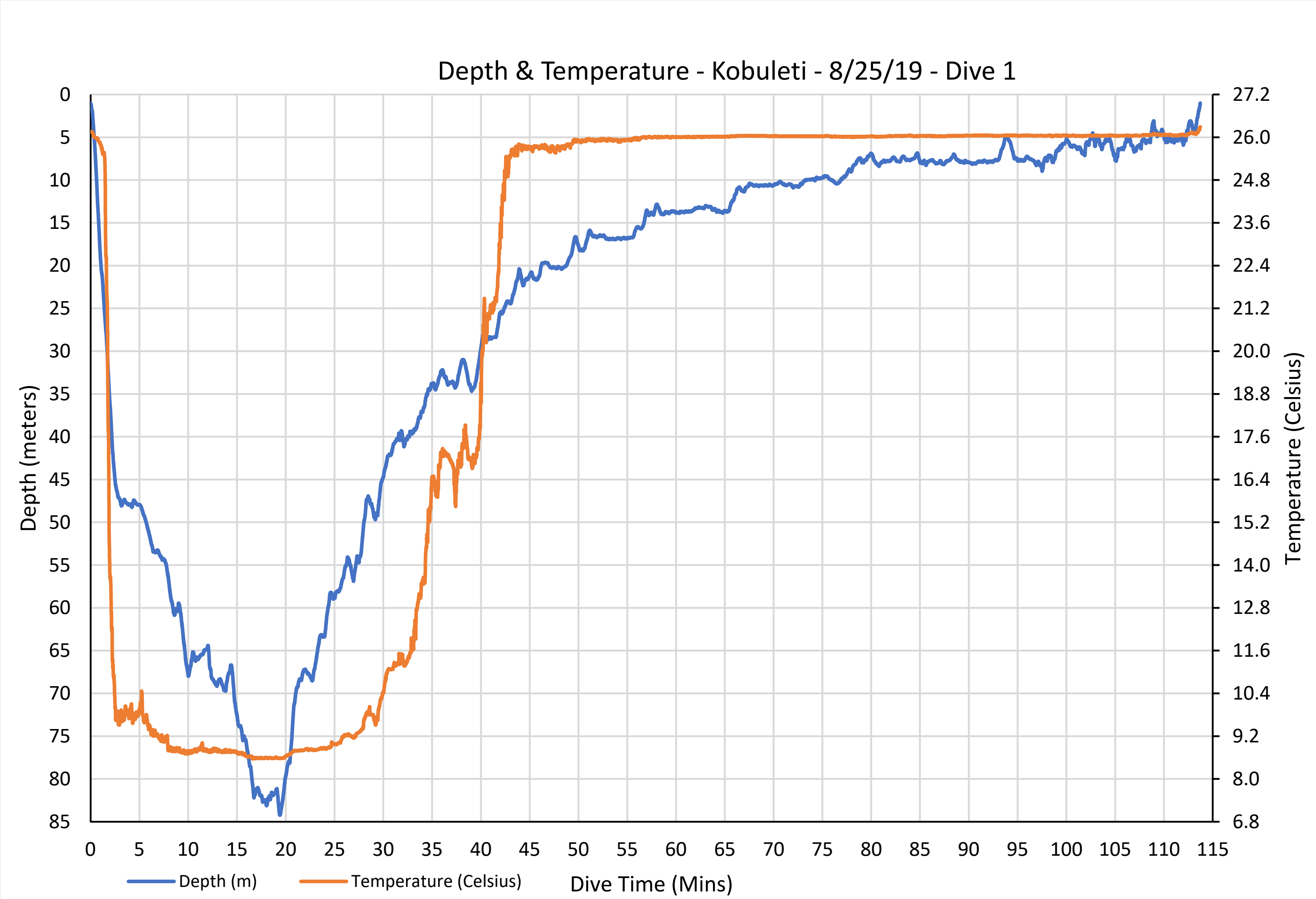
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135


Depth & Temperature - Kobuleti - 8/25/19 - Dive 1
Depth (meters)
Temperature (Celsius)
Dive Time (Mins)
Depth (m)
Temperature (Celsius)
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85
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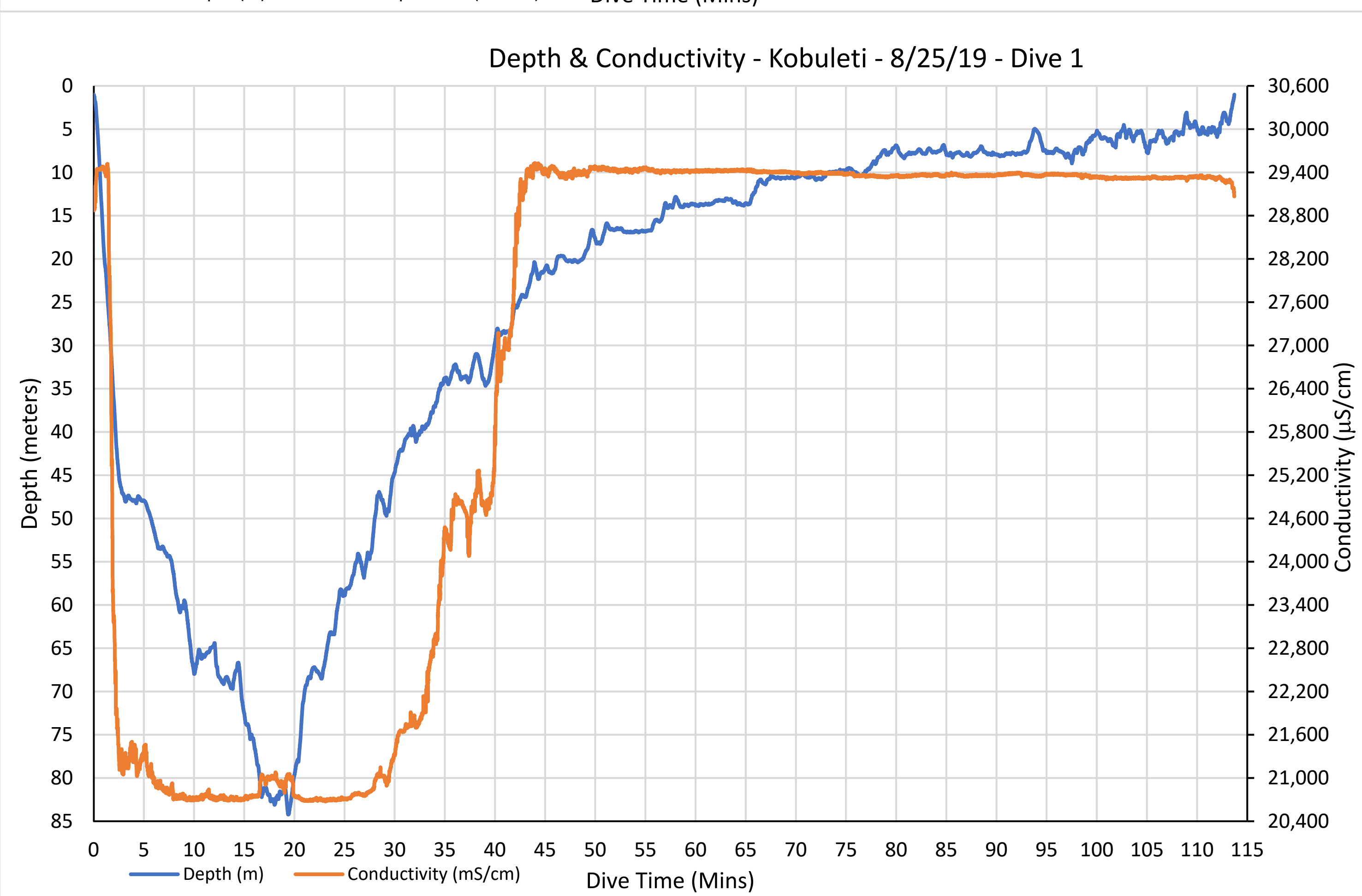
26.0
24.8
23.6
22.4
21.2
20.0
18.8
17.6
16.4
15.2
14.0
12.8
11.6
10.4
9.2
8.0
6.8
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115


Depth & Conductivity - Kobuleti - 8/25/19 - Dive 1
Depth (meters)
Conductivity (µS/cm)
Dive Time (Mins)
Depth (m)
Conductivity (mS/cm)
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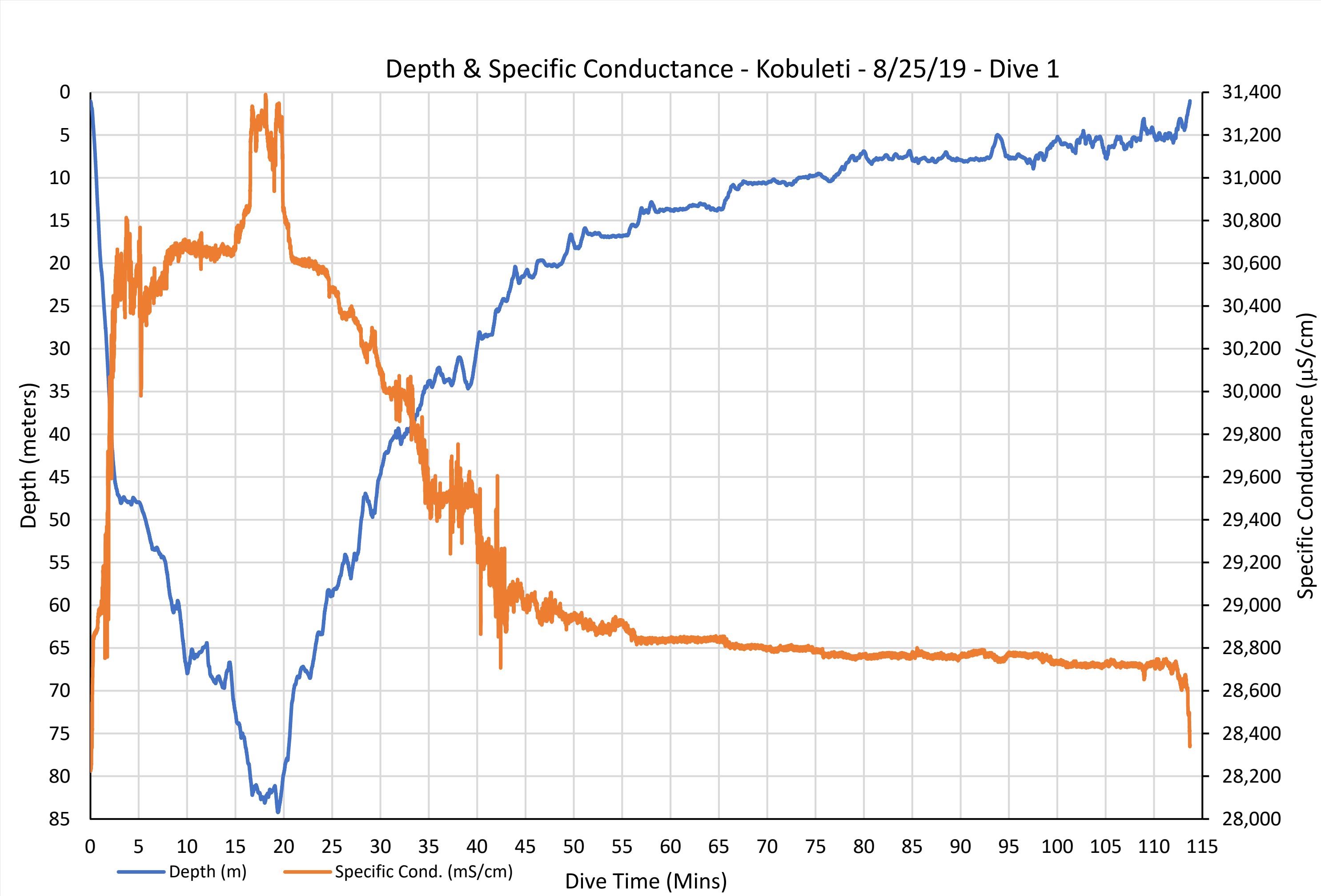
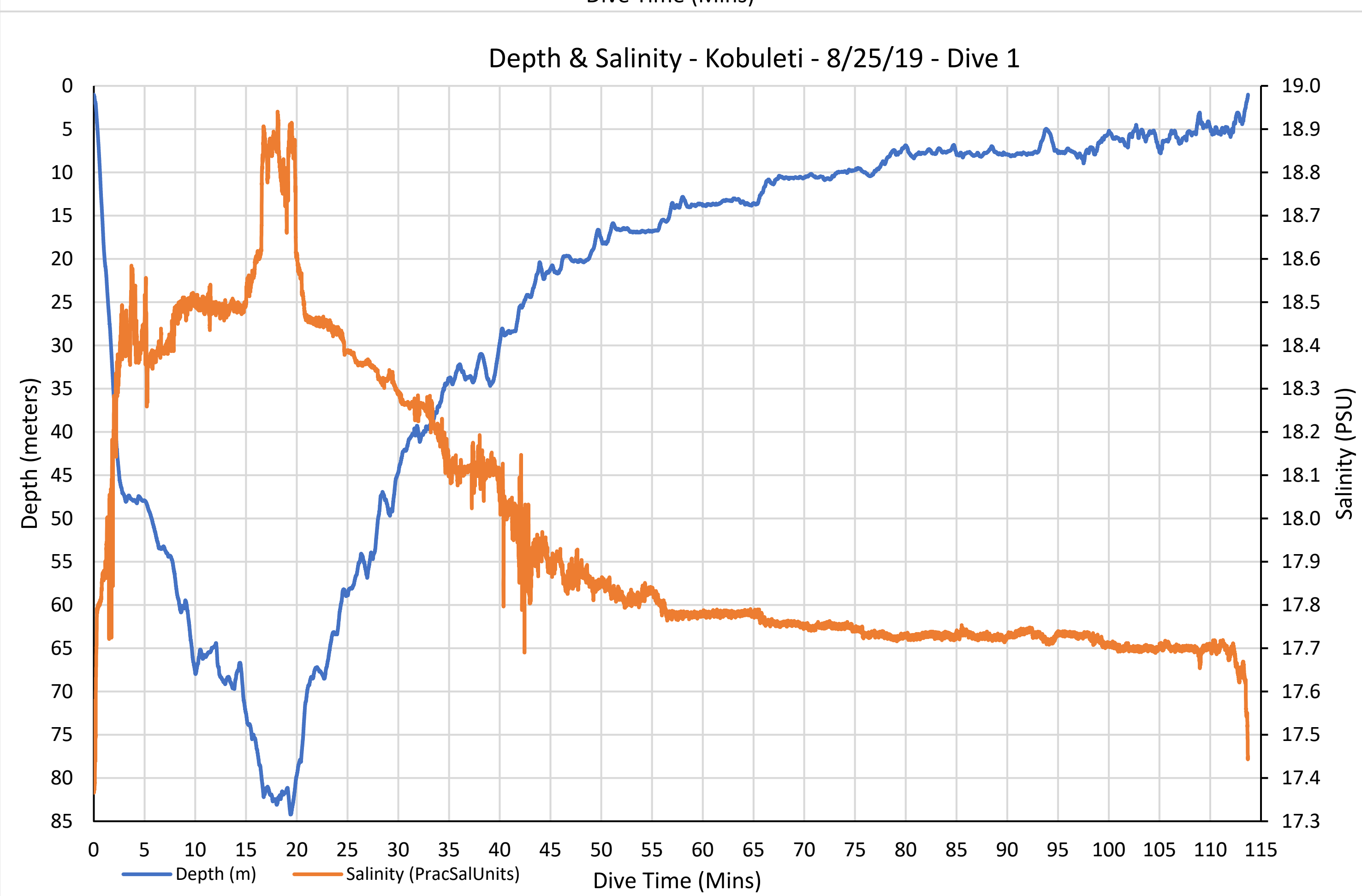
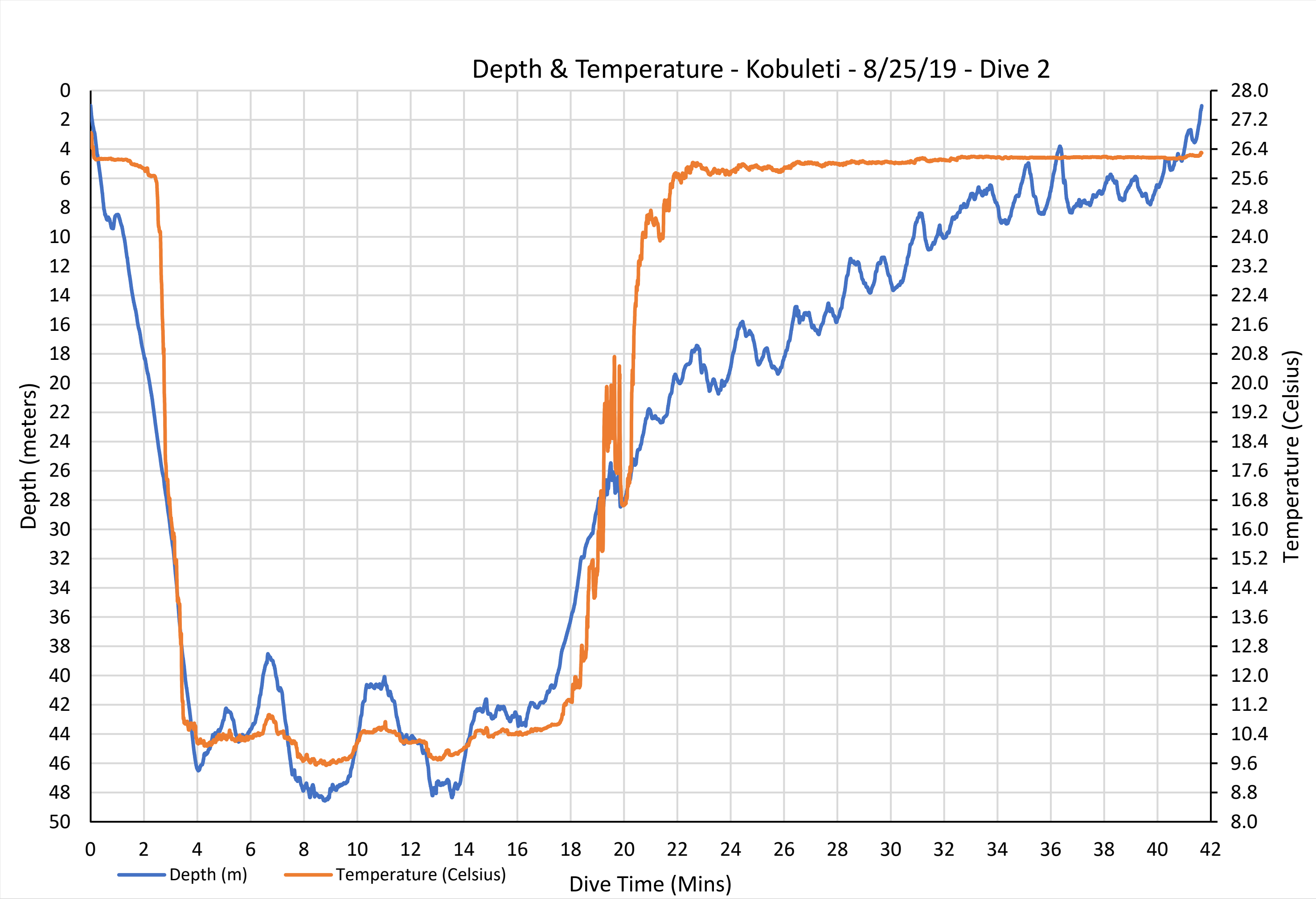

Depth & Specific Conductance - Kobuleti - 8/25/19 - Dive 1
Depth (meters)
Specific Conductance (µS/cm)
Dive Time (Mins)
Depth (m)
Specific Cond. (mS/cm)


Depth & Salinity - Kobuleti - 8/25/19 - Dive 1
Depth (meters)
Salinity (PSU)
Dive Time (Mins)
Depth (m)
Salinity (PracSalUnits)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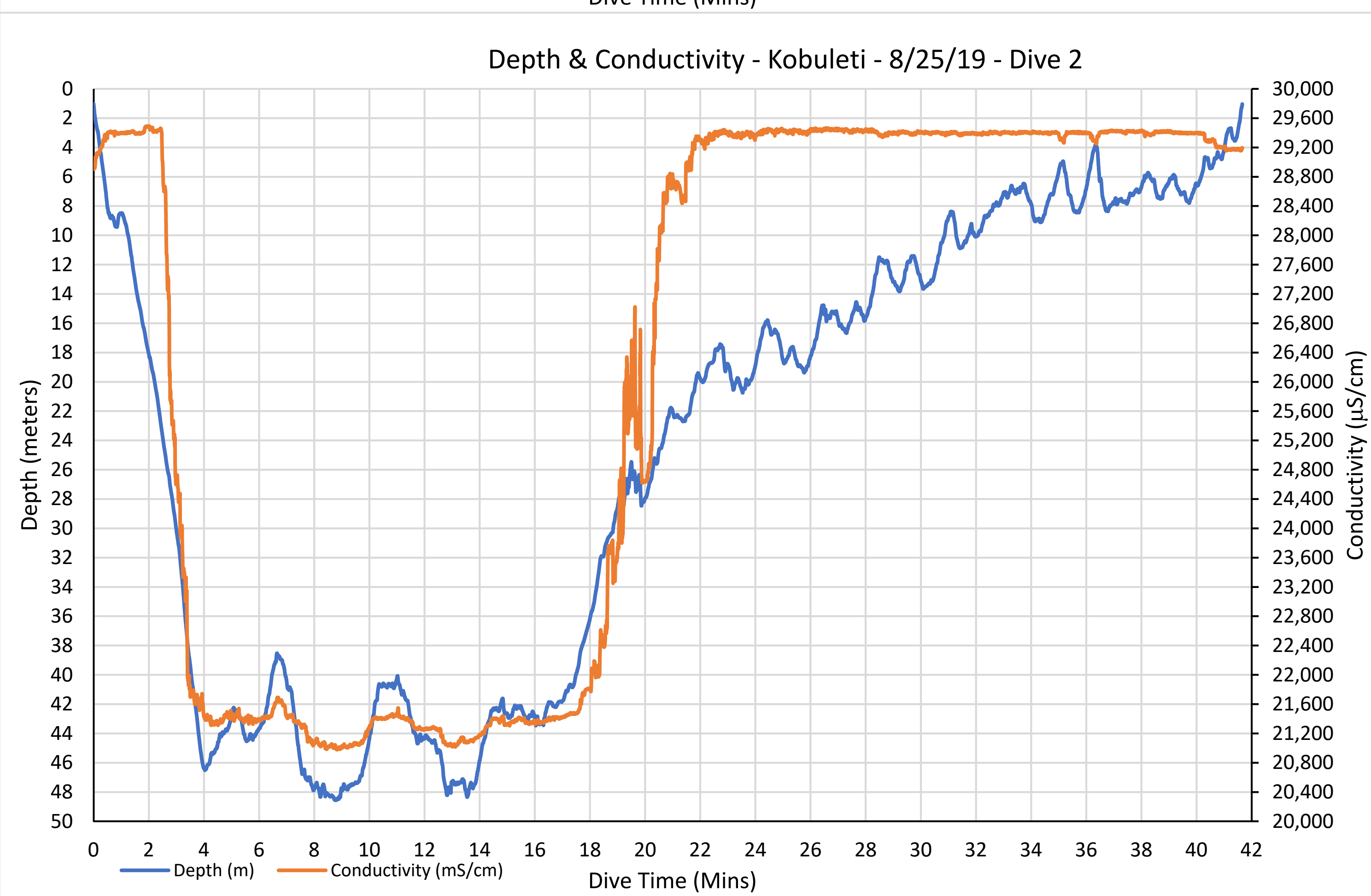
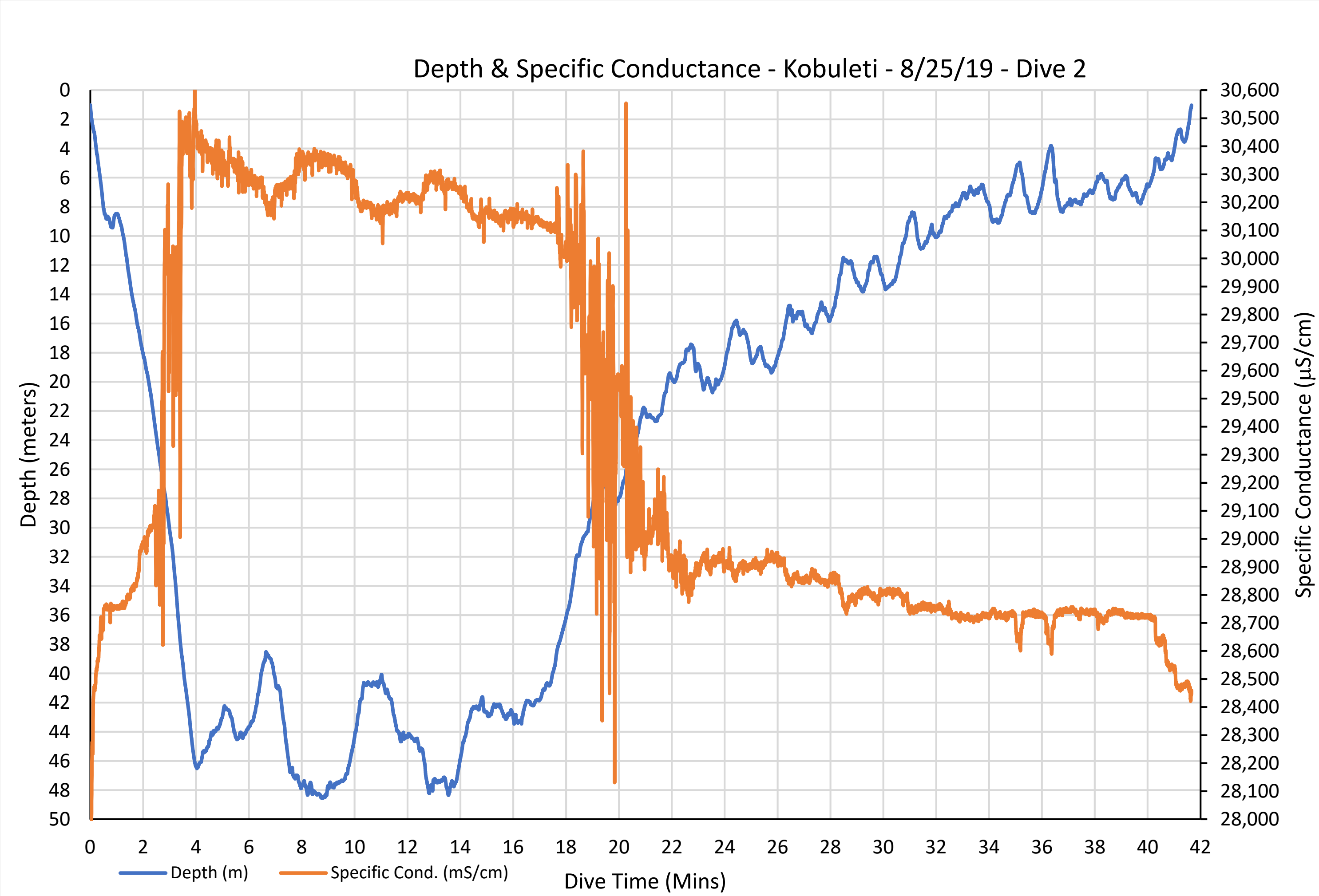
Depth (meters)
Temperature (Celsius)
Dive Time (Mins)
Depth (m)
Temperature (Celsius)


Depth & Conductivity - Kobuleti - 8/25/19 - Dive 2
Depth (meters)
Conductivity (µS/cm)
Dive Time (Mins)
Depth (m)
Conductivity (mS/cm)


Depth & Specific Conductance - Kobuleti - 8/25/19 - Dive 2
Depth (meters)
Specific Conductance (µS/cm)
Dive Time (Mins)
Depth (m)
Specific Cond. (mS/cm)
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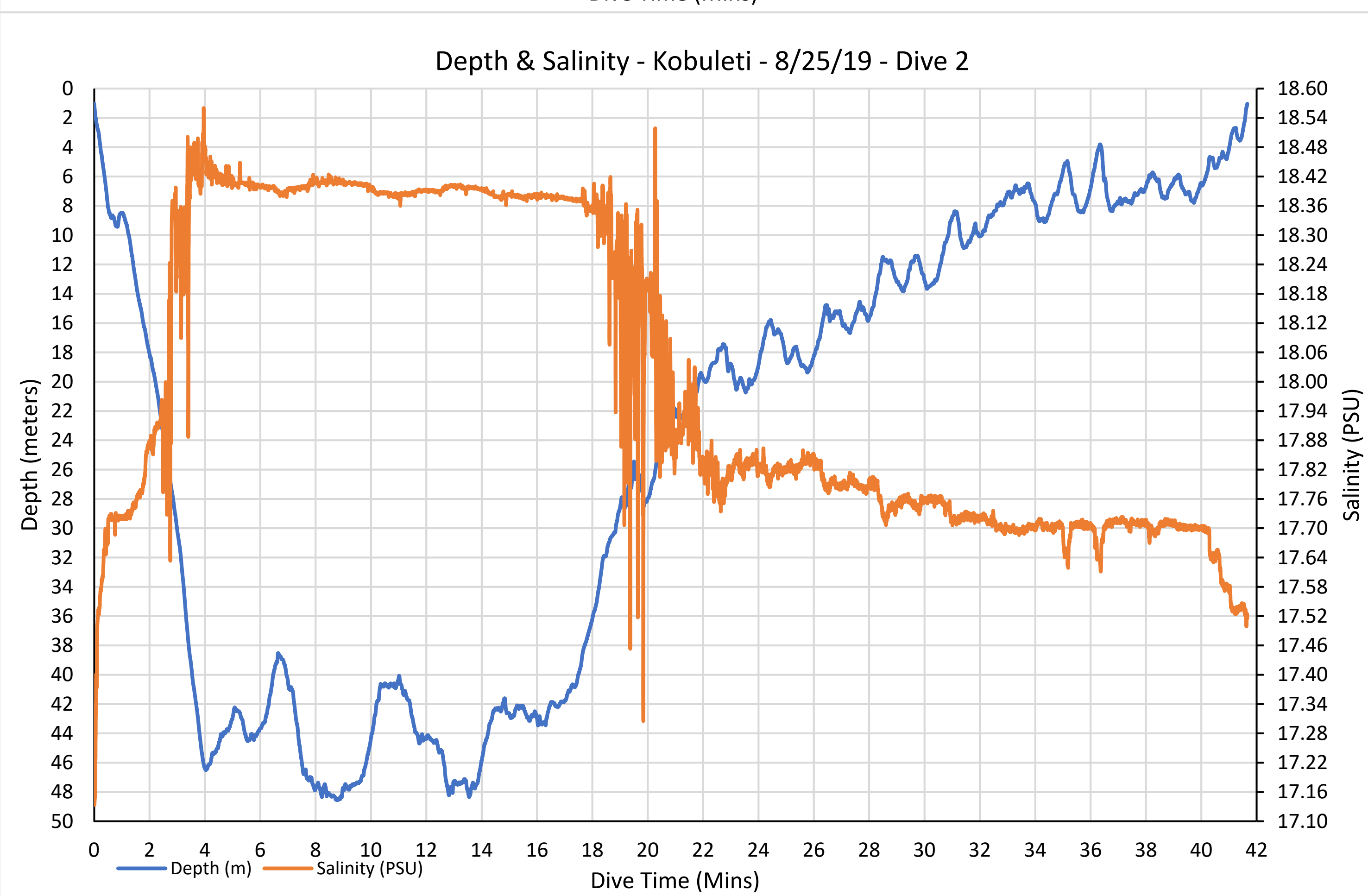
Depth & Salinity - Kobuleti - 8/25/19 - Dive 2
Depth (meters)
Salinity (PSU)
Dive Time (Mins)
Depth (m)
Salinity (PSU)
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18.12
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17.88
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