Workshop on the future of Scientific Ocean Drilling with MSPs and *Chikyu*

Phase 2 - HYBRID

18 - 20 March 2024
followed by a 2-day field trip

Nachikatsuura, Kii Peninsula

Nachikatsuura Town Sports & Cultural Center, 441-8 Tenma, Nachikatsuura-cho, Higashimuro-gun, Wakayama, 649-5331, Japan

WORKSHOP REPORT

August 20, 2024

Table of Contents

This report can be downloaded openly on the Workshop Website

Workshop Scope

The aim of **Phase-2 Workshop** was set to promote the implementation of drilling proposals or workshop proposals to be submitted for funding using in the framework of IODP^3 building on the scientific ideas emerged during the Phase-1 Workshop and including new scientific ideas emerged after the workshop. Another goal was to consolidate initial drilling initiatives to strengthen their scientific merit towards excellent proposals to finally have a set of promising drilling proposals for the first phase of the new joined drilling program. Since January 2023, the landscape of scientific drilling after the end of IODP has evolved to the present situation where an International Ocean Drilling Programme (IODP^3) has been announced (https://sd.copernicus.org/articles/33/89/2024) with ECORD and Japan as MSP and Chikyu operators Core Members and ANZIC and India as candidate Associate Members. The Programme will work in strict collaboration with the International Scientific Continental Drilling Program (ICDP) and will seek the highest possible level of collaboration with national scientific drilling programs such as those that will be funded at national level by NSF and by China.

With this landscape in mind, researchers, with a special focus on early career researchers (ECR), were invited to participate in the Phase-2 Workshop after the submission of **a**bstracts of scientific ideas addressing drilling expeditions and legacy assets project (LeAPs in IODP, SPARCs in IODP^3). The opportunity was offered to take advantage of an international workshop as a scientific brokerage event where potential partners not only from the European and Japanese scientific community, but also from candidate IODP^3 Associate Partners and the world wide scientific community come together to learn more about each other's skills, interests and needs in a favourable environment for researchers to interact, form new partnerships, and contribute to the development of IODP^3 science.

The Phase-2 Workshop was expected to offer the following benefits to participants:

- Allow a direct contact between proponents and operators
- Allow a direct contact between proponents and experienced senior scientists who will provide scientific advice
- Move from design to implementation

The keywords of the on the future of Scientific Ocean Drilling with MSPs and *Chikyu* have been ‘inform’, ‘connect’, ‘share ideas’, ‘networking’, ‘interaction’, ‘work together’ and ’opportunity for collaboration’.

From the 87 abstracts submitted, and the scientific ideas that they contained, a different, likely smaller, number will evolve in scientific drilling proposals stimulated by the opportunities offered by the new operational setup of IODP^3 and the need for thematic and geographical mixing of submitted abstracts. The initial grouping in Thematic sub groups following the 4 themes already addressed in the Phase 1 workshop (Climate Change and Ocean Health, Deep Earth, Geohazards, Deep Life) should be re-organized geographically to explore latent synergies that will improve the chances of success.

The brokerage of scientific ideas is expected to generate input for the thematic and geographic focusing of the early phase of IODP^3, including the needs to implement Flagship Initiatives as described in the 2050 Science Framework document.

The Workshop has followed a dual structure, in which Information on IODP^3 has been provided in plenary sessions to all participants with ample time for discussion and Questions&Answers alternated to scientific presentations in breakout sessions followed by plenary discussions. Two days of field excursions have crowned the scientific workshop offering a unique taste of cultural and geological heritage in the Kii Peninsula.

Acknowledgments

WORSKSHOPS (1&2) Steering Committee			
Angelo Camerlenghi (Co- Chair)	*OGS, Trieste, Italy*	Tomo Morishita	*Kanazawa University, Japan*
Masa Kinoshita (Co-Chair)	*University of Tokyo, Japan*	Yuki Morono	*JAMSTEC, Japan*
Natsue Abe	*JAMSTEC, Japan*	Antony Morris	*University of Plymouth, UK*
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Steffen Kutterolf	*GEOMAR, Kiel, Germany*	Sanny Saito (PMO representative)	*J-DESC, Japan*
Kenji Matsuzaki	*The University of Tokyo, Japan*	Hanno Kinkel (PMO representative)	*ESSAC, Italy*

THEMATIC BREAKOUT SESSIONS CONVENERS	2023	2024
Climate Change and Ocean Health	Helen Coxall Junichiro Kuroda	Junichiro Kuroda Thorsten Bauersachs Kenji Matsuzaki
Deep Earth	Esther Schwarzenbach Tomo Morishita	Natsue Abe Damon Teagle Lotta Ternieten
Geohazards	Becky Bell Kohtaro Ujiie	Steffen Kutterolf Asuka Yamaguchi
Deep Life	Vanni Aloisi Yuki Morono	Vanni Aloisi Yuki Morono

J-DESC Support Office/Local Organizing Committee (LOC)
Saneatsu Saito (Sanny)
Moe Kyaw
Kae Takahashi
Yukari Kido
Yumi Ebashi
Atsuko Watanabe

Phase 2 Workshop Agenda

Day-0. 2024/3/17 Sunday		
15:00-17:30	Pre-workshop mini excursion: Welcome Stroll Tour	
18:00 -	Ice breaker/dinner	
Day-1. 2024/3/18 Monday		
09:00-	Registration	
09:30–10:40	**Plenary Session-1: Introductions**	
09:30-09:40	Welcome, Logistics, and Introductions	Kinoshita/Saito/Camerlenghi
09:40-10:00	Updates on IODP3 planning	Camoin
10:00-10:20	Drilling capabilities in IODP^3	McInroy/Eguchi
10:20-10:40	Legacy Assets in IODP and IODP^3	Camerlenghi
10:40-11:00	Coffee break	
11:00–11:30	Discussion, Q&A on Plenary Session-1	ALL
11:30- 13:00	**Plenary Session-2: Overview presentations on workshop themes**	**Session Conveners**
11:30-12:00	Climate Change and Ocean Health	Kuroda, Bauersachs, Matsuzaki
12:00-12:25	Geohazards	Yamaguchi, Kutterolf

12:25-12:45 12:45-13:00 12:00-12:20	Deep Earth Deep Life Organize breakout groups	Teagle, Abe, Ternieten Aloisi, Morono WS Co-Chairs
13:00-14:00	Lunch	
14:00–15:30	**Breakout Session-1:** Climate Change and Ocean Health Geohazards Deep Earth Deep Life	**Session Conveners**
15:30-16:00	Coffee Break	
16:00-17:00	Poster Session-1	

Day-2. 2024/3/19 Tuesday		
09:00-10:40	Breakout Session-2: continued	Session Conveners
10:40-11:00	Coffee Break	
11:00-12:30	Plenary Session-3: Reporting from Breakout Sessions	WS Co-Chairs
12:30-14:00	Lunch Poster Session-2	ALL
14:00–15:30	Breakout Session-3: reorganised	Session Conveners
15:30-16:00	Coffee Break	
16:00-17:00	Plenary Session-4: Reporting & Discussion	WS Co-Chairs

18:00	Official Dinner at Hotel Urashima	

Day-3. 2024/3/20 Wednesday

09:00-10:40	Breakout Session-4: Finalization	Session Conveners
10:40-11:00	Coffee Break	
11:00-12:30	Plenary Session-5	WS Co-Chairs
11:00-12:20	Reporting, wrap-up	
12:20-12:30	Introduction to Nanki Kumeno Geopark	Masuda
12:30-	Closing remarks	
12:30-11:00	Lunch/Adjourn	
14:00-	Report writing by Steering Committee members	

Day-4. 2024/3/21 Thursday (optional)

08:00-17:00	Field Trip #1: Nachikatsuura-Nachikatsuura	Prof. Miura/LOC

Day-5. 2024/3/22 Friday (optional)

08:00-16:00	Field Trip #2: Nachikatsuura-Shirahama	Prof. Yamamoto/LOC
	End of Workshop and departure	

Participation

248 Registered participants (see list in link provided in Annex 1)

131 On-site

117 Online

Of which:

Career Stage	On-site	Online	Total
Undergraduate Students	3	1	4
Master Students	5	2	7
PhD Students	6	5	11
Early Career Researchers	28	23	51
Mid Career Researchers	23	30	53
Senior (Experienced) Scientists	64	51	115
Not known	2	5	7

Gender	On-site	Online	Total
Females	29	36	65
Males	102	81	183

Geography	On-site	Online	Total
ECORD	**38**	**35**	**73**
Austria	1	1	2
Canada	31	1	32
Denmark	-	-	-
France	98	1	109
Germany	10	10	20
Ireland	-	-	-
Italy	5	78	13

Portugal	-	-	-
Spain	1	0	1
Sweden	0	2	2
Switzerland	0	1	1
The Netherlands	1	1	2
UK	11	10	21
Japan	**74**	**54**	**128**
ANZIC	**5**	**6**	**11**
Australia	4	4	8
New Zealand	1	2	3
USA	**6**	**3**	**9**
Others	**8**	**19**	**27**
Brasil	4	0	4
Chile	1	1	2
China	0	4	4
Czech Republic	0	1	1
India	0	6	6
Korea	4	1	5
Pakistan	0	1	1
Philippines	0	1	1
Taiwan	2	0	2

Participation in thematic breakout sessions (average number)

~70	Climate Change and Ocean Health
~40	Geohazards
~40	Deep Earth
~10	Deep Life

Fig. 1 – Group photo of the participants

Outcomes and Outlook

Overview

The Workshop has been attended beyond expectations by a large and diverse scientific community. A superb organization has contributed to the success.

The objective of communicating the state-of-the-art in the shaping of IODP^3 to a wide audience has been achieved. All presentations given throughout the Workshop to illustrate IODP^3 can be accessed through the link provided in Annex 2. Shortly after the end of the Workshop, IODP^3 was officially presented to the scientific community as an article in the April 2024 Issue of the journal Scientific Drilling (https://sd.copernicus.org/articles/33/89/2024/).

The single slides requested from participants to illustrate each of the 87 abstracts submitted and the related abstracts, can be accessed through the link provided in Annex 3. A map locating the areas of interest of the submitted abstracts can be accessed through the link provided in Annex 4.

Such attendance on the Workshop has proven that there is a need for scientific ocean drilling, including land-to-sea (L2S) drilling to improve the understanding of our planet. It is not only a matter of understanding the past. What we can offer to the broader scientific community is also the understanding of processes, which are equally important to understand the past, present and future.

The level of the discussion and interaction among participants has proven that the scientific community is ready to adapt to the changing landscape of scientific ocean drilling. We should not hide the reality that IODP^3 will preferentially address research questions scaled to the available tools (MSP, *Chikyu*, including seabed drills and Long Piston Coring (LPC)). However, the diversity of tools at our disposal will offer new opportunities with respect to IODP. Nevertheless, we should never abandon ambitious scientific plans, and maintain the pressure for sophisticated and expensive tools and consider collaboration between scientific drilling programs to maximise the scientific outcomes.

A very positive aspect is the numerous participation allowed to cover a large spread of geographic areas and many research questions within each scientific theme, which enabled the identification of gaps in scientific interests and the development of plans to involve more scientists to fill these gaps. Participants demonstrated to be open to widen the scope of the proposed ideas across disciplines, and in many cases they were ready to team up with other colleagues.

In summary, the 'brokerage' aspect of our workshop worked well. This a merit of all participants and above all, the breakout session conveners.

It is hoped that the short term outcome of the Workshop will be the implementation of planning workshops, for both drilling expeditions and SPARCs. To date the available instruments are the ECORD Magellan+ Workshop Series (https://www.ecord.org/science/magellanplus/) and the J-DESC and JAMSTEC Workshop Support Program. However other possibilities exist for supporting planning workshops using national funding schemes.

It is envisaged that planning workshops can be focussed not only on one single drilling initiative, but also on a cluster (geographic/thematic) of drilling initiatives, perhaps bridging drilling expeditions and Legacy Assets.

Of course, anyone will be free to submit pre- or full- proposals to IODP^3 without going through a planning workshop.

The Workshop was seen as an encouragement to Early Career Scientists (ECR) to submit drilling proposals and SPARCs. Many original ideas have been presented that can be transformed into

successful drilling proposals. ECRs are encouraged to talk to more experienced colleagues to create a team for the proposal. The IODP^3 Program Members Office (PMO) and/or any of the senior scientists that participated in the Workshop are available to provide guidance and support.

Finally, following the plenary discussion, the Program Members Office (PMO) of IODP (https://www.iodp.org/about-iodp/program-member-offices) and IODP^3 are encouraged to re-start the discussion on how to implement the Flagship Initiatives stated in the 2050 Science Framework (https://www.iodp.org/2050-science-framework). It is likely that the next opportunity for large-scale scientific workshops on scientific ocean drilling will be related to the implementation of one (or more) Flagship Initiatives. In that case, the workshops will be inevitably more thematically focused compared to the one that was just accomplished.

Below are the reports produced in the thematic breakout session during the workshop:

Climate Change and Ocean Health

During the workshop, a total of 44 project concepts were presented, ranging from scientific drilling ideas to well developed drilling proposals that are presently under consideration by the IODP Science Evaluation Panel. The majority of concepts were related to Climate Change and only one proposal addressed topics related to Ocean Health. The workshop participants were grouped into four oceanic regions of common interest (Atlantic Ocean, Pacific Ocean, Indian Ocean and Southern Ocean/Antarctica). Results of the group discussion are provided below.

North Pacific: Eight ideas for drilling proposals in the North Pacific Ocean were presented and discussed with respect to their feasibility. The proposals were centered around the Strategic Objectives Earth's Climate System as well as Tipping Points in Earth's History. As such they aim at improving our understanding of carbon storage by the ocean and heat balance mechanism from the Mesozoic to the Late Cenozoic. Key areas included Taiwan, the Japanese coast, the central Northwest Pacific and Shatsky Rise. MSPs were proposed as platforms with most of them requiring either MEBO or giant piston coring onboard. One proposal needs a MSP with XCB onboard to drill sediments to a depth of 500 m. In several cases, cross-thematic synergies with Geohazards were identified. Considering that most drilling proposals are in an early stage, the group will concentrate on building a North-Pacific climate network for which a Magellan+ Workshop will be installed. This will allow an in-depth scientific discussion of key target intervals as well as the required platforms and coring tools. In addition, possible SPARC proposal were discussed to test new research hypotheses.

South Pacific and Indian Ocean: For the South Pacific and Indian Ocean, nine proposals dealing with ocean circulations, the onset of modern thermohaline circulation, terrestrial climate and tectonics, were submitted. The thematic areas fall within the flagship initiative "Ocean Health". The idea was to drill using a Riserless vessel such as a geotechnical vessel or the Chikyu. Three proposals are at a very mature stage and these target the Tasman Sea and the Gulf of Papua. However, some critical aspects for implementation that relate to drilling technology, water depths, drilling capacity and sediment types have to be considered. SPARC proposals are currently developed, some of which are included in a ReCoRD program. Like for the North Pacific Ocean, possible crossthematic synergies with the thematic area Geohazards were identified and a Magellan+ Workshop will also be planned.

Southern Ocean*/Antarctica*: Eleven abstracts, addressing scientific oceanic drilling in the Southern Ocean and Antarctica, were submitted. These primarily focus on the thematic area "Climate Change and Ocean Health". Five abstracts covered a second thematic area, including „Deep Earth" and „Geohazards". In addition, one abstract had „Deep Life" as third thematic area, indicating that there is a general community-driven interest for interdisciplinary research in the Southern Ocean and offshore Antarctica. The main geographical areas of interest by the workshop participants included

the South Atlantic sector (2 proposals) and the Ross Shelf region (9 proposals). Key scientific questions for future research identified by the proponents were: *How did climate variability affect the ice sheet stability of Antarctica? How quickly did the ice sheet respond to climate variations and how did it contribute to global sea level rise? How did solid Earth processes affect ice sheet dynamics?* To achieve the scientific objectives in this challenging environment, it was pointed out that a variety of platforms (including geotechnical drilling ships) and drilling equipment is needed. The latter includes giant piston coring, MEBO and importantly riserless drilling to achieve sediment recovery in deep water settings. Importantly, the need for new technological developments (e.g. ice marginal drilling, marine subglacial sediment drilling) has been put forward. Those techniques presently are not available.

Arctic-Atlantic Ocean: The Arctic and Atlantic Ocean region (including the Mediterranean Sea) received a total of 15 proposals. The majority of proposals focus on the Atlantic Ocean, while only one proposal has the Arctic region as target. All of the proposals are related to the investigation of Earth's climate change. Main geographical regions of scientific interest are the equatorial Atlantic and the subpolar North Atlantic Ocean. In these regions, the response of the ocean to periods of intensive warming shall be investigated, including e.g. the extent of ocean deoxygenation and associated biogeochemical cycles and destabilization of gas hydrates. Other key research questions include the glaciation history of the Arctic and tipping points in Earth's history. In order to implement the scientific drilling, riserless geotechnical rigs that for several proposals need to be equipped with pressure core systems to obtain methane hydrates, are mandatory. In addition, ice breaker support for MSPs offshore northern Greenland and the central Arctic has been identified as crucial.

There was a high variability in the degree of maturity of individual proposals with numerous proposals related to the Southern Ocean and Atlantic Ocean currently reviewed by SEP, while proposals from the North Pacific are primarily at a very early draft stage. There was general consensus among the community to establish theme-specific Magellan+ Workshops to foster exchange of research ideas and collaborations as well as initiate SPARC legacy core programs to test scientific hypotheses on already available core material.

Thematic Session *Climate and Ocean Health – Summary Table*

Number of abstracts with thematic 1st option	44
Number of abstracts with thematic 2nd option	3
Number of abstracts with thematic 3rd option	1
Main geographical areas of interest	Arctic, North and South Atlantic, North and South Pacific, Mediterranean Sea, Southern Ocean (including Weddell Sea, Ross Sea, Wilkes Land)
Main scientific questions	• Tipping points in the Earth and ice sheet climate system • Interhemispheric connections • Ocean circulation (including the onset of the modern ocean circulation) • Carbon storage and heat balance in deep time • Impact of global warming on deoxygenation and ecosystems changes • Climate change and ice sheet dynamics in the Arctic
Main drilling tools needed	MEBO, geotechnical drilling ships, giant piston coring, riserless drilling, new technological developments for polar research (e.g. ice marginal drilling, marine subglacial sediment drilling, pressure coring)
Maturity level of submitted abstract	10 at Level 1; 13 at Level 2; 22 at Level 3

Any thematic/geographic gaps identified among the submitted abstracts?	• Interaction between climate and biosphere change with new developments in ancient DNA • Lack of data especially in sea ice-covered area
Critical aspects for implementation	• Icebreaker support for polar research projects and ice capable geotechnical vessels • Technical development (improved drilling technologies for greater water depth and sediment types
Potential for SPARC proposals	SPARC proposals are planned (e.g. regarding the development of the west African margin and the British-Irish Ice Sheet)
Potential for teaming (participants willing to join forces to develop drilling/SPARC proposals)	Yes, potential for joint drilling proposals identified during the workshop
Potential for cross-thematic synergies	Geohazards, Deep Earth and Deep Biosphere/Life
Potential for thematic/geographical clustering proposals	Yes, in particular in polar regions
Potential for submission of workshop proposals (Magellan or others), if possible, when?	Yes, multiple workshops are planned (e.g. on Northern Hemisphere glaciation and African/South American conjugate margins)
Statement about suitability to be considered for Flagship Initiative implementation	Future climate change, Ocean health, Exploring life and its origin

Deep Earth

Deep Earth science was the founding driver of Project MoHole (1960), which led directly to the implementation in 1968 of the Deep Sea Drilling Project (DSDP) that has been followed by international collaboration in scientific ocean drilling since 1975 – arguably the most successful, productive, influential and enduring international science partnership, certainly in the wider Earth and environmental sciences.

Deep Earth science includes a broad and interconnected range of planetary geology targets concerning the operation of the plate tectonic cycles, associated biogeochemical exchanges, resource formation, and related geohazards. These science questions are closely linked with the ambitions of many of the Deep Life targets as well as Geohazards. Exchanges between the solid Earth and the oceans and atmosphere impact the climate system over geological, and sometimes shorter, time scales.

The Deep Earth Science presented at the Kii-Katsuura IODP[3] workshop included:

- Moderate depth drilling of intact ocean crust (off Hawaii; Umino, Abe, Teagle) as preliminary activities to full drilling of intact ocean crust and into the mantle (a MoHole; Niu; off Hawaii, Umino, Abe, 20 Ma Cocos Plate, Henstock);
- Aging of fast and intermediate Pacific crust (NE of Hawaii) as a complement to South Atlantic drilling (Abe);
- The origin and history of the Pacific plate (Tominaga; Kletetschka);
- In-coming plates into subduction zones, bend faulting (Kinoshita; Morishita) and associated serpentinization (Conin);
- Petit spots – impacts on geochemical cycles and seismicity (Yamaguchi) and as windows into the deep Earth (Teruaki);

- Forearc offset drilling to deep crust and mantle (Michibayashi);
- Forearc serpentine mud volcanoes and "gold" hydrogen production (Sissmann);
- Oceanic core complexes, the structure of back-arc basins (Ohara), and tectonics of the western Pacific (Lee);
- Large Igneous Provinces with a focus on Ontong Java Niu (Sano) and soft collision of OJP (Musgrave);
- Subduction polarity reversal (Andaman Is; Chatterjee).

Most of the proposed experiments in Deep Earth science require blue ocean, deep water riserless or riser drilling. This presents a significant challenge, as none of the Deep Earth projects suggested were appropriate for implementation by a low-cost mission-specific platform. Most proposals were concentrated in the western Pacific, with a scattering across the Pacific, the eastern fringes of the Indian Ocean, and one in the Atlantic. Despite encouragement, there was little desire amongst those present to prioritize or gather around one or two particular targets.

Topics and approaches within the science framework and previous science plans that weren't suggested for this workshop include:

- Rifting of continental margins and the ocean-continent transition
- Zero-age ocean crust
- Active hydrothermal systems
- Long-term monitoring and sub-surface experiments

We note that at least 22 Deep Earth proposals were with the IODP-2 Science Evaluation Panel and the Facility Boards (mostly JRFB) at the time of the Kii-Katsuura IODP^3 workshop.

Most of the Deep Earth science described in the current (2013-2023/4) IODP science plan and the future 2050 Scientific Ocean Drilling Framework requires deep drilling in deep water and often requires seafloor engineering, re-entry cones, casing, wireline logging, and for some objectives, the installation of CORKS and other types of long-term monitoring and sensor packages. However, even the current operations aboard the JOIDES Resolution (and Chikyu) are insufficient to return the cores and samples essential to answer many of the science questions posed because of poor and biased recovery provided by rotary coring systems that have improved little since the first voyages of the Glomar Challenger.

It is important to note that progress with Deep Earth science in the new IODP^3 is not without challenges, leading to some despondency, disenfranchisement, and possible disengagement from this core community. It would be irresponsible to encourage the writing, particularly by early career researchers, of new proposals requiring blue ocean deep riser or riserless operations with a near-zero chance of implementation. This applies to all scientific ocean drilling communities. Although hypothetically, a JR-like riserless ship could be hired as a mission-specific platform, candid explanations from the ESO indicated that such operations would be exceptions, perhaps only 1 or 2 a decade and that they could only be done by restricting other ECORD activities. Similarly, resources for even riserless Chikyu operations remain limited, with deep hard rock targets (more than a few hundred meters sub-basement) likely to remain elusive for the next decade or more. Even well-developed experiments such as the Hawaii upper crustal drilling, where the international community has set aside scientific differences to concentrate on a single moderate depth target (<2.5 km), appear beyond the capacity of Chikyu operations. The quest of drilling a MoHole and in situ sampling of the uppermost mantle, an explicit flagship ambition since the formation of the Integrated Ocean Drilling Program (e.g., Challenge 8 of the 2013-2023 science plan, Illuminating Earth), appears to have been surrendered.

However, the Deep Earth science group has been active with recognition some years ago of the likely absence of a globally roaming riserless vessel. The 2022 MagellanPlus workshop "Investigating the Oceanic Life Cycle of Tectonic Plates with Mission-Specific Drilling" (Harris et al., 2022, Plymouth) concentrated on three subjects:

1) Drilling zero-age basalt

2) Mantle processes in the context of continental break-up and subduction initiation

3) Mantle processes in the context of mid-ocean ridges.

This workshop has been supplemented by two further MagellanPlus workshops, the Mantle Remelting and hydrothermal chemical Exchange at Knipovich Ultraslow Spreading Ridge (MAREXKUS, Sanfilippo et al., 2023, Rome) and the Accessing the Circum-Iberian mantle archive of Wilson Cycle processes through Land-to-Sea drilling (MANTLE- L2S, Parsons et al., 2023, Plymouth). It is hoped that these will lead to drillable MSP proposals. The zero-aged ocean crust community has yet to self-organize. Still, deep-water seabed rock drills deployed at bare-rock ocean ridges could tackle a range of important science issues, including the origin of magnetic minerals and stipes and the earliest stages of hydrothermal alteration and colonization by sub-seafloor microbial life.

There are also numerous opportunities for the Deep Earth community to re-analyze legacy cores using new scanning techniques (e.g., X-ray CT, Infrared spectroscopy) with data synthesized using machine learning algorithms. This approach could provide objective quantification of igneous, alteration, and structural phenomena, forming the basis of SPARC or national funding opportunities.

Thematic Session *Deep Earth – Summary Table*

Number of abstracts with thematic 1st option	14
Number of abstracts with thematic 2nd option	6
Number of abstracts with thematic 3rd option	9
Number of active proposals SEP, FB	22
Main geographical areas of interest	Global
Main scientific questions	**Refer to the overarching 2050 SOD Framework** **Examining the plate tectonic life cycle** Continental breakup and new ocean basins The genesis of oceanic crust Zero-age crust Ocean core complexes Ocean crust maturation Serpentinization processes Hotspot volcanism and Large Igneous Provinces Plate destruction in subduction zone Subduction initiation Mantle composition and properties **Earth as a system of interconnected reservoirs** Energy cycling Matter cycling: water, carbon, hydrogen, metals, and microbes Exploring the limits of Life Constraining the origin of Life Discovering the signatures of life **ML and AI data mining of observations and data** **<u>Flagship initiatives: Probing the deep Earth:</u>** Probing Earth interiors with deep drilling Explaining differences in lower crustal accretion

	Deciphering oceanic lithosphere biogeochemical exchange Global geochemical cycling
Main drilling tools needed	Riser drilling, riserless drilling, diamond coring, seabed-rockdrills, piston coring,
Maturity level of submitted abstract	0 - 3
Any thematic/geographic gaps identified among the submitted abstracts?	Zero-age crust, seamounts, transform faults Mineral deposits and active hydrothermal systems, MoHole drilling No (few) proposals in the Atlantic or Indian Oceans, Mediterranean, Polar regions
Critical aspects for implementation	● We need more funding. ● Effective seafloor rock drills suitable for deep water (2000 - 7000m, currently max 4000m), hard-rock diamond coring up to 400m penetration (like the Chinese). ● Wireline logging in shallow holes. ● Continuous monitoring using of sensors and experiments within the boreholes (new and LEGACY boreholes). ● Deep water riser system with high core recovery ● Deep water riserless system with high core recovery ● Oriented drill core ● High-temperature gas sampling ● Improved borehole stability (should be available, standard in industry, real-time thermal-mechanical modeling during drilling, also improves recovery) ● New standards of routine core description ● 360° optical images ● 360° near visual and short-wave infrared spectroscopy ● Hole core X-ray CT scans ● Optical images and split core near visual and short-wave infrared spectroscopy ● AI and ML core logging feature reorientation ● Geochemical borehole logging tools (eg. Lithoscaner II) ● Microbial borehole logging tools ● Improved drill bits for ultra-deep coring and casing strategies and experience for ultra-deep coring
Potential for SPARC proposals	LEGACY core analyses using post-Victorian 21st Century core description and analyses
Potential for teaming (participants willing to join forces to develop drilling/SPARC proposals	yes
Potential for cross-thematic synergies	Yes, potential with deep life, volcanic hazards, geochemical exchanges, subduction zone inputs
Potential for thematic/geographical clustering proposals	Planetary geology of Earth and beyond
Potential for submission of workshop proposals (Magellan or others), if possible, when?	There is potential for a proposal writing workshop (missing thematic gaps) – e.g. zero-aged ocean crust
Statement about suitability to be considered for Flagship Initiative implementation	Probing Earth interiors with deep drilling Explaining differences in lower crustal accretion Deciphering oceanic lithosphere biogeochemical exchange Global geochemical cycling

Geohazards

The Geohazards topic group met during three breakout sessions additionally to one breakout session grouped into regions. During the first breakout session 38 proponents introduced potential drilling proposals or initiatives having geohazard as 1st to 3rd thematic option by one to five slides in more depth than during the plenary session as a base for the follow up discussions.

Within breakout session two the goal in the discussion was to identify the major topics of geohazards tackled by the drilling community in future which are: Earthquakes, volcanic eruption, and submarine slope instabilities, all of them capable to create tsunamis, as well as hazards from active mud volcanoes. Additionally, secondary hazard-producing or triggering effects like for example climate-related sea level change have been outlined as one of the major cross-disciplinary mechanisms that affect hazard-related research and drilling. The group identified overall thematic umbrella topics under which the new proposals in terms of hazards may be formulated and which may also serve as a new flagstaff initiative or focus topics: e.g., short- to long-term time-series in geohazards, rheology of subduction plate boundary. Japan and the Cascadia margin has been identified as potential focus areas although this does not exclude other regions, which have not been covered or been under-represented at the workshop like for example Central and South America, Europe, and passive margins in general. It was noted that some geohazard topics have been less present, although having a strong appearance in the first workshop (e.g. slope failures).

Additionally, the possibility of a mentoring program for early career or first-time proponent was raised which should serve as a help for those initial drilling initiatives.

The group also discussed the relation to other thematic groups which may be well-established to oceanic crust hydration, to deep earth and to deep life, and to climate change. The implementation of SPARCs proposals as well as the use of observatories to cover the very short time series in hazards have been outlined as critical components from the past and also for the future research regarding geohazards.

In the 3rd breakout group the intention was to bring proponents from different disciplines together and great synergies at the same regional locations. As a result, the Pacific region identified several focus regions where interdisciplinary drilling proposals, covering all sorts of geohazard-deep earth-deep life-climate interactions, will be fostered. The Eastern Indian Ocean region defined as a result of their discussions the intention to submit a Magellan^3 workshop to the system to streamline and strengthen the different multi-disciplinary drilling initiatives into few mature drilling proposals.

For the 4th breakout session, the Geohazard group reconvened and after a plenary discussion how to proceed in terms of future Magellan^3 workshops the group split up again into smaller regional groups. The ultimate goal to do this was to condense the different pre-mature to mature drilling proposals into fewer and stronger drilling proposals, depending on the scientific feasibility. As a result of these fruitful discussions, summarized in the table below, the major future umbrella themes for geohazards have been defined. Major questions driving the geohazard related science in the future drilling proposals have been identified to be: What controls different timescale phenomena in geohazards? What is the nature and variability of locking and slow/fast strain release? What are the sizes and recurrence rates of large explosive eruptions?

Additionally, it can be highlighted that for some regions e.g. the cabled Cascadia Margin observatory proposals and the Indian Ocean initiatives, proponents will combine their efforts into one or few very strong proposals accompanied by Magellan^3 workshops. In the case of the Cascadia margin the goal of the workshop will also be to develop synergies with the Nankai observatories and seafloor geodesy.

In total three Magellan[3] workshops will be kicked out of the meeting to condense the different drilling initiatives in the regions into few and stronger and therefore more competitive drilling proposals.

Thematic Session *Geohazards – Summary Table*

Number of abstracts with thematic 1st option	29
Number of abstracts with thematic 2nd option	11
Number of abstracts with thematic 3rd option	0
Main geographical areas of interest	Circum-Pacific (Japan, Cascadia and Central America/Caribbean), Eastern Indian Ocean, but other regions also
Main scientific questions	● What controls different timescale phenomena in geohazards? ● Nature and variability of locking and slow/fast strain release? ● Sizes and recurrence rates of large explosive eruptions?
Main drilling tools needed	Observatory, drilling into unstable strata, mid-depth drilling platform
Maturity level of submitted abstract	#15 at level 3; #11 at level 2; #14 at level 1; N/A: #3
Any thematic/geographic gaps identified among the submitted abstracts?	Submarine landslide, Mud volcano, zero-age crust
Critical aspects for implementation	● Increase data quality ● Importance of common sense of material science (Geology, geophysics, and geochemistry) and develop/fund observatories ● Develop full stress tensor measurements technics
Potential for SPARC proposals	● Reanalyze fault zones ● Evolution of Pacific Plate
Potential for teaming (participants willing to join forces to develop drilling/SPARC proposals	Communication between proposals of climate change, deep earth, and microbiology
Potential for cross-thematic synergies	● Life cycle of oceanic plate linking to geohazards ● Volcano-tectonic interaction ● Ocean current/climate linking to tectonics
Potential for thematic/geographical clustering proposals	● Cascadia unified proposal with strong linkage to Nankai Borehole Observatory – subduction zone comparison ● Eastern Indian Ocean
Potential for submission of workshop proposals (Magellan or others), if possible, when?	● Life cycle of oceanic plate linking to subduction zone and outer-rise geohazards ● Borehole, observatory workshop tied to seafloor geodesy may be proposed to e/g CRESCENT ● Eastern Indian Ocean subduction zone and shelf systems
Statement about suitability to be considered for Flagship Initiative implementation	● Fit to earthquake and tsunami hazards ● Cabled borehole observatories

Deep Life

The Deep Life thematic breakout session discussed 21 abstracts three of which declared the Deep Life as the major research theme, 10 mentioned Deep Life as 2nd theme, five as 3rd theme and three as 4th theme. The main geographical area targeted is the western Pacific, with the central Pacific, high latitude oceans and Mediterranean Sea coming in next. One abstract mentioned a number of

proposals developed within the ANZIC consortium around Australia, New Zealand and Antarctica. Clustering proposals geographically is a possibility, although no clear plan was identified.

The majority of the proposals target subduction zones (11 proposals), 5 target the oceanic plate and 2 proposals target passive ocean margins. A wide range of lithologies are targeted including oceanic sediments (including mud volcanoes and evaporites), the oceanic crust (including basalts, dykes and gabbros) and the mantle (peridotites and serpentinites). The main research question, that is recurrent in most proposals and geodynamic settings, is to investigate the metabolic and phylogenetic diversity of the microbial deep biosphere, and its role in driving material cycles of elements involved in biological processes (carbon, sulfur, iron, nickel…). Some of these settings have seldom (serpentinization environments) or never (saline giants) been investigated for their deep biosphere potential. Three proposals do not target a specific geographical area but are designed either to (i) test specific research questions such as the temperature range adaptation of single microbial taxa and the temperature limit of life, or (ii) propose the utilization of pore water samples with the goal of investigating the role of trace metals as limiting life in the deep biosphere.

Abstracts present drilling projects at all levels if maturity, from drilling ideas open to collaborations to the Deep Life community to three IODP Full proposals that have been evaluated positively by SEP and the JR Facility Board. Ten proposals need riser drilling to be implemented, while 5 can be implemented with riserless drilling and one requires the deployment of the advanced piston corer. The session identified substantial potential for collaboration, both in joining the Deep Life theme with other themes, especially the Deep Earth theme, and in developing SPARC proposals designed to explore the microbial diversity in legacy cores. Furthermore, the discussions underliend the need for consistency of microbiological methods across different drilling platforms in order for results of microbiological investigations to be compared across expeditions. The need for coordinating Deep Life research in IODP^3 countries over long time-periods was stressed, as well as the need to maintain contacts with the US Deep Life community.

Thematic Session *Deep Life – Summary Table*

Number of abstracts with thematic 1st option	**3**
Number of abstracts with thematic 2nd option	**10**
Number of abstracts with thematic 3rd option	**5**
Number of abstracts with thematic 4th option	**3**
Main geographical areas of interest	Western Pacific, central Pacific, High latitudes, Mediterranean Sea.
Main scientific questions	Factors limiting life in the deep biosphere (eg Temperature, pH...), methods to detect life in the deep biosphere, mechanisms used by microbes to adapt to life in the deep biosphere
Main drilling tools needed	Riserless drilling, some projects require de deployment of pressure coring
Maturity level of submitted abstract	All levels of maturity
Any thematic gaps identified among the submitted abstracts?	Limits of life, life in evaporites, life in serpentinization environments
Critical aspects for implementation	Finding a non-deep life proposal to team up with.
Potential for SPARC proposals	Exploring microbial diversity in legacy cores. Signatures of life in (bio-)minerals and their isotope compositions.
Potential for teaming (participants willing to join forces to develop drilling/SPARC proposals	Yes.
Potential for cross-thematic synergies	Yes. Via the effect of microbial activity on Biogeochemical cycles of carbon and sulfur.

Potential for thematic/geographical clustering proposals	Possibly
Potential for submission of workshop proposals (Magellan or others), if possible, when?	The "TR-limit" and "Beyond the Limit" proposals are candidates for a Magellan workshop. Goal: to find the best site for achieving these drilling goals.
Statement about suitability to be considered for Flagship Initiative implementation	Deep Life is widespread, so this theme can be coupled to others and implemented in IODP^3 to implement multiple flagship initiatives.

Annexes

1- Link to participants list

https://drive.google.com/drive/folders/1wsY3cYI-D14R0ngSgAEMW367ZM2P-Agh?usp=drive_link

2- Link to invited speakers' presentations

https://drive.google.com/drive/folders/1BafJR5hy2jsIfYgkOuCh35xiBdwNjcWj?usp=drive_link

3- Link to abstracts and single slides

https://drive.google.com/drive/folders/1sUepdyjZKZ2tLXQb1-c0cDVIxpeiLOvI?usp=drive_link

4- Link to location map

https://www.google.com/maps/d/edit?mid=1To0PuX7_v8euyorgyXNdTNH6Ou9ZlPk&usp=sharing