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Short Cruise Report

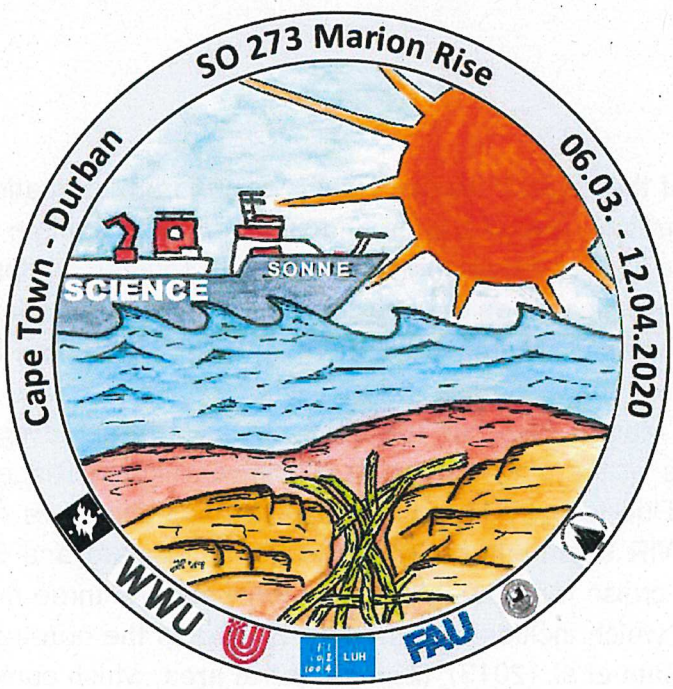
R/V Sonne – SO273

Cape Town, South Africa – Emden, Germany

7. March 2020 – 22. April 2020

Chief Scientist: Jürgen Koepke

Captain: Lutz Mallon



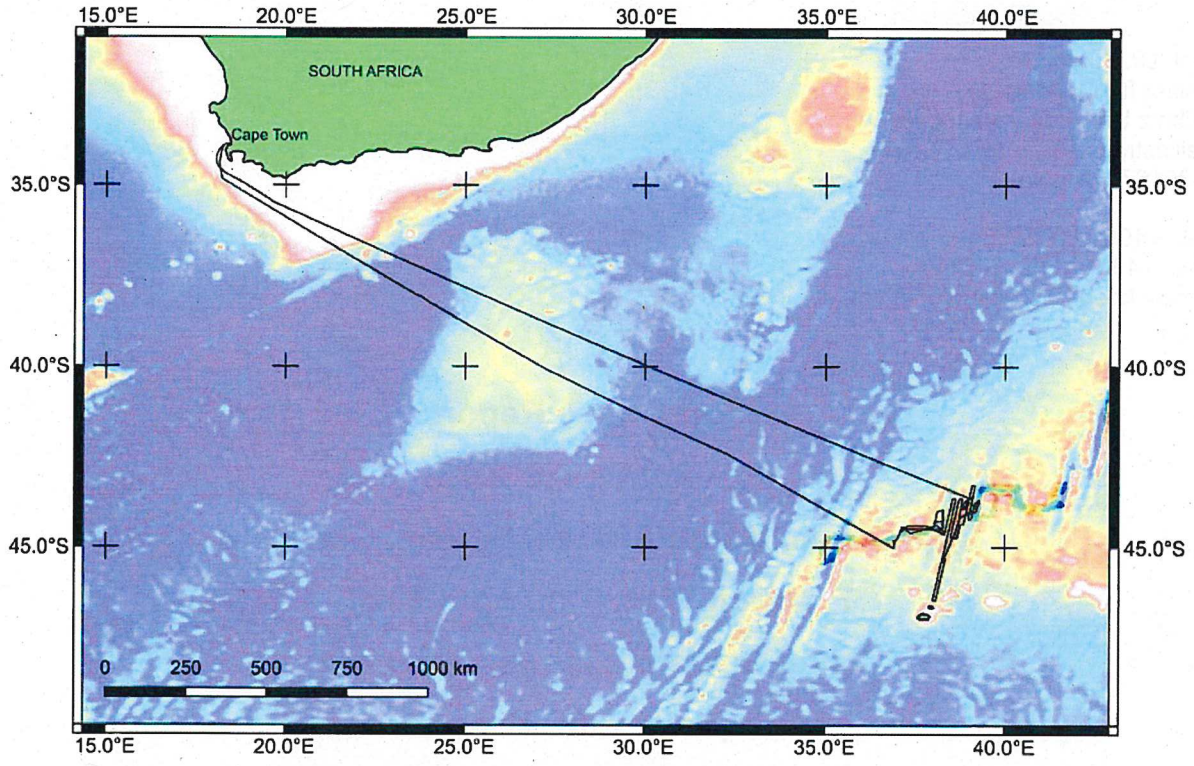


Figure 1: *Shiptrack of RV Sonne during SO273 Marion Rise.*

Objectives

The primary aim of the project "Marion Rise", which is an international program between scientists from Germany, United States and China, was to explore and sample two main working areas along the Southwest Indian Ridge in the southern Indian Ocean. The Northern working area was investigated during Leg 1 performed by our American partners with cruise TN365 with RV Thomas G. Thompson from 18.2. to 28.3.2019. The Southern working area was investigated by Leg 2, cruise SO273 with RV Sonne. The research program of expedition SO273 Marion Rise had the main objective of sampling rocks and fluids and mapping segments of the slow spreading Southwest Indian Ridge (SWIR) near Marion Island (Figure 1). Due to the early abortion of the expedition, we restricted the research program to the SWIR segments between the Prince Edward and Eric Simpson Fracture Zone. In this short cruise report we distinguish between the three main working areas: (1) the **western area**, which includes segments P2, P3 and the non-transform discontinuities (NTD) defined by Sato et al. (2013); (2) the **central area**, which consists of a magmatically robust segment between (38°E-39°E), a transect towards Marion Island, and the off-axis Mahoney seamount located North of the active spreading axis; (3) the **Nicolas-Ridge area** refers to a transpressional ridge in the Eric Simpson Fracture Zone (see Fig. 2). During and after the cruise we aim to test the following hypotheses with our working program:

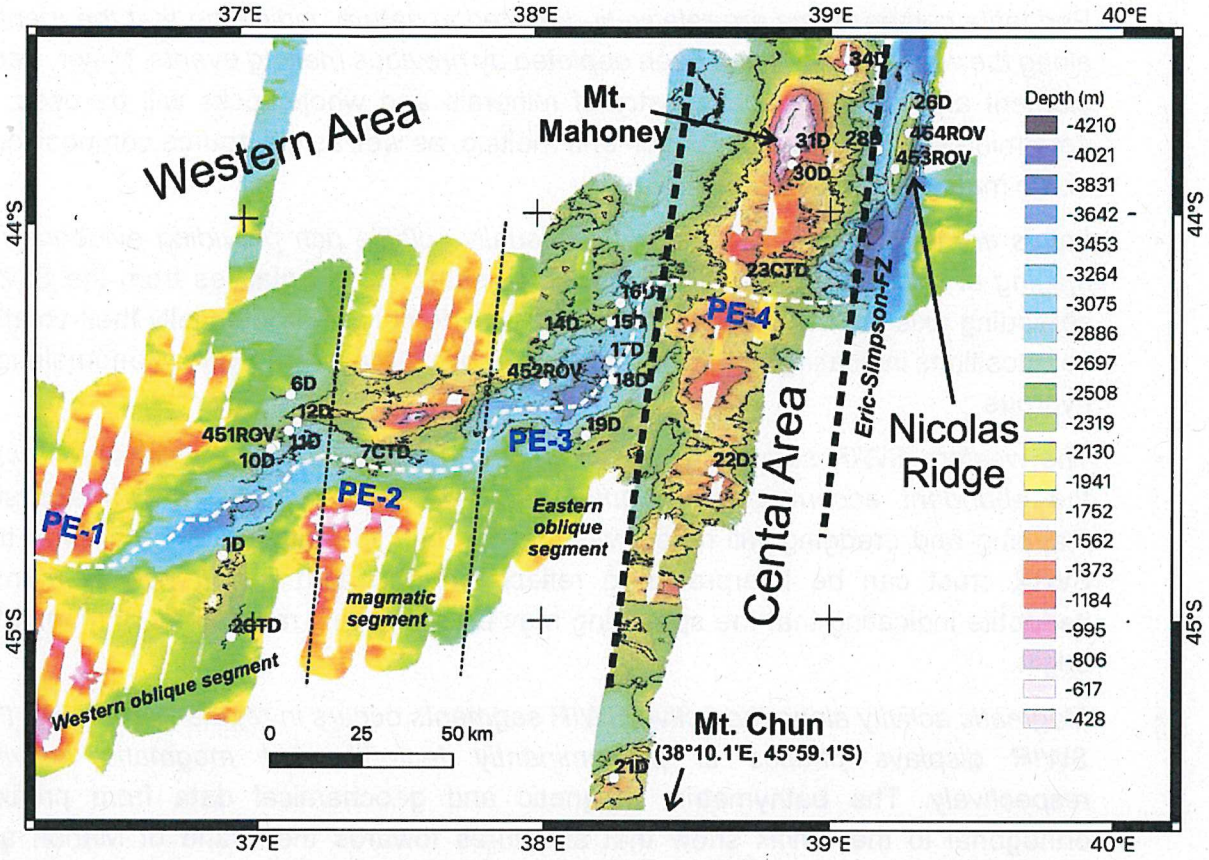


Figure 2: *Overview of the SO273 working area (combined KH-07-04 and KH-09-05 (Sato et al., 2013) and SO273 bathymetry) consisting of the western area, the central area, and the Nicolas-Ridge. The Western area is subdivided into the western oblique, the magmatic, and the eastern oblique segment. Included are also the sites of Mt. Mahoney and Mt. Chun, as well as the inferred present day spreading axis (white dashed line) as well as the segment names (in blue) according to Sato et al. (2013).*

- *The formation of the anomalously shallow Marion Rise results from melting of a heterogeneous mantle, as opposed to melting during plume-ridge interaction with a melting anomaly related to the formation of Marion Island and the surrounding seamounts*. We will use major element, trace element and Sr-Nd-Pb isotope data of the basalt and peridotite samples to determine the degree of mantle heterogeneity. The major element and trace element data will be used to determine the depths and degree of partial melting being able to differentiate between melting of hydrous, delaminated sub-continental lithospheric mantle and plume/hotspot related material.
- *Crustal thickness at Marion Rise is relatively thin, exposing mantle peridotite despite relatively shallow water depths. Asymmetric spreading exposes mantle peridotite preferentially at the inside corner high detachment fault termination.* ROV and dredge sampling along magnetically and magmatically weak segments were used to test whether these exposures consist of mantle peridotite rather than mafic lavas. The majority of exposures along the western SWIR display weak magnetic signatures, however, dredging recovered basaltic lavas.

- *Peridotite compositions are relatively depleted in nature, indicating that the mantle along the western SWIR has been depleted by previous melting events.* Major, trace element and isotope geochemistry of minerals and whole rocks will be used to determine the degrees of depletion and melting, as well as the source compositions of the mantle.
- *Lavas erupted along the SWIR are unusually volatile rich providing evidence for melting of hydrous mantle.* The whole rock samples and glasses from the SWIR spreading axis will be analysed for their trace element and potentially their volatile compositions indicating whether mantle melting in the western SWIR is anomalously hydrous.
- *The western SWIR segment displays crustal magnetic signatures consistent with the abundant occurrence of mantle peridotite.* Marine gravity, hydroacoustic mapping and dredging will reveal whether the lack of magnetic anomalies in the SWIR crust can be interpreted to reflect the abundant occurrence of mantle peridotite indicating that the spreading may be of tectonic rather than of magmatic origin.
- *Magmatic activity along the active SWIR segments occurs in regular pulses, i.e. the SWIR displays phases of predominantly tectonic and magmatic activity, respectively.* The bathymetric, magnetic and geochemical data from profiles orthogonal to the SWIR show that structures towards the island of Marion are reflecting increasing magmatic activity along the ridge.
- *The elevated bathymetry along the N-S striking Nicolas-pressure Ridge in the Eric Simpson Fracture Zone at 39°E is formed from mantle peridotite for which the mechanism of emplacement can be determined.* The sampling of structurally oriented mylonitic-peridotite samples allows to determine the strike and dip of the mantle peridotites. Geochemical investigations will reveal whether the degree of depletion for these peridotites is anonymously strong.
- *The segmentation pattern of the western SWIR (west of 39°E) is largely controlled by the oblique, asymmetric spreading along the SWIR resulting in amagmatic, tectonic and magmatically active segments, respectively.* Magnetic and high-resolution hydroacoustic data from the western SWIR segments will be used to distinguish between magmatically and tectonically active segments allowing to determine a structural model for the evolution of the western SWIR.
- *Hydrothermal activity along the SWIR is restricted to magmatically robust segments along the SWIR and occurs more frequently than previously observed.* CTD single casts, Tow-Yo's, ROV dives and MAPR deployments with the rock dredges have determined subtle temperature anomalies in the magmatically active segment of the western SWIR.
- *The newly discovered Mahoney Seamount North of the magmatically robust segment reveals young, alkaline, volatile rich volcanism.* Dredge samples recovered from this seamount are alkaline in nature. Major element, trace element and radiogenic short- and long-lived isotope geochemistry will be used to determine the

eruption ages, sources and mechanisms of melting in the off-axis environment of the western SWIR.

In general, the sampling strategy was based on the multibeam surveys of SO273 and previous cruises on a daily basis. The sampling was preferentially done by Remotely Operated Vehicle (ROV MARUM QUEST 4000) and dredging to ensure consistent and accurate sampling as well as structural and geological control of the sampling. We also successfully performed CTD casts and a Tow-Yo on the magmatically robust segment of the SWIR. During the dredge and CTD sampling we used Miniature Autonomous Plume Recorders (MAPR) devices provided by the Pacific Marine Environmental Laboratory of NOAA. These recorders of turbidity, E_H and temperature were aimed at detecting potential hydrothermal plumes in the water column.

Cruise Narrative

R/V Sonne cruise SO273 Marion Rise had been subject to several short notice changes in the scientific party due to SARS-COVID19 pandemic related travel restrictions and quarantine bans prior to departure of the vessel in Cape Town. A delegation of scientists from the University of Hannover, Westfälische Wilhems Universität Münster, Woods Hole Oceanographic Institution, MARUM, University of Wyoming and Florida State University arrived in Cape Town on the 4th of March. All scientists boarded the vessel during the morning of the 5th of March followed by the remaining scientists arriving from the GeoZentrum Nordbayern of the Friedrich-Alexander-Universität Erlangen-Nürnberg, the University of Helsinki and the government of the Republic of South Africa. Due to the late arrival of the Remotely Operated Vehicle (ROV) and scientific containers the port stay was extended by one day. During port stay on the 6th of March, the installations for the ROV QUEST 4000, magnetometer and dredges were done and the labs were prepared for operations at sea.

On Saturday the 7th of March, R/V SONNE left the port of Cape Town at 8:53 am UTC and reached the open sea 9:20 am with no wind and sea followed by wales and sea lions. Steaming through moderate swells during the 7th and 8th of March, R/V Sonne headed towards the southern working area (Figure 1) with increasing seas and winds. At noon 8th of March during the 9th and 10th of March we performed our first hydroacoustic and magnetometer survey towards the working area. Slowed down by currents we arrived in the working area during the early evening of the 11th of March. We started our sampling program 11th March 17:00 with a water column calibration CTD followed by two dredges at moderate swell and low winds. In the morning of the 12th of March, we performed the first ROV dive on the northern wall of the western segment. The ROV was recovered at 6:00 pm and a successful dredge was performed on the northern shoulder of the western segment. Early in the morning of the 13th of March we completed a long CTD cast on an hourglass segment prior to a ROV dive on the northern rift shoulder. During the evening of the 13th of March and the morning hours of the 14th of March, a hydroacoustic and magnetometer survey was performed over the dredge targets of the central segment of the western SWIR and towards three dredge sites of the northern rift shoulder along the western area. During the night from

the 14th to 15th of March we performed an additional hydroacoustic survey from the western to the central area, followed by 6 dredges during the 15th of March with winds reaching up to 9 Bft calming in the early afternoon and during the following night.

At midnight of the 16th of March we started a hydroacoustic and magnetometer survey towards Marion Island lasting until 17th of March 8:30 am followed by 2 dredges approaching the SWIR axis during the day. We performed a CTD Tow-Yo during the early morning hours of the 18th of March in the central area and performed a successful dive along the Nicolas-Ridge during the daytime of the 18th of March prior to 36 hours of hydroacoustic and magnetometer survey of the segment adjacent to Nicolas-Ridge. In the morning of the 20th of March, we performed a dredge at Nicolas-Ridge, prior to commencing an ROV dive on the northeastern fault systems of the ridge. During the evening of the 20th of March, we performed a dredge on the western wall of the Eric Simpson transform fault mapping a section west of the Mahoney seamount followed by two successful dredges at the Mahoney seamount. During the early morning, a hydroacoustic and magnetic survey targeted the area west of Mahoney seamount. An early ROV dive during the 21st of March was aborted due to technical issues and the final dredge station was placed north of the seamount.

At noon of the 21st of March the scientific program was aborted due to increasing concerns about the SARS-COVID19 pandemic onshore as well as advice from the US foreign affairs to US citizens to return to the US as soon as possible. While no cases were determined onboard, psychological concerns were raised forcing R/V Sonne to head to the bay of Cape Town arriving in at 6 am on the 26th of March, disembarking the South African observer. R/V Sonne then transferred to the harbour of Emden in Germany and arrived at April, 22th, around midday.

Acknowledgments

We gratefully acknowledge the help of the Foreign Office in Berlin, the German Embassy in Pretoria, the Petroleum Agency SA, and the Leitstelle Deutsche Forschungsschiffe in Hamburg in achieving the research permission, scheduling the cruise and advising and helping during the arrangements for the return of all scientific crew members on-shore. The cruise was financed by the Bundesministerium für Bildung und Forschung (BMBF). We thank Captain Lutz Mallon and his crew for their help in carrying out a successful cruise and for the pleasant and professional atmosphere on RV Sonne during challenging and difficult times. We acknowledge the help and support of the captain and crew of SO273 also during the ROV, dredge and CTD operations.

Participants

Name	Discipline	Institution
Prof. Dr. Koepke, Jürgen	Chief Scientist, Petrology	UHAN
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Klose, Marie	Petrology	UHAN
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Moreno, Pilar-Valsera	Petrology/Geochemistry	WWU
Waag, Milena	Petrology/Geochemistry	WWU
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Zeh, Alexandra	Petrology	GZN, FAU
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Dr. Klein, Frieder	Metamorphic geology	WHOI
Codillo, Emmanuel	Metamorphic geology	WHOI
Dr. Zhou, Ziang	Petrology	WHOI
Dr. Wölki, Dominic	Geochemistry	NHMFL
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Klar, Steffen	ROV	MARUM
Schröder, Marcel	ROV	MARUM
Tibebu, Abraham	ROV	MARUM
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Reuter, Michael	ROV	MARUM
Schade, Tobias	ROV	MARUM
Mufanadzo, Thomas	Observer	RSA

UHAN	Institute for Mineralogy, Leibniz University Hannover, Germany
UH	Department of Geosciences and Geography, University of Helsinki, Helsinki, Finland
WWU	Institut für Mineralogie, Westfälische Wilhelms-Universität Münster, Germany
UB	Petrologie der Ozeankruste, Universität Bremen, Bremen, Germany
MARUM	Zentrum für Marine Umweltwissenschaften, Bremen, Germany
FU	Freie Universität zu Berlin, Berlin, Germany
GZN, FAU	GeoZentrum Nordbayern, Friedrich-Alexander Universität Erlangen-Nürnberg, Erlangen, Germany
WHOI	Woods Hole Oceanographic Institution, Woods Hole, MA, USA

NHMFL	National High Magnetic Field Laboratory and Department of Earth, Ocean and Atmospheric Sciences, Florida State University, Tallahassee, Florida, Magnetic Fields Laboratory
WYMO	University of Wyoming, Wyoming, USA
UMode	University of Modena, Modena, Italy
RSA	Republic of South Africa

Figure 3: *Scientific Party of ship expedition SO273*

References

Sato, T., et al. (2013). Magmatic activities on the Southwest Indian Ridge between 35°E and 40°E, the closest segment to the Marion hotspot. Geochemistry, Geophysics, Geosystems 14, 5286-5307. doi:10.1002/2013GC004814

Station list of cruise SO273 Marion Rise. ROV = Remotely Operated Vehicle Marum Quest 4000, MAG = combined data from EM 122 and magnetometer

Station	ROV-station (Marum)	Date (UTC)	Start (UTC)	Start (Position)	Water depth [m]	Ende (UTC)	End Position	Water depth [m]	Waterdepth On Bottom [m]	On Bottom		Waterdepth Off Bottom [m]	Off Bottom		Sample time Off Bottom (UTC)	comments	Size/number of samples
				Latitude (°S) / Longitude (°W)			Latitude (°S) / Longitude (°W)			Latitude (°S)	Longitude (°W)		Latitude (°S)	Longitude (°W)			
001_MAG		08.03.2020	12:08	36° 59.474' S	021° 52.031' E	3467	16:31	44° 59.520' S	036° 51.367' E	3229							
002_CTD		11.03.2020	16:58	45° 01.991' S	036° 55.389' E	2511	20:37	45° 01.801' S	036° 55.404' E	2511						Water sampling	
003_DREDGE		11.03.2020	22:08	44° 49.474' S	036° 54.036' E	2241	01:06	44° 49.751' S	036° 53.997' E	2194	2261.21	44° 49.501' S	036° 53.997' E	2194	44° 49.763' S	036° 53.999' E	00:10		49.8 kg/ 36 samples
004_DREDGE		12.03.2020	01:50	44° 48.882' S	036° 58.529' E	2637	04:31	44° 48.907' S	036° 58.772' E	2598								Empty	0
005_ROV	451	12.03.2020	06:49	44° 33.712' S	037° 06.483' E		17:51	44° 33.567' S	037° 05.379' E										15.6 Kg/ 8 samples
006_DREDGE		12.03.2020	18:51	44° 28.320' S	037° 08.677' E	2561	21:42	44° 25.519' S	037° 08.876' E	2338	2630.22	44° 46.900' S	036° 58.504' E	2335	44° 25.920' S	037° 08.881' E	20:40		172.2 Kg/ 83 samples
007_CTD		12.03.2020	23:07	44° 36.350' S	037° 23.013' E	2748	01:33	44° 36.419' S	037° 22.978' E	2727									
008_ROV	452	13.03.2020	06:00	44° 25.074' S	038° 01.168' E		16:14	44° 24.369' S	038° 01.250' E										12.2 Kg/ 7 samples
009_MAG		13.03.2020	18:22	44° 24.231' S	038° 01.229' E	2969	04:49	44° 32.214' S	037° 07.102' E	2479									
010_DREDGE		14.03.2020	05:13	44° 34.229' S	037° 04.414' E	2697	08:08	44° 33.966' S	037° 04.405' E	2496	2689.9	44° 34.241' S	037° 04.436' E	2494	44° 33.965' S	037° 04.412' E	07:12	Empty	0
011_DREDGE		14.03.2020	09:50	44° 31.502' S	037° 08.182' E	2737	14:49	44° 31.391' S	037° 08.252' E	2721	2735.72	44° 31.408' S	037° 08.272' E	2710	44° 31.354' S	037° 08.243' E	13:44		31.3 Kg/ 28 samples
012_DREDGE		14.03.2020	15:43	44° 28.165' S	037° 11.846' E	2319	18:27	44° 28.887' S	037° 11.853' E	2040	2368.06	44° 28.139' S	037° 11.835' E	2040	44° 28.868' S	037° 11.859' E	17:37		54.8 Kg/ 16 samples
013_MAG		14.03.2020	18:47	44° 26.179' S	037° 14.854' E	1965	22:52	44° 28.420' S	038° 11.205' E	3377									
014_DREDGE		15.03.2020	00:52	44° 17.957' S	038° 01.199' E	2494	04:24	44° 17.761' S	038° 01.249' E	2189	2485.76	44° 17.954' S	038° 01.191' E	2196	44° 17.755' S	038° 01.264' E	03:32		26.2 Kg/ 9 samples
015_DREDGE		15.03.2020	06:00	44° 16.097' S	038° 15.199' E	2606	09:17	44° 15.932' S	038° 15.132' E		2602.33	44° 16.102' S	038° 15.196' E	2545	44° 15.919' S	038° 15.127' E	07:23		15.2 Kg/ 13 samples
016_DREDGE		15.03.2020	09:56	44° 13.156' S	038° 16.826' E	2769	12:00	44° 13.477' S	038° 16.974' E	2342	2748.56	44° 13.168' S	038° 16.812' E	2341	44° 13.477' S	038° 16.971' E	11:06		107.5 Kg/ 65 samples
017_DREDGE		15.03.2020	13:12	44° 21.970' S	038° 14.631' E	3348	16:16	44° 21.669' S	038° 14.798' E	3215	3379.77	44° 21.976' S	038° 14.834' E	3215	44° 21.660' S	038° 14.789' E	15:04	Empty	0
018_DREDGE		15.03.2020	17:16	44° 24.859' S	038° 15.352' E	3246	20:32	44° 25.207' S	038° 15.325' E	3187	3262.23	44° 24.884' S	038° 15.314' E	3187	44° 25.258' S	038° 15.332' E	19:22	Empty	0
019_DREDGE		16.03.2020	21:27	44° 32.630' S	038° 09.781' E	2504	02:32	44° 32.972' S	038° 09.667' E	2341	2603.1	44° 32.645' S	038° 09.667' E	2343	44° 32.962' S	038° 09.663' E	23:34		49.3 Kg/ 54 samples
020_MAG		16.03.2020	00:50	44° 33.039' S	038° 09.353' E	2418	07:38	45° 18.745' S	036° 19.642' E	2170									
021_DREDGE		17.03.2020	06:25	45° 23.228' S	038° 14.991' E	1651	10:50	45° 23.341' S	038° 14.972' E	1467	1661.79	45° 23.260' S	038° 14.944' E	1501	45° 23.343' S	038° 14.053' E	10:01		19.4 Kg/ 8 samples
022_DREDGE		17.03.2020	15:07	44° 38.182' S	038° 35.832' E	1546	18:43	44° 38.173' S	038° 35.666' E	1554	1592.14	44° 38.137' S	038° 35.876' E					Dredge stuck, empty	0
023_CTD		17.03.2020	21:40	44° 09.753' S	036° 43.159' E	1906	03:02	44° 11.953' S	036° 42.445' E	1884								Tow-Yo	
024_ROV	453	18.03.2020	06:50	43° 53.658' S	039° 12.871' E	2557	17:13	43° 53.634' S	039° 13.497' E										47.3 Kg/ 26 samples
025_MAG		19.03.2020	17:30	43° 53.374' S	039° 13.459' E	2117	01:38	43° 45.704' S	039° 09.809' E	3133									
026_DREDGE		20.03.2020	02:19	43° 45.517' S	039° 17.163' E	2302	04:54	43° 45.486' S	039° 16.966' E	2261	2335.72	43° 45.593' S	039° 17.224' E	2257	43° 45.484' S	039° 16.964' E	04:00		3.9 Kg/ 3 samples
027_ROV	454	20.03.2020	05:30	43° 48.511' S	039° 16.186' E		13:43	43° 48.391' S	039° 16.081' E	2187									22.7 Kg/ 15 samples
028_DREDGE		20.03.2020	14:24	43° 50.949' S	039° 09.812' E	3117	17:27	43° 50.836' S	039° 09.445' E	2952	3113	43° 50.937' S	039° 09.855' E	2950	43° 50.841' S	039° 09.437' E	16:19	Empty	0
029_MAG		20.03.2020	17:31	43° 50.772' S	039° 09.402' E	2927	20:00	43° 54.195' S	038° 53.955' E	1596									
030_DREDGE		20.03.2020	20:27	43° 53.295' S	038° 52.278' E	1216	22:20	43° 52.956' S	038° 52.095' E	913	1196.69	43° 53.250' S	038° 52.287' E	912	43° 52.955' S	038° 52.101' E	21:49		123.2 Kg/ 40 samples
031_DREDGE		20.03.2020	23:06	43° 51.244' S	038° 52.746' E	604	00:55	43° 51.149' S	038° 52.720' E	611	639.11	43° 51.367' S	038° 52.877' E	616	43° 51.146' S	038° 52.726' E	00:29		131.7 Kg/ 20 samples
032_MAG		21.03.2020	01:03	43° 51.179' S	038° 52.546' E	592	04:02	43° 38.635' S	038° 59.854' E	2150									
033_ROV	455	21.03.2020	06:55	43° 38.274' S	038° 59.846' E		06:29	43° 38.369' S	038° 59.837' E									aborted dive	0
034_DREDGE		21.03.2020	07:42	43° 39.213' S	039° 03.776' E	1430	10:44	43° 39.212' S	039° 03.782' E	1433	1424.1	43° 39.206' S	039° 03.784' E	1425	43° 39.210' S	039° 03.787' E	10:08	Empty	0