EXtreme ecosystem studies in the deep OCEan : Technological Developments
Publishable final activity report

DEEP/LEP 07-24

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Abstract

The general objective of the EU STREP EXOCET/D (GOCE-CT-2003-505342) was to develop, implement and test specific technologies aimed at exploring, describing and quantifying biodiversity in deep-sea fragmented habitats as well as at identifying links between community structure and environmental dynamics. The first leg of the MoMARETO cruise, held in summer 2006 on the new French oceanographic vessel Pourquoi pas? constituted the final demonstration action of EXOCET/D. In addition to sea trials, the scientific objective of the cruise was to study the spatial and temporal dynamics of hydrothermal communities colonizing active hydrothermal sites on the Mid-Atlantic Ridge. Three vent fields, ranging from 850m to 2300m, were visited by the ROV Victor 6000 during the cruise.

The first deployment and at sea validation of 13 prototype instruments developed within EXOCET/D are presented. The instrument improvement and development were focused on three major topics: i) Quantitative imaging, ii) Sampling and in situ measurements and, iii) Faunal sampling and in vivo experiments.

1. Project Objectives

The aim of EXOCET/D was the technological development of a specific instrumentation allowing the study of natural or accidentally perturbed ecosystems found in the deep ocean.

These ecosystems are related to the emission of reduced fluids (cold seeps, hydrothermal vents), peculiar topographic structures (seamounts, deep corals), and massive organic inputs (sunken woods) or to unpredictable events (pollution, earthquakes). Beside their insularity in the abyssal plain, the targeted ecosystems are characterized by patchy faunal distributions, unusual biological productivity, steep chemical and/or physical gradients, high perturbation levels and strong organism/habitat interactions at infra-metric scales.

Fig. 1: Mussel bed on the hydrothermal edifice Tour Eiffel (Lucky Strike-MAR)-   MoMARETO 2006© Ifremer

Their reduced size and unique biological composition and functioning make them difficult to study with conventional instrumentation and require the use of submersibles able to work at reduced scales on the seafloor. The development of autonomous instruments for long-term monitoring [seafloor observatories e.g. EU projects ASSEM (Blandin & Rolin, 2005), ESONET http://www.ifremer.fr/esonet/] is also urgently needed. In addition, the increasing anthropogenic pressure on these poorly known deep-sea ecosystems emphasizes the need for a rapid development of technologies dedicated to their investigation.Several European countries are now purchasing or developing deep-sea underwater vehicles but their acquisition alone is not sufficient to realize effective integrated deep-sea studies. There is an urgent need for fast but long term stable multi-sensor instrumentation that can be either connected to autonomous seafloor observatories or deployed on underwater vehicles.

The objective of this project was to develop, implement and test specific technologies aimed at exploring, describing and quantifying biodiversity in deep-sea fragmented habitats as well as at identifying links between community structure and environmental dynamics. Onboard experimental devices complemented the approach, enabling experiments on species physiology. The themes that were addressed in EXOCET/D include:

- 3D video imagery and small scale reconstruction, long term video module, potential of acoustic imagery vs. video imagery for ecosystem mapping,
- in situ analysis of habitat chemical and physical components using in situ analyzers and sensors (methane, flow) associated with water sampling,
- quantitative sampling of macro- and micro-organisms and, in vivo experiments in simulated in situ conditions;
- integration of multidisciplinary and multi scale data on a SIG software,
- instrument implementation on deep-submersibles,
- sub-system and scientific validation during final demonstration cruise in 2006.

EXOCET/D was a three-year project started in 2004 and funded by the European Commission (STREP, FP6-GOCE-CT-2003-505342). It involved partners from ten research institutions and three Small and Medium Enterprises (SME). The project co-ordination was carried out by Ifremer (P.M. Sarradin DEEP/LEP). The project was organized in 7 thematic workpackages. The

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project management and animation was carried out through a web site http://w3.Ifremer.fr/exocetd. This site gathered both a private access for the Exocet/d consortium, acting as a management and information sharing tool, and a public access presenting the objectives and progress of the project to the general public.

2. MoMARETO cruise: the final demonstration action of EXOCET/D

The first leg of the MoMARETO cruise (Sarrazin et al. 2006) was held from August 6 to September 6, 2006 on the new French oceanographic vessel Pourquoi pas? with the ROV Victor 6000 (Fig.2). This cruise constituted the final demonstration action of EXOCET/D. The main objective of this cruise was to study the spatial and temporal dynamics of hydrothermal communities colonizing the MoMAR zone, located on the ATJ. The cruise was organized in two legs permitting fifty-six scientists to work on board.

Fig. 2: Victor 6000 on the deck of the oceanographic vessel Pourquoi pas?   MoMARETO 2006 © Ifremer
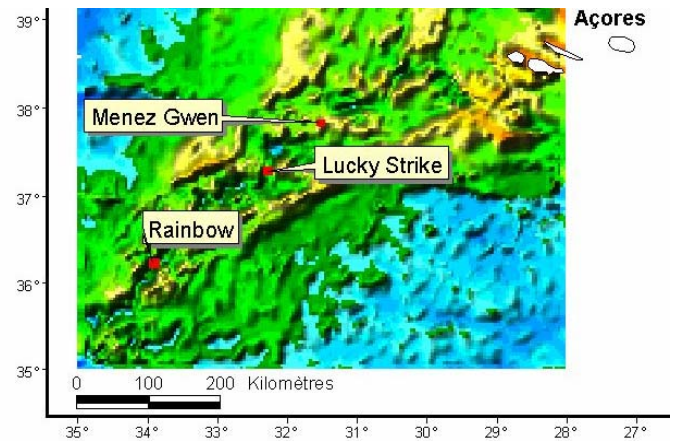

**Fig. 3:** Localization of the 3 hydrothermal vent fields on the Mid Atlantic Ridge.

The first leg of the cruise was dedicated to the final integration and validation phase of 13 equipment prototypes developed during the project. A fine-scale bathymetric study of the Lucky Strike area was also conducted (Simeoni et al. 2007). The proposed approach for the second leg was to study the response of different hydrothermal species to their environment at two temporal scales: a very short-term response of organisms to habitat micro-variations (hours-days) and a longer observatory-type scale where the dynamics of faunal assemblages will be linked to broader-scale habitat variations (months-years). The second leg heavily relied on the instrumentation tested during the first leg. Three vent fields, ranging from 850m to 2300m, were visited by the ROV Victor 6000 during the cruise.

The Mid Atlantic Ridge (MAR-Fig.3), located close to the Azores Triple Junction (ATJ), has been extensively studied over the past 15 years. Over ten cruises where conducted in the area, leading to the discovery of three major vent fields - Menez Gwen, Lucky Strike and Rainbow -, located on three segments of the south-eastern limb of the ATJ (Fig. 4-6). The vent fields differ by their depths (850 to 2350 m), their tectonic settings, the composition of their host rocks (mantle-derived serpentinized peridotite vs. basalt), the nature of associated volcanism, their fluid composition and the dominance of different key faunal assemblages (Charlou et al. 2000, 2002; Desbruyères et al. 2001 ; Douville et al. 2002).
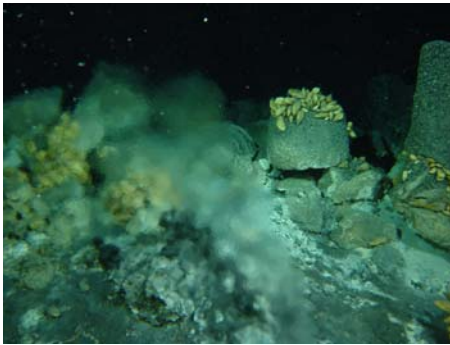
Fig.4: Diffusing fluid at the Menez Gwen vent field, depth 850 m
MoMARETO 2006©Ifremer
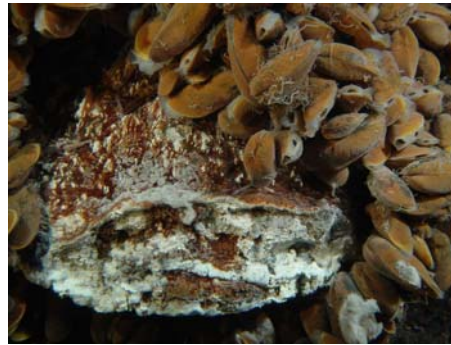
Fig.5: The mussel *Bathymodiolus azoricus*, Lucky Strike vent field, depth 1650 m,
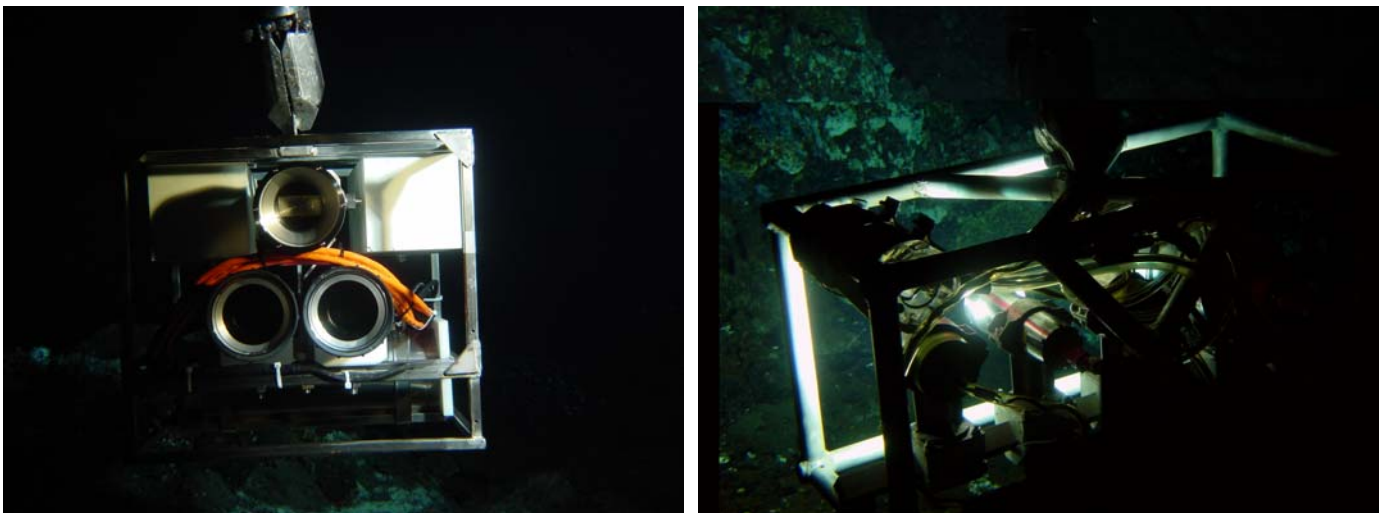
Fig.6: Black smoker at Rainbow, 2350 m depth.

3. Validation of the EXOCET/D prototypes

3.1 Quantitative imaging

Two stereo-video camera, CAMEREO and IRIS (Fig.7), were developed and tested during the cruise. The underwater video imagery obtained by the cameras will be used to make projective 3-D reconstructions of small-scale scenes.

Fig.7: Camereo (left) and IRIS (right) are stereo-video cameras developed EXOCET/D and tested during the cruise. MoMARETO 2006©Ifremer

IRIS is based on stereovision techniques and is operated by Victor 6000 robotic arm (Brandou et al. 2007). The image acquisition phase was done by visual servoing that allows a precise control of the camera position. This not only improves the image mosaicking process but permits the scaling of the features present in the image (e.g. organism size and density) and to associate the precise positioning of in situ measurements to faunal distribution.

An advanced 3D viewer software (A3DV) was tested during the cruise. For this, real 3D data issued from IRIS stereo camera imagery were to be annotated and visualized by the A3DV. Unfortunately, 3D reconstructions from the stereo camera were too long to process on board and were not available during the trials. A compromise solution was found by using recently acquired bathymetric data as a 3D mesh. The newly-developed A3DV was able to visualize and annotate the 3D bathymetric mesh.

TEMPO (Fig.8) is a long-term imaging module developed to study community dynamics and patterns of succession in remote habitats (Sarrazin et al. 2007a). This module is composed of a deep-sea autonomous video camera and two LED projectors. The video camera is able to pilot the projectors and to record digital pictures on a hard disk. A biofouling protection, based on

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localized microchloration, was installed on the camera port hole and on the lights. TEMPO was also equipped with a CHEMINI Fe in situ analyzer and with three temperature probes, and is powered by a Sea-Monitoring Node (SEAMON [Blandin & Rolin, 2005]).
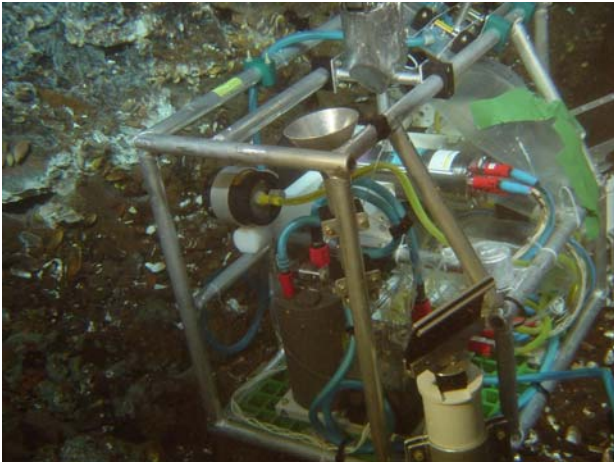
Victor 6000 was used to precisely position the module near a mussel assemblage and a CLSI link was used to control the complete setting (camera and CHEMINI probe). The operational module was moored for one year and will be recovered during the RECO cruise in the summer 2007.

Fig.8: In situ chemical analyzer CHEMINI implemented on the TEMPO autonomous station.

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To evaluate the potential of using acoustic backscatter data to study deep-sea community distribution and dynamics, a Tritech Super SeaKing Dual Frequency Profiler was installed on Victor 6000. The longitudinal axis of the sonar housing was perpendicular to the axis of Victor's main video camera. The sonar was programmed to acquire and log each ping's backscatter at the highest resolution available. A series of tests were performed to acquire acoustic and vision data. Several vertical transects were done on different hydrothermal edifices and habitat types during both legs. Visual data were used to train classification algorithms and validate the results obtained (Cardigos et al. 2006). Future work will include the use of these algorithms to georeference acoustic bottom returns, thus contributing to the development of accurate 3D models of the observed structures.

3.2 Sampling and in situ measurements

Deep-sea ecosystems are characterized by limited spatial scales, steep biogeochemical and physical gradients, and the coexistence of chemically reactive species (hydrogen sulphide, reduced metals) and dissolved gases (oxygen, methane). Appropriate instrumentation is necessary to study the extreme variability of environmental factors. In situ analyses are preferable when possible in order to circumvent sample artefacts and alterations caused by depressurization and temperature effects. Different analyzers and sensors were adapted and optimized from existing instruments and tested during the cruise.


Fig.9: CHEMINI deep sea version

Fig.10: The DPA system is mounted in horizontal position, inside its mooring frame in Victor's toolsled

A second-generation in situ chemical analyzer based on flow analysis and colorimetric detection was tested. Two CHEMINI modules (Fig.9) were used for the analysis of total sulphide and iron II or total iron (Vuillemin et al. 2005). The module is designed around an engraved manifold and a miniaturized photometric system. The first results obtained showed analytical performance comparable to a bench-top system, with detection limits close to 0.2 µM for both variables. In parallel, a second in situ chemical analyzer (Deep Probe Analyzer DPA-Fig.10), was developed and tested for the same chemical variables.
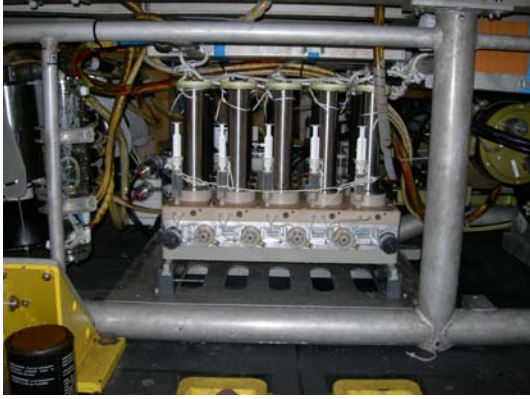
Fig 11: PEPITO implemented in the toolsled of Victor 6000 during the MoMARETO cruise.

Sampling followed by on-board analysis often remains the only analytical way to complement the range of geochemical species covered by in situ sensors. It is also used to validate data obtained by in situ measurements. PEPITO (Fig.11) is a small-volume water sampler enabling the intake of a high number of samples (Le Roux et al. 2005). It has been tested and used during the whole cruise for many different purposes: ground-truthing of the CH4 sensor, in situ filtration on 0.45 µm filters, water sampling in the vicinity of hydrothermal assemblages (pH, CH_4, dissolved and particulate Fe, Cu, Cd, Pb and organic matter) and microbial mat sampling.

Capsum (Germany) type methane sensors (METS), that had been modified and optimized within EXOCET/D, were tested during the cruise (Sauter et al. 2006). Two different sensors were used in a flow system using either a CTD pump or the PEPITO pump (Fig.12). The sensors were installed on the Victor 6000 survey module in line with the PEPITO water sampler. Water samples were taken in parallel with the in situ measurements for direct comparison with the sensor signal.

Fig. 12: Methane sensors installed in Victor 6000's survey module (left). They are in line with the newly developed water sampler PEPITO allowing a direct comparison of sensor signals and water sample methane measurements. Right: The power supply of the autonomous methane module.

Fig.13: Fluid flow measurements on a small vent diffusing a translucent hot fluid, Menez Gwen field,
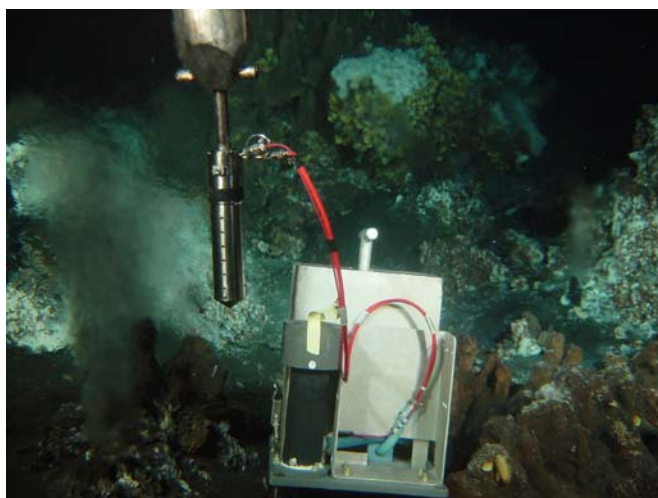
MoMARETO 2006©Ifremer

The isosampler (ISObaric SAMPLER) hydrothermal flux sensor (Earth-Ocean Systems Ltd, UK) is designed to determine simultaneously the temperatures and flow rates in the hydrothermal vent habitat. The isosampler was deployed to quantify the fluxes of fluid and heat within faunal assemblages located on Menez Gwen and Lucky Strike fields. It operated over a wide variety of temperatures and flow rate regimes (Fig.13).

3.3 Faunal sampling and in vivo experiments

Microorganisms play a crucial role in biogeochemical processes and recent studies, based on molecular biological methods, suggest that less than 5% of marine microbial species have been identified. Thus a variety of biochemical pathways and key enzymes remain to be discovered. The development of advanced sampling technologies is required to pursue the discovery of new microorganisms. AISICS (Fig. 14) is an instrumented microbial colonization system. This autonomous device allows the in situ colonization of a specific substratum by indigenous microorganisms. It is coupled with a water sampler and a temperature probe, providing information on temperatures and fluid composition during colonization events. AISICS was deployed four times (from 50 to 70 h periods) on an active hydrothermal chimney during the cruise. Temperature was continuously recorded inside the system and fluids were sequentially sampled (4 samples per deployment).

Fig.14: Deployement of AISICS at Lucky Strike
MoMARETO 2006©Ifremer
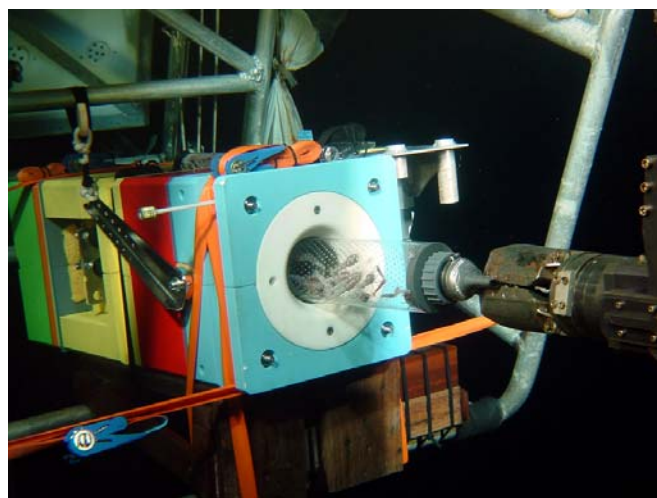
Fig. 15: PERISCOP hyperbaric sampling device.
MoMARETO 2006©Ifremer

Live organisms studies represent a luxury that biologists studying deep-sea fauna rarely access. Yet, this type of research has proved very valuable towards understanding the biology of such organisms. In the case of hydrothermal vent ecosystems, relevant biological features such as thermotolerance, reproduction, or primary production have been determined using in vivo experimentation but at native pressure. Nevertheless, a pre-requisite to successful in vivo pressure experiments of collected organisms is to insure their survival throughout recovery. PERISCOP (Fig.15) is a hyperbaric sampling device, allowing the collection and recovery of deep-sea organisms at their natural pressure (isobaric collection) at depths reaching 3000m (Fig. 15). It allows an access to live animals or bacteria, by avoiding a traumatic and often lethal decompression (Shilito et al. 2006). PERISCOP was tested successfully during the first leg. At the end of the cruise, the pressure retention of PERISCOP was almost perfect (95%) and the temperature inside the system remained fairly low (6.5°C for a bottom temperature of 4.5°C). Several types of organisms were collected using the PERISCOP, from two different depths, 1700 and 2300m.

In addition to collection devices, high-pressure instruments to study the physiological processes developed by the endemic fauna of vents and other deep-sea habitats are still rare.

DESEARES (DEep-SEA RESpirometer- Fig.16) was developed to better understand, by an ecophysiological approach, the mechanisms responsible for the life and evolution of key organisms living in extreme deep-sea habitats. DESEARES is composed of three small pressure chambers, two dedicated to experiments and a third one serving as the control. The temperature inside the chambers is controlled and the circulating fluid is composed of sea water with known concentrations of different gases mimicking the in situ conditions of the animals. The system that controls fluid composition is called SYRENE. It was developed during the VENTOX European project. DESEARES and SYRENE were installed on-board the ship during the entire cruise.

Fig16: One of the three pressure chambers making Deep-Sea respirometer system.

In the same time, an In Situ Incubator (InSinc) designed for applications on remotely operated vehicles and submersibles was successfully deployed during 3 expeditions to cold seeps (Viking cruise to Haakon Mosby Mud Volcano with R/V Pourquoi pas? and ROV Victor, Bionil cruise to the Nile deep sea fan with R/V Meteor and ROV Quest and JAMSTEC cruise to the Nankai trough with R/V Yokosuka and submersible Shinkai). This incubator allows the in situ injection and incubation of radiotracer in surface sediments (0-40 cm). HMMV, the Nile deep sea fan and the Nankai trough are characterized by elevated methane concentrations thus AOM and SR rates in surface sediments which makes these structures ideal for InSinc applications.

3.4 Communication plan during the MoMARETO cruise

Aside scientific and technological objectives, one of the major goals of this cruise was to share the excitement of our science with the public. For this, the results of the project were shared through different media. A day-to-day log book of the cruise allowed close interactions with web users and cruise events were reported in several national and international newspapers, radio and TV shows. The most challenging communication event was the real-time transmission of Victor 6000 video imagery from the bottom to a 250 person audience on land (Sarrazin et al. 2007b). Finally, a movie tracing the cruise was presented to Oceanopolis aquarium during the Oceanographic film festival and was also used during several general public conferences.

4. Conclusion

MoMARETO cruise was the main demonstration action of the EXOCET/D project. After nearly 3 years of development, the project was a real success with the at sea trial and validation of 13 instrument prototypes developed for the study of deep-sea extreme habitats tested and validated during the first leg of the cruise. After this necessary validation step, the prototypes were effectively used for scientific studies during different cruises. Future cruises and European projects (Hermes, ESONET) should make the most of this up-to-date technology.

Acknowledgments

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