FK180731 Cruise Report

1. **Ship name**: Falkor
2. **Cruise Dates - Day Departed**: 7/31/2018
3. **Cruise Dates - Day Returned**: 8/16/2018
4. **Cruise Number**: FK180731
5. **Departure Port**: Astoria, OR, USA
6. **Arrival Port**: Astoria, OR, USA

Ship track

7. **Participating Organizations, Institutions, Foundations, Government Agencies, etc.**: University of Southampton, The University of Tokyo, Kyushu Institute of Technology, The University of the Balearic Islands, Tokyo University of Marine Science and Technology, University of Sydney, University of Aberdeen, National Oceanography Centre, Sonardyne International Ltd, Greybits Engineering LLC.
8. **Funding Sources**: Cross-Ministerial Strategic Innovation Program (Japan), Next-generation Technology for Ocean Resources Exploration - Development of ecosystem survey and long-term monitoring technologies; Natural Environment Research Council (United Kingdom), NE/P020887/1, BioCam - Mapping of Benthic Biology, Geology and Ecology with Essential Ocean Variables; Natural Environment Research Council (United Kingdom), NE/R01227X/1, RamaCam - In situ holographic imaging and chemical spectroscopy for long term scalable analysis of marine particles in deep-sea environments; Engineering and Physical Sciences Research Council (United Kingdom),

EP/S001182/1, Mapping in the Background: Scalable capabilities using low-cost passive robotic systems for seafloor imaging

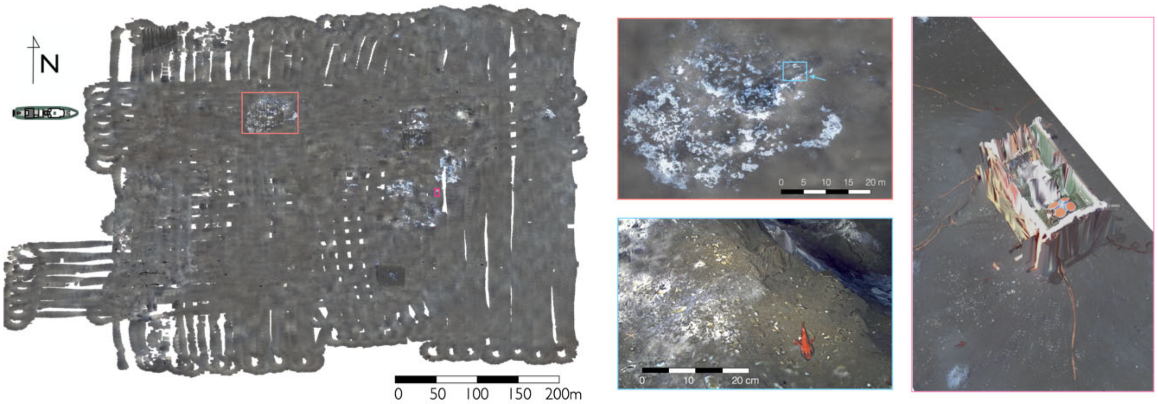
9. **Describe all of the geographical area(s) where the science occurred**: Hydrate Ridge, Cascadia Margin, Eastern Pacific.
10. **Name of Chief Scientist**: Blair Thornton
    Organization: University of Southampton, adjunct The University of Tokyo
    Mailing Address: B176, Boldrewood Innovation Campus, Burgess Road, Southampton
    City/Town: Southampton
    State and Zip/Postal Code: S016 7QF
    Country: United Kingdom
    Phone: +44 (0) 2380597322
    Email: B.Thornton@soton.ac.uk
11. **Cruise Objectives**: This is an engineering development cruise to demonstrate adaptive mission planning of multiple underwater robots when surveying dynamically changing gas hydrate environments at Hydrate Ridge. The objective is to demonstrate how efforts in seafloor observation can be focused using algorithms to visualise, explore and interpret large volumes of seafloor imagery and chemical measurements in operationally relevant time-frames. The effectiveness of this approach will be shown by generating multi-parameter and multi-resolution seafloor data products that have increased levels of detail and information in the regions that are of most scientific value. The focus is on advancing robotic survey technology rather than oceanographic exploration.
12. **Cruise Summary**:
    More than 2TB of seafloor imagery (1.3 million images), chemical sensor data and multibeam data were collected using 4 underwater robotic platforms (IIS UTokyo Autonomous Underwater Vehicles (AUVs) AE2000f, Tuna-sand, Tuna-sand 2 and the SOI Remotely Operated Vehicle (ROV) Subastian) and the RV Falkor. A total of 19 AUV dives, including 8 multi-vehicle dives, and 13 ROV dives were carried out. Since small boats were used to assist the recovery of the AUVs, operations were restricted to daylight hours. The AUVs were launched and recovered using the aft deck starboard crane and their position was monitored using an over-the-side USBL and modem setup that was lowered from the ship's CTD crane. The ROV was launched and recovered using the aft-deck A-frame.

    A 2 phase strategy was employed for data collection, where in phase 1, the AE2000f acted as our scout to identify areas of interest for more detailed observation. AE2000f was deployed at 2 sites (Southern summit at a depth of 780m and Northern summit at a depth of 680m) to collect ~17.4 hectares of dense grid 3D seafloor imagery at a resolution of approximately 1 cm. This data (consisting of ~620,000 images) was processed during the cruise to generate colour corrected 3D visual reconstructions with overlaid seawater pH and temperature plots and the results of unsupervised clustering algorithms to summarise the observations and highlight the broad-scale patterns in the observations. Overnight multibeam bathymetry surveys of the study sites were also carried out in the regions surrounding these 2 sites using the RV Falkor.

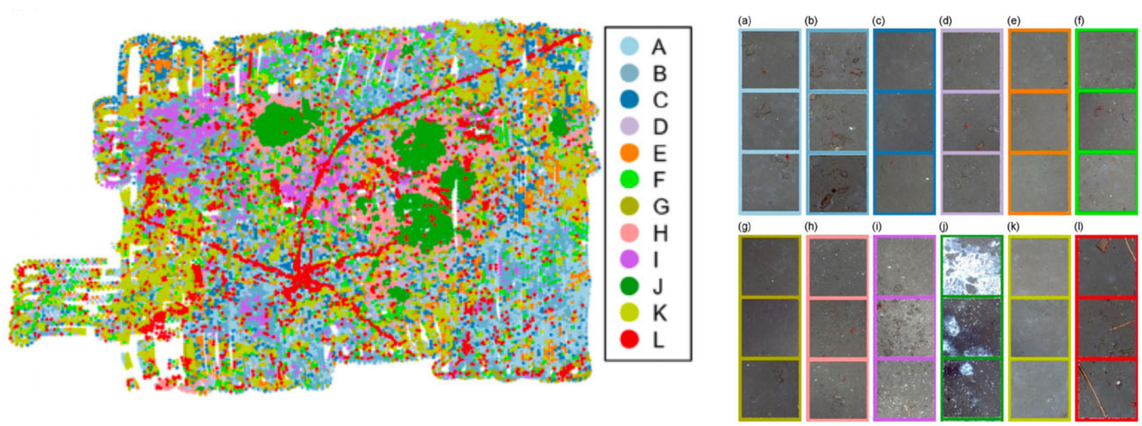
At the Northern summit, drill holes and infrastructure at Ocean Drilling Program (ODP) site 892 and an anomalous region of the seafloor were identified by the algorithms. At the Southern summit, a number of bacterial mats, drill holes at ODP site 1249 and cabled arrays of the Ocean Observatories Initiative (OOI) were identified. These sites formed the focus of the next phase (phase 2) of operations to collect more detailed information at higher resolution. For this, the AUVs Tuna-sand and Tuna-sand 2 were used. During one of the early deployments of Tuna-sand 2, an issue occurred with the vehicle's main CPU that could not be addressed while on-board the RV Falkor, preventing useful data from being collected by this AUV. Tuna-sand was therefore deployed to the locations of interest identified in AE2000f's data. Tuna-Sand successfully carried out 10 dense 20 x 20m grid surveys (consisting of ~730,000 images) with water-column pH and temperature overlays. These datasets were also processed to generate colour corrected 3D visual reconstructions with overlaid seawater pH and temperature plots and unsupervised clustering algorithms were used to summaries their observations. Tuna-Sand was deployed simultaneously with AE2000f on several occasions in order to fill in gaps and extend its wide-area mapping data.

As part of phase 2, the ROV Subastian was also deployed to make detailed visual observations using its forward looking camera, collect water-column CTD, pH and temperature data, and also carry out Laser Raman spectroscopic measurements of sub-surface sediment pore water at depths of 10, 20 and 30 cm below the sediment surface. In order to achieve this at key points of interest identified in the data collected by AE2000f and Tuna-Sand, a Geographic Information System (GIS) populated with the observational data of the AUVs and their interpreted summaries was generated, with the real-time location of the ROV overlaid onto it. This allowed the ROV pilots to navigate to regions of interest, avoid known hazards such as cables and infrastructure, and visit specific locations, such as bubble plumes, particular rocks and areas with discoloured seafloors, to efficiently perform precisely targeted measurements. A mechanical issue with the pump system used by the Laser Raman probe prevented useful data from being collected during the initial deployments. These mechanical issues were addressed during the cruise, allowing sub-surface chemical measurements to be obtained at a number of key locations during the latter stages of the cruise.

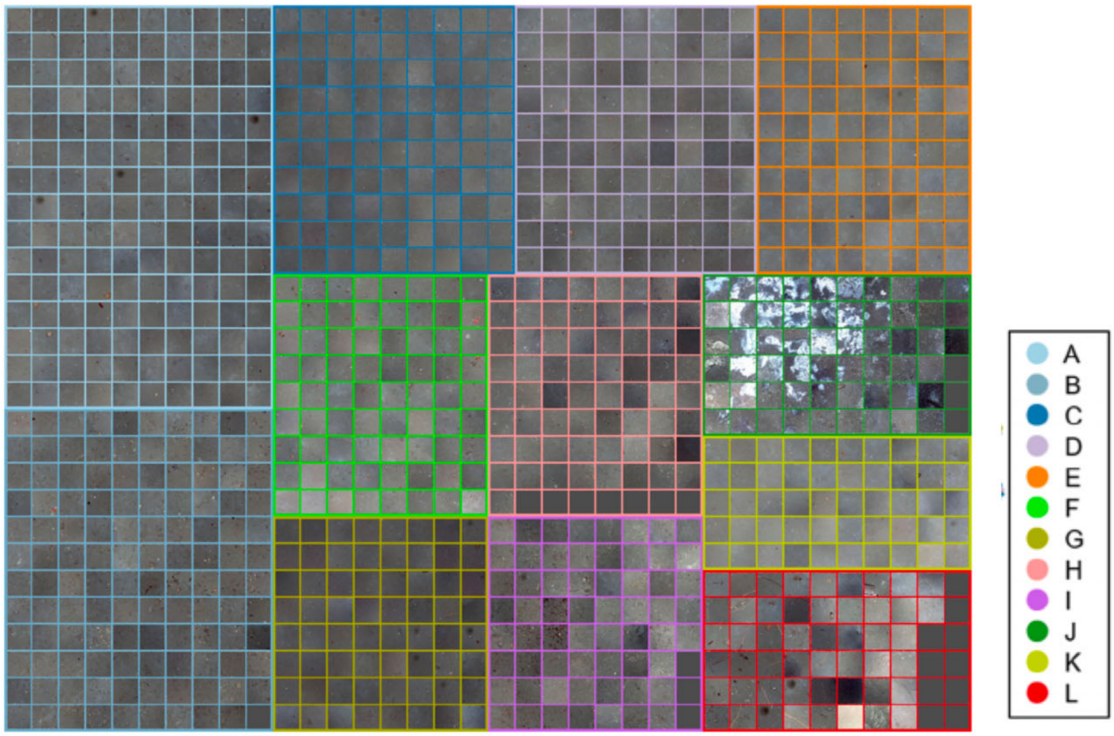
The figures below shows an example of the mapping data that was collected during this expedition. Together with that results of automated analysis that were used to decide the deployment locations of Tuna-sand.



Example of 3d visual mosaics generated during this cruise. The left panel shows a region of the Southern Hydrate ridge covering 11.8ha that was mapped at a resolution of 1cm using AE2000f. The centre top panel shows a bacteria mat, that was subsequently mapped using Tuna-sand at 1mm resolution. The centre bottom panel shows part of the mapping data from Tuna-sand in this area. The right panel shows an isometric view of the cabled infrastructure in this region that is part of the OOI Regional Scale Nodes.



Unsupervised clustering outputs of AE2000f images together with representative examples. Unsupervised clustering analysis was conducted during the cruise, and the results were used to assist decision making during the expedition. Tuna-sand was deployed in 3 regions with bacterial mats identified (cluster J) areas highlighted by the automated interpretation, and a control site without bacterial mats. Regions with cable and infrastructure (L) were avoided due to the low altitude of Tuna-sand.



A tree map representation showing a subset of 1000 images taken by AE2000, where the number of images in each cluster are in proportion to the total number of images grouped into each cluster.

13. Did you collect Measurements or Samples, including biological specimens? Seafloor imagery, pH, CTD, temperature, sub-surface Raman spectra, sub-surface temperature

14. Did you deploy and/or recover any Moorings, Bottom Mounted Gear, or Drifting Systems? A seafloor camera calibration board was deployed and recovered during the cruise.

15. Equipment Used: AE2000f, a 2000m depth rated flight-style AUV instrumented with a high-altitude (8m range) 3D imaging system and a water-column pH and temperature sensor. AE2000f operates at approximately 2knots at an altitude of 8m, allowing it to visually map the seafloor at a rate of up to ~40,000m2/h at ~8mm pixel resolution. AE2000f is 3m long and weighs 370kg in air.

Tuna-sand, a 1500m depth rated hover-capable AUV equipped with a high-resolution 3D imaging systems and a water-column pH and temperature sensor. Tuna-sand operates at approximately 0.4knots from ~2m altitude to map the seafloor at a rate of ~800m2/h at ~0.8mm pixel resolution. Tuna-Sand is 1.1m long and weighs 280kg in air.

Tuna-sand 2, a 2000m depth rated hover-capable AUV equipped with high-resolution 3D imaging systems and a water-column pH and temperature sensor. Tuna-sand 2 operates at approximately 0.4knots from ~2m altitude to map the seafloor at a rate of ~800m2/h at ~1.2mm pixel resolution. Tuna-Sand 2 is 1.4m long and weighs 380kg in air.

Laser Raman probe, a 2000m depth rated chemical analytic device consisting of a main bottle (containing a 532nm laser, spectrometer, detector and control CPU) coupled through a 6m long fibre optic cable to a focusing optic that can be held by an ROV manipulator. During this cruise, the focusing optic was coupled to a pump to draw in sub-surface sediment pore water to the measurement region of the device. The main body of the device is 0.8m without the fibre, and weighs 75kg in air.

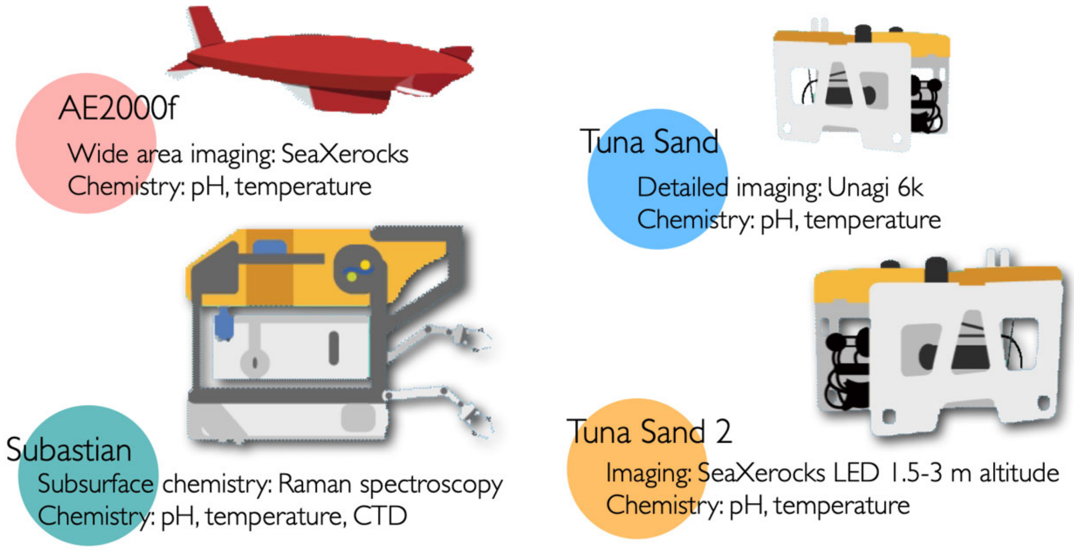


Illustration of the four robotic systems that were deployed during this cruise together with their relevant sensor payloads

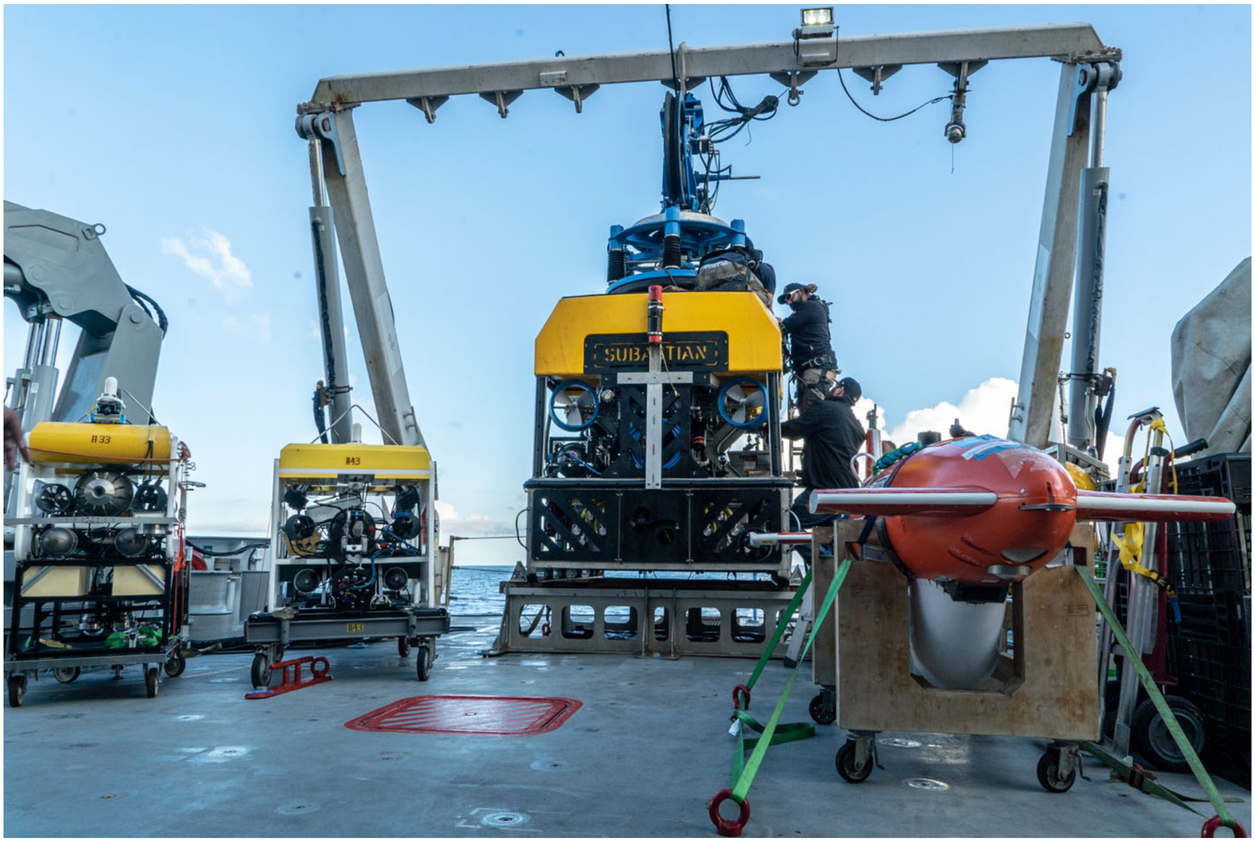


Photo of the platforms used during this cruise on the back deck of the RV Falkor

16. **Other:** Outreach activities consisting of ship to shore video live feed events and ask-me-anything discussions were carried out on the following dates:

31st July 2018, Ship to Shore: Secondary school students participating in the Smallpiece trust summer school programme at the University of Southampton.
6th August 2018, Ask-me-anything: Underwater Robotics in Oceanography
9th August 2018, Ship to Shore: Smithsonian National Museum of Natural History
15th August 2018, Ship to Shore: Smithsonian National Museum of Natural History

Related publications:
All image data collected during this cruise are available at: SQUIDLE+ (campaign ID 51, 53) with expert annotated examples available through the following links:
https://soi.squidle.org/geodata/collection?media_collection_id=74&annotation_set_id=51
https://soi.squidle.org/geodata/collection?media_collection_id=80&annotation_set_id=62
To cite this work or acknowledge use of the annotated datasets, use:

Takaki Yamada, Adam Prugel-Bennet, Blair Thornton, Learning Features from Georeferenced Seafloor Imagery with Location Guided Autoencoders, Journal of Field Robotics, DOI: 10.1002/rob.21961