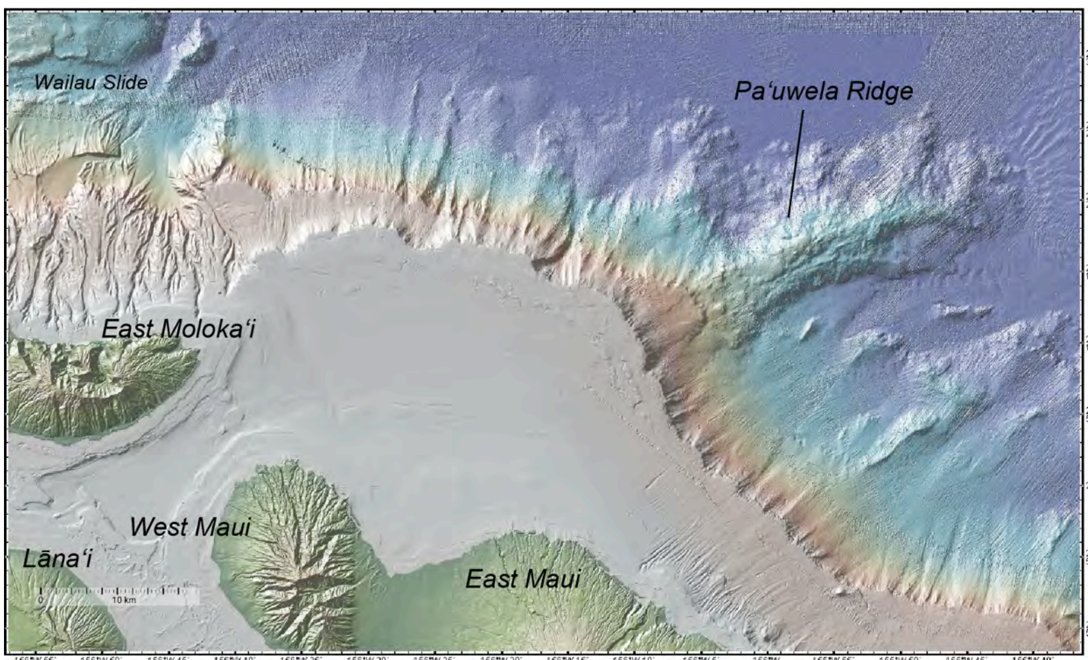
REU Cruise 2017 – Pa‘uwela Ridge

Cruise Report
R/V *Kilo Moana* KM17-10
July 17 – July 19, 2017
Honolulu, HI -to- Honolulu, HI



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1. Introduction & Cruise Summary

The primary objective of this cruise was to explore the relationship between Paʻuwela Ridge and Maui Nui, specifically to test whether Paʻuwela Ridge is (1) the submarine extension of East Molokaʻi, or (2) the rift zone of an as-yet unrecognized volcano that has since been buried. To do this, we mapped the structure of north Maui Nui using geophysical methods (sonar, gravity and magnetics), and sampled Paʻuwela Ridge via rock dredging.

In addition to this geologic study, we conducted net tows for two additional projects: a larval fish study being conducted by a UH graduate student, and a NIST/UH collaborative study on microplastics. Both projects sampled the ocean surface using a manta trawl provided by the science party.

The cruise was ~2.5 days long, from 17-19 July 2017. The ship departed Honolulu at 0800 and proceeded to the survey area just east of Molokaʻi to conduct the geophysical survey. The first ~24 hours were spent collecting sonar, gravity and towed-magnetics data, in addition to two surface tows to sample the surface water for larval fish and microplastics. Following the main geophysical survey, we proceeded further east to Paʻuwela Ridge, where we conducted 3 dredges, 2 of which successfully returned rock samples. Owing to the short cruise and quick turnaround times, only minimal sample processing was conducted at sea. After dredging operations were complete, we redeployed the magnetometer and collected additional geophysical data on the way back to port.

This cruise was conducted as part of a Research Experience for Undergraduates (REU) program funded by NSF. More than half of the science crew consisted of undergraduate and high school students, many of whom were getting their first experience conducting scientific research at sea.

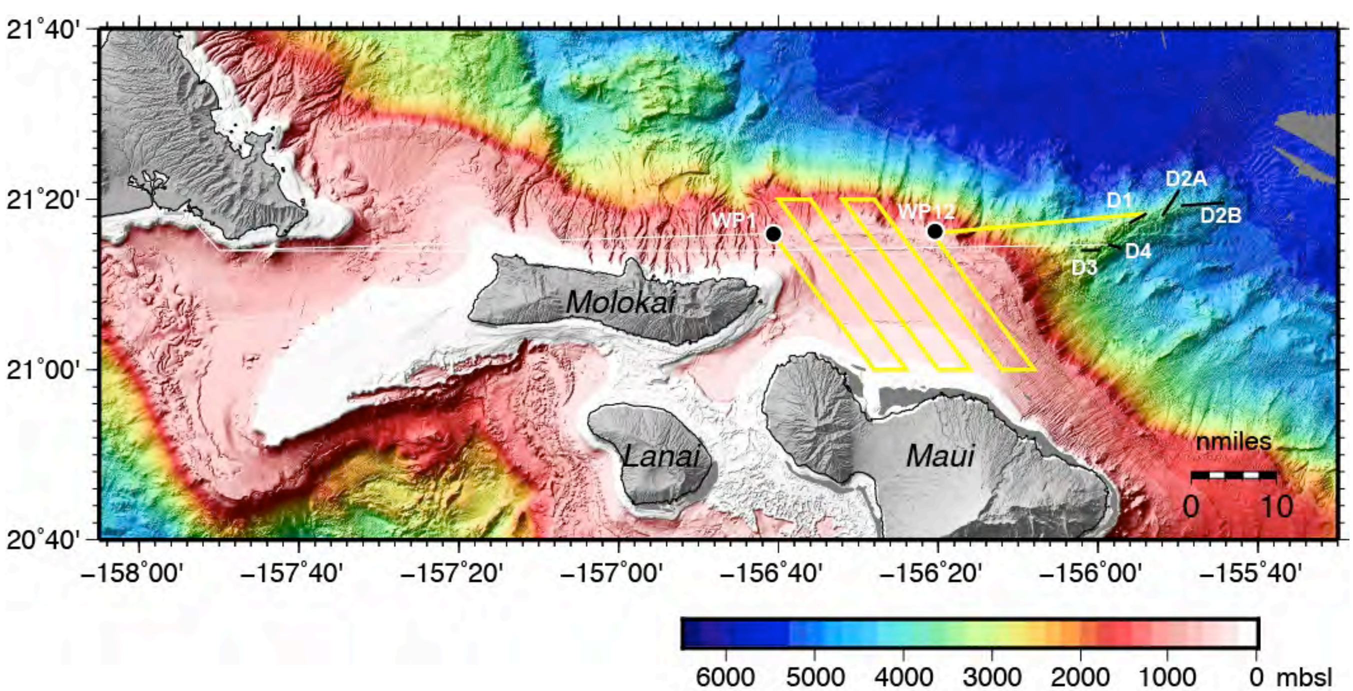


Figure 1: Map of planned geophysical survey (yellow lines) and potential dredge sites (black lines).

1.1. Background

The Hawaiian-Emperor seamount chain forms as a result of hotspot volcanism: the Hawaii hotspot is a relatively stationary mantle melting anomaly that produces a chain of volcanic islands and seamounts as the Pacific tectonic plate moves over it in a northwesterly direction. Situated near the young end of the chain are the islands of Maui, Molokaʻi, Lānaʻi, and Kahoʻolawe. This group of islands is the remnant of a larger volcano complex known as Maui Nui (greater Maui), consisting of at least six known volcanoes, including West Molokaʻi, East Molokaʻi, Lānaʻi, West Maui, East Maui, and Kahoʻolawe (Fig. 2). Ages of lava samples from this group range from more than 2.1 million years old (West Molokaʻi) to nearly present day, with roughly a dozen eruptions of East Maui in the last ~1,000 yrs.

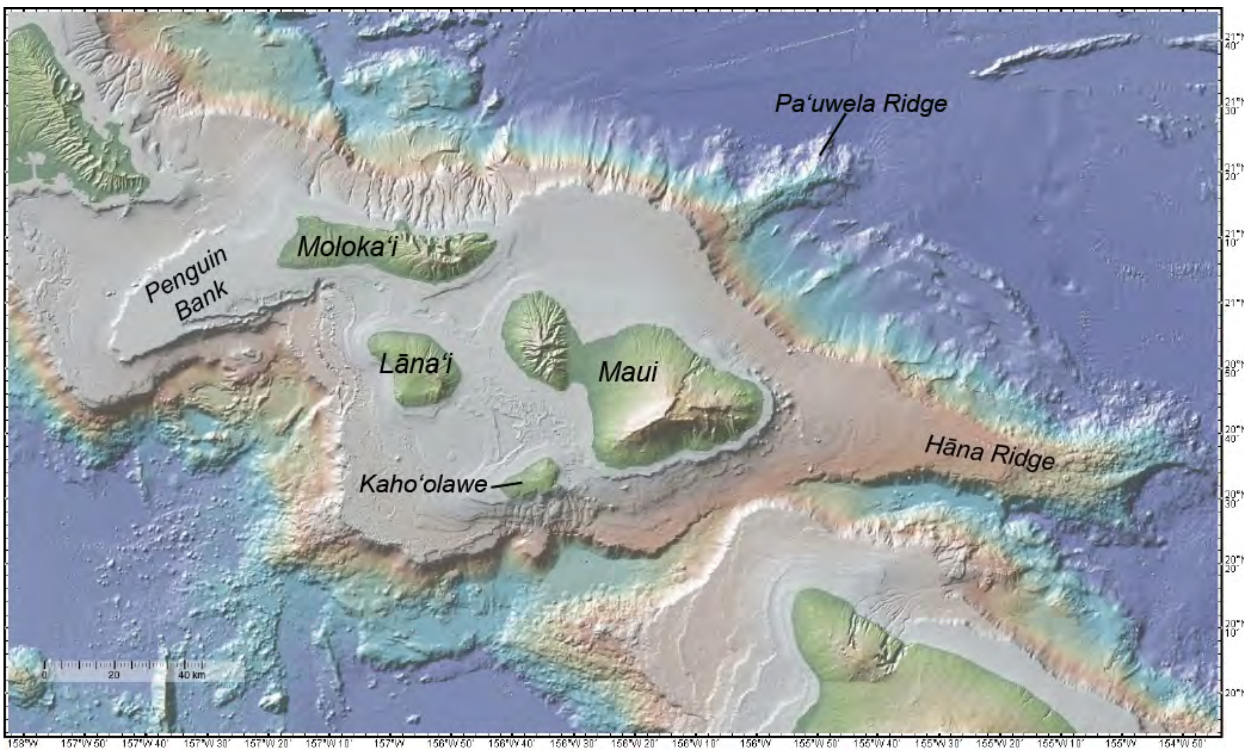


Figure 2. Map of the islands and submarine volcanic structure of Maui Nui.

Although now divided into four separate islands, this large volcano complex was once a single emergent island (Fig. 3). Many of the shallower regions that surround these islands, including the large region west of Molokaʻi known as Penguin Bank, were subaerial at the time of their formation. At various points in Maui Nui's history, one could have walked between some or even all of these islands, particularly during glacial periods when sea level was relatively low (including as recently as 20,000 years ago). At its largest (~1.2 Ma), Maui Nui covered an estimated ~14,600 km^2, exceeding that of the present-day 'Big Island' of Hawaiʻi (10,458 km^2; Price and Elliot-Fisk, 2004). Since then, these islands have been gradually sinking as they move away from the hotspot.

The effects of island subsidence and sea level variations are evident today in the series of submerged shorelines and drowned reefs visible in bathymetric data. Former shorelines are visible in the bathymetric data as major changes in slope between the gentle slopes of subaerial shield volcanoes and their much steeper submarine flanks. In addition, sea level variations have resulted in a series of coral terraces on some of the shallower portions of Maui Nui, obscuring once subaerial lava flows and geologic structures.

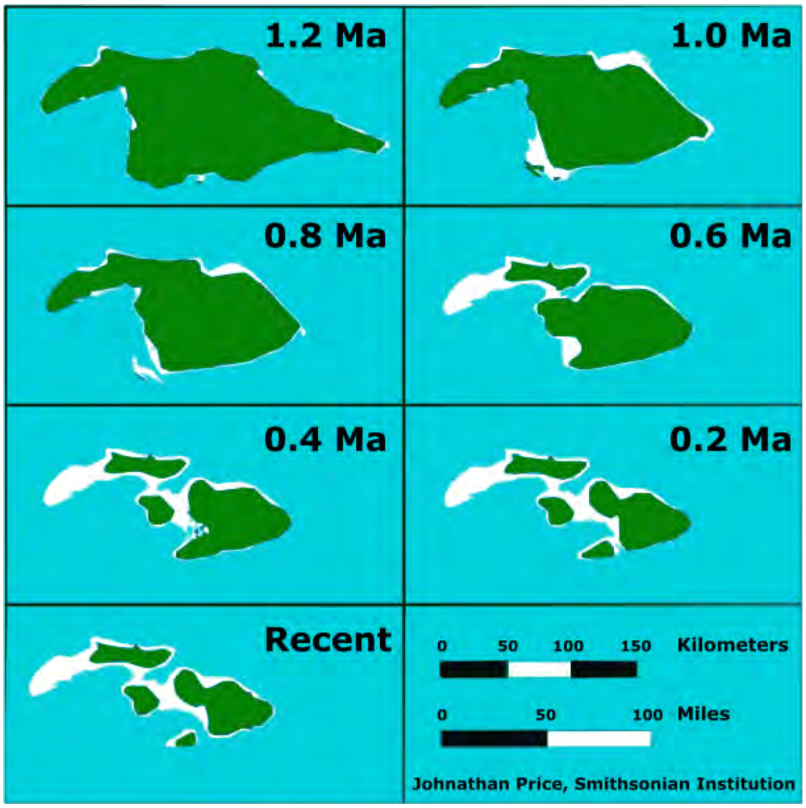


Figure 3. Summary of Maui Nui history at 0.2 Myr intervals, starting 1.2 Ma and ending in the present. Green shading represents land area during high sea stands of interglacial periods and white shading represents areas during low sea stands of glacial periods. (Modified from Price and Elliot-Fisk, 2004)

Most Hawaiian volcanoes experience four main stages of volcanic formation: (1) an early submarine stage (like Lōʻihi, currently forming just south of the Big Island); (2) the main *shield*-building stage, when most of the subaerial shield volcano forms (e.g., present-day Kīlauea and Mauna Loa); (3) a *postshield* stage, when volcanism is waning but may form a small volume of ʻcappingʼ lavas; and finally, (4) after a long period of inactivity and erosion, some volcanoes enter a *rejuvenation* stage, producing one last gasp of eruptive activity. Diamond Head on Oʻahu and Kalaupapa on Molokaʻi are both examples of rejuvenation volcanism. These volcano growth stages are also accompanied by changes in lava composition, which reflect changes in mantle melting and magma evolution as the volcano moves over and away from the hotspot.

While extensive geologic mapping and sampling has been done on subaerial portions of most of these edifices, far less is known about their submarine regions. Since most of their volumes are underwater, this leaves significant gaps in our understanding of the formation and evolution of these volcanoes. As a result, we know little about the early stages of their formation, including the formation of rift zones and how they might change over time, magmatic processes, mantle melting and plume dynamics, and the composition and heterogeneity of the mantle plume, to name a few.

Determining the submarine geologic structure, composition, and evolutionary history of Hawaiian volcanoes is important to our understanding of ocean islands, their many associated geologic hazards, natural resources, and even their ecosystems and the formation and destruction of habitats. In particular, an often-overlooked hazard in these islands is underwater landslides, which can generate life-threatening tsunamis. The steep submarine slopes of the Hawaiian volcanoes have resulted in many pre-historical underwater slumps and debris avalanches, some of which were massive in size, as evidenced by the extensive debris fields on the seafloor. The spectacular sea cliffs on the northern side of Molokaʻi are what remain after major mass wasting (a general term for slumping and sliding of land) that formed the Wailau Slide deposit (Fig. 4) (Moore et al., 1989). Much of the northern half of subaerial East Molokaʻi has been removed. These giant landslides are an integral part of Hawaiian volcano evolution, and are thought to occur predominantly during the main period of volcano growth, when the constant delivery of new material leads to oversteepened, unstable flanks.

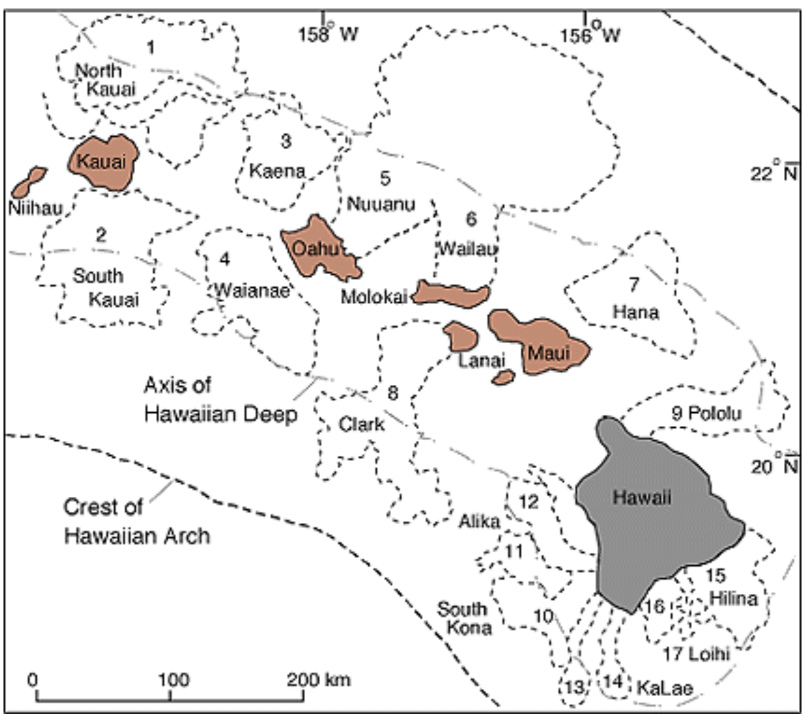


Figure 4. Map of the principle Hawaiian islands showing the estimated extents of major submarine landslide debris fields.

1.2. Paʻuwela Ridge

Paʻuwela Ridge (Fig. 5) is a particularly enigmatic feature of Maui Nui: it is thought to be a submarine extension of a Hawaiian rift zone (e.g., Moore et al., 1989; Holcomb and Robinson, 2004), but is partially buried by East Maui and an overlying carbonate platform, obscuring its relationship to the adjacent volcanoes. Its location and orientation are generally consistent with it being part of East Moloka'i, but lacking gravity data over the shallow marine terraces, we are unable to confidently follow the trace of the now buried rift zone to confirm its identity. Additionally, Pa'uwela Ridge has never been sampled, so it is unknown whether its age and lava compositions are consistent with it being part of East Moloka'i.

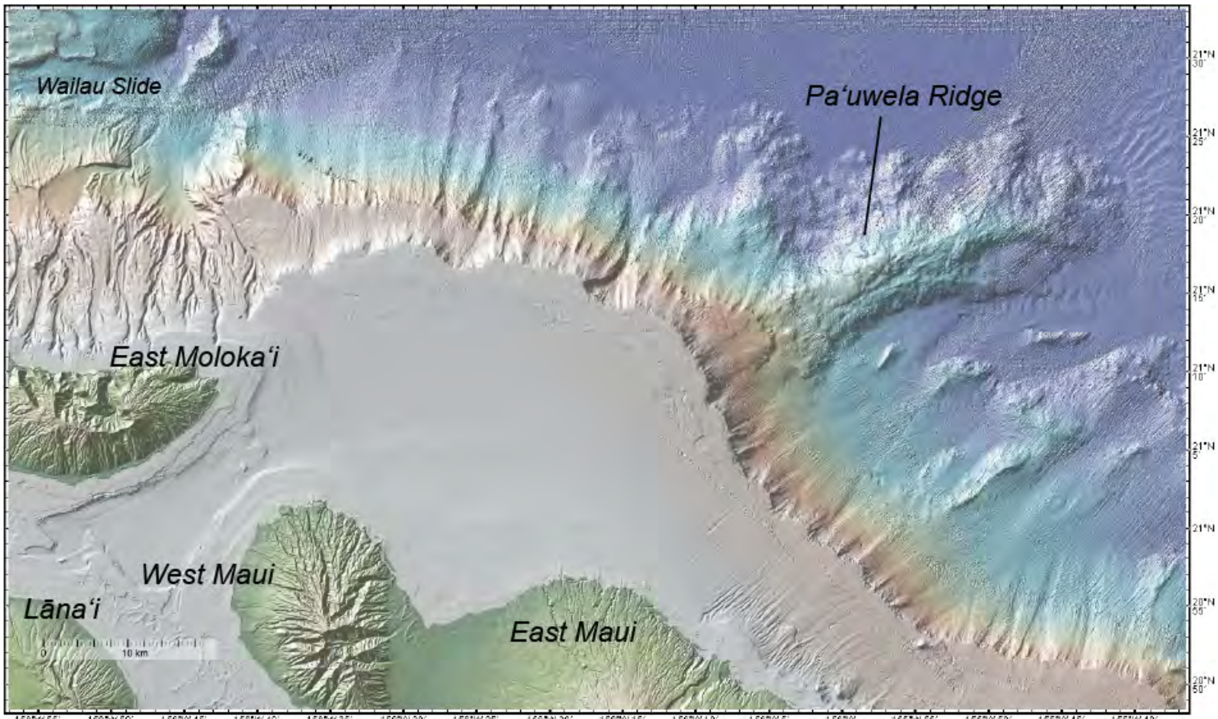


Figure 5. Map of Pa'uwela Ridge and nearby volcanoes of Maui Nui.

One additional feature has raised questions about its identity: a small submarine terrace capping the ridge's western end is interpreted to be part of the formerly subaerial volcano due to its low-angle slope (Eakins and Robinson, 2006). However, this terrace (P-terrace, Fig. 6) is ~600 m deeper than expected for East Moloka'i's K-terrace, suggesting the shoreline (and thus relative sea level) was significantly different at the time of its formation. It is in turn mostly buried by the younger H-terrace formed by East Maui and a thick sequence of overlying carbonate.

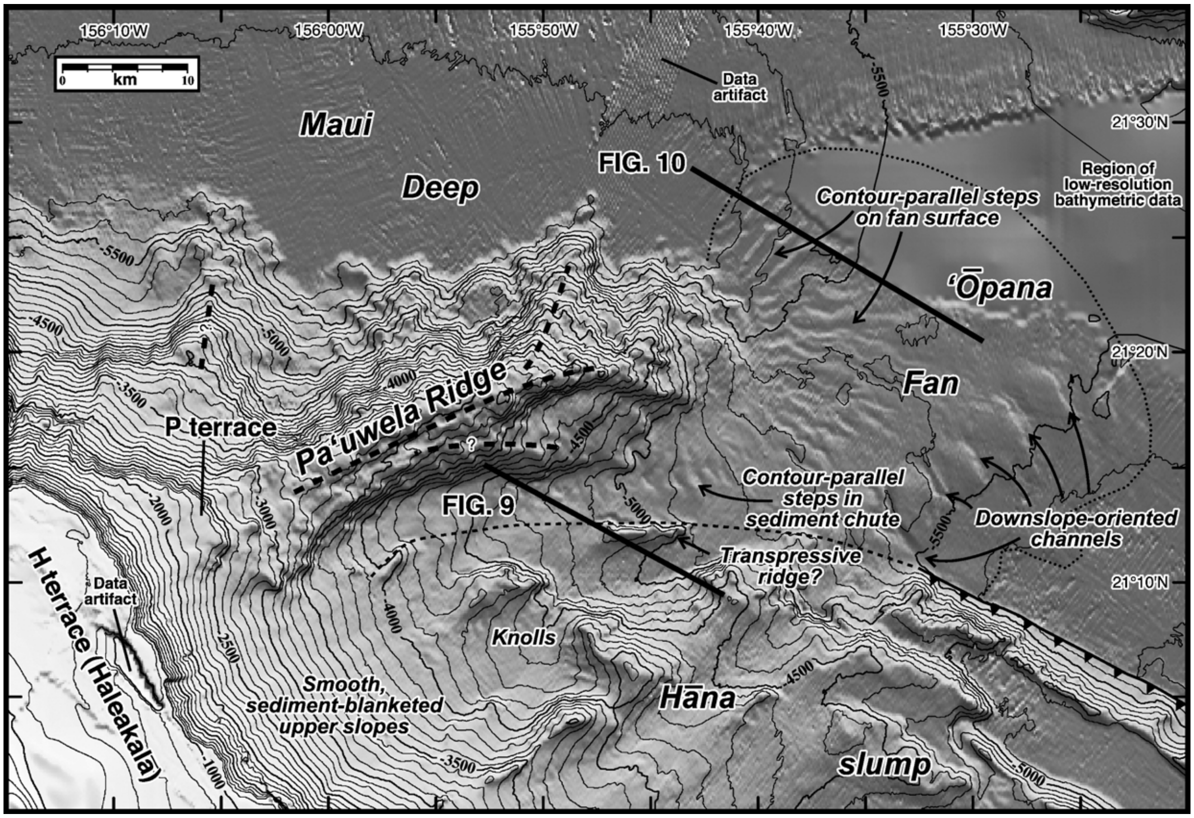


Figure 6. Shaded relief bathymetric map of Paʻuwela Ridge and surroundings. Contour interval: 100 m, bold every 500 m. (From Eakins and Robinson, 2006)

If Paʻuwela Ridge *is* part of East Molokaʻi, then the significant difference in these shorelines must be explained. Perhaps volcanism ended earlier along Paʻuwela Ridge than near the summit of East Molokaʻi, where eruptive activity continued to build a subaerial shield while this older shoreline subsided. *Alternatively*, Paʻuwela Ridge may instead belong to an as-yet unrecognized volcano that has since been buried.

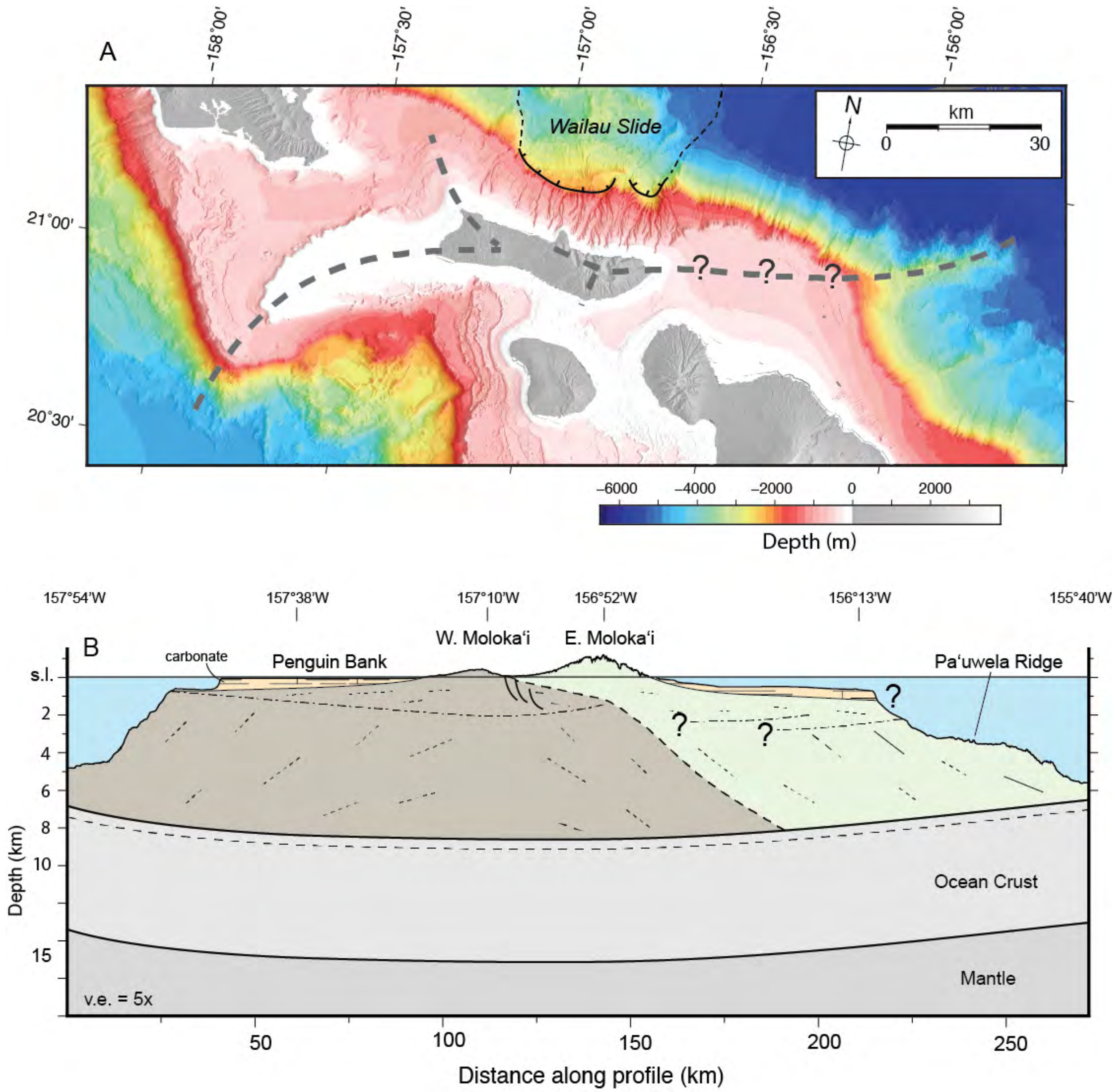


Figure 7. (A) Map of Molokaʻi showing inferred rift zones (dashed gray lines), including possible connection with Paʻuwela Ridge. The cruise aims to test this proposed connection. The Wailau Slide has removed much of the northern part of East Molokaʻi. (B) Interpretive cross section through Molokaʻi showing its two volcanoes (W. and E. Molokaʻi) on the underlying oceanic crust and mantle, which bends under their load. Profile includes Penguin Bank, Paʻuwela Ridge, and the overlying carbonate terraces. Subaerial to submarine transitions (dash-dot lines) are constrained at a few locations from drowned shorelines, but relationship between Paʻuwela Ridge and East Molokaʻi is uncertain. (Modified from Sinton et al., 2017)

1.3. Science Goals

In order to test the proposed relationship between Paʻuwela Ridge and East Molokaʻi, we designed this cruise to geophysically map the subsurface structure of Paʻuwela Ridge using gravity and magnetic techniques, and sample the ridge via rock dredging.

Primary objective: To determine whether Paʻuwela Ridge is the submarine extension of East Molokaʻi's rift zone. Or alternatively, whether Paʻuwela Ridge is part of a previously unrecognized edifice that has since been buried.

Previous mapping in the study area has resulted in variable quality multibeam sonar data. Gravity data from the surrounding areas reveal some of the broader structure of Maui Nui (Fig. 8; Flinders et al., 2013), but were critically lacking in the study area itself. Prior to the current cruise, only a few sparse gravity lines with insufficient resolution to reveal structural relationships within the edifice crossed the area in question (Fig. 1). When combined with data on southwest Maui Nui collected during a 2014 cruise on the *R/V Falkor* (FK140418), the data collected on the current cruise will fill some of the most significant holes in the gravity map in the main Hawaiian Islands. We will also produce the first detailed submarine magnetization map of this area.

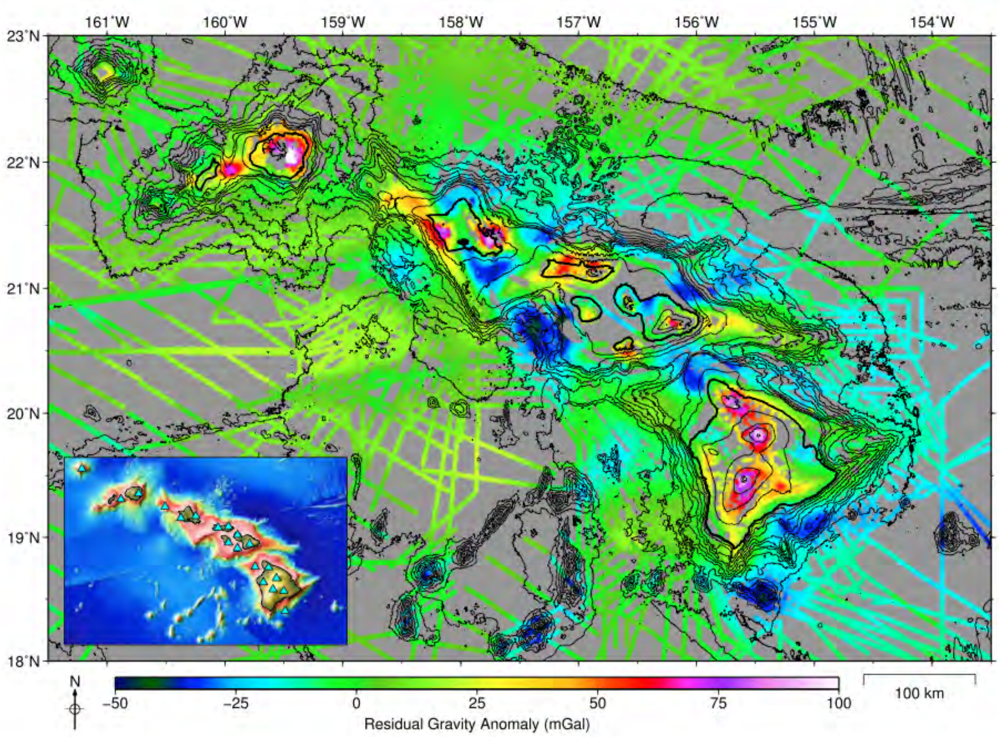


Figure 8. Residual Bouguer gravity (after correction for estimated flexural response of the lithosphere) of the Hawaiian Islands. (After Flinders et al., 2013)

Marine gravity data, once corrected for the ship's motion and the topography of the seafloor, will reveal the lateral variation in density of the crust and mantle. Ideally, the gravity data will reveal intrusive dike complexes and any cumulate core within the edifice. Magnetic data may also reveal dike complexes and their relationship to East Molokaʻi. The combined datasets will elucidate the structural relationship between Paʻuwela Ridge and the volcanological centers of Molokaʻi and Maui.

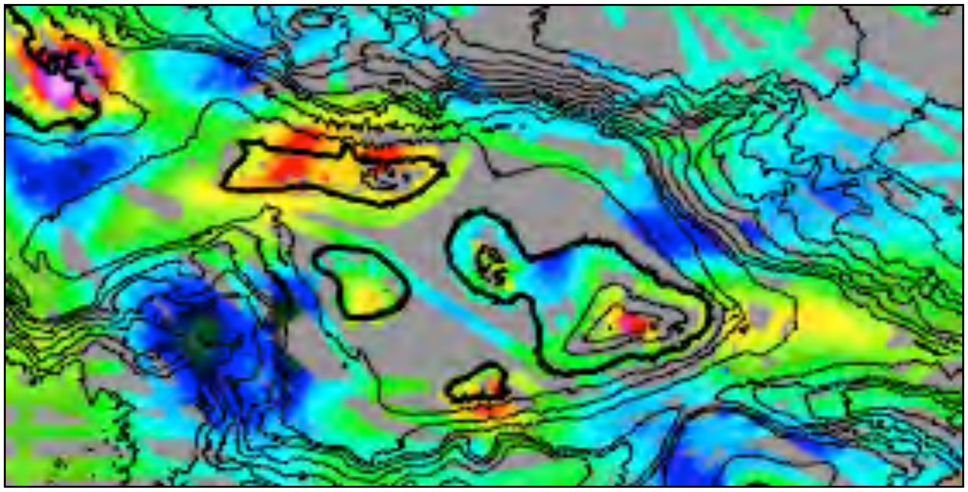


Figure 9. Gravity map of the Maui Nui complex with data gaps indicated by the gray areas. This experiment will focus on filling the gap east of Molokaʻi and north of Maui (northeastern Maui Nui).

In addition, we will collect the first seafloor samples from Paʻuwela Ridge via rock dredging. Rock samples will be critical to evaluating the composition of the lavas that form this volcanic ridge. Geochemical analyses of these samples will allow us to evaluate magmatic processes and formation conditions, as well as compare with East Molokaʻi lava compositions to determine whether they are consistent. In addition to helping confirm whether Paʻuwela Ridge is an extension of East Molokaʻi's rift zone, these samples will provide useful information on the magmatic and volcanic processes at the distal edges of Hawaiian rifts, as well as add to our understanding of submarine volcanism in Hawaii more generally.

In addition to the primary geologic study, surface net tows will be conducted for two additional projects: a larval fish study being conducted by a UH graduate student, and a NIST-sponsored undergraduate summer research project on microplastics. Both samples will contribute to datasets for student projects leading to theses. The microplastic sampling is part of a larger marine debris study examining plastics on beaches, as well as ocean samples in other locations around the islands. Undergraduate Kayla Brignac will gain experience sampling at sea, and the plastics will contribute to her undergraduate research on marine plastics in the Hawaiian Islands.

Fish larvae are being collected to determine their diet in the wild. Previously thought to be opportunistic planktivores, there is a growing recognition that marine fish larvae can be highly selective in their prey consumption and that this specificity plays and important role in their survival (Llopiz 2013; Robert et al. 2014). Graduate student Cassie Lyons will be using next-generation DNA sequencing to identify stomach contents of fish larvae in the wild, in order to overcome some of the difficulties associated with traditional stomach content analysis (i.e. small size, inability to identify digested prey, and 'empty stomachs'). Application of this technology will allow us to reveal aspects of larval fish diet that previously eluded prior investigation (Oyafuso et al. 2016). To date, no one has applied this technology to fish larvae.

2. Cruise Operations Plan

Summary of operations: geophysical survey (including multibeam, gravity, and towed magnetics), rock dredging (~3-4 dredges), and sampling the ocean surface for larval fish and microplastics (~4 or more deployments of a manta trawl (Fig. 10) provided by the science party).

Depart Honolulu 0800 July 17
Return Honolulu 1700 July 19

57 hours available for operations
Transit & survey speed: 12 knots

# Hrs	*Description / Notes*
0.0	Depart harbor
0.5	Transit to start of survey line (WP1). (Estimated time: 5.5 hrs) *En route:* test tow of manta trawl (when convenient, location flexible). (Estimated time for tow: 30 min) After net tow, deploy magnetometer and continue to WP1.
6.5	Arrive at first waypoint of the survey area (WP1). Collect multibeam sonar, gravity, and towed-magnetics along survey lines (WP1-WP12). We expect to launch a few XBTs as needed for the acoustic systems. (Estimated time: 14 hrs)
(~18)	WP10 – conduct night-time surface tow: recover magnetometer, deploy net. Tow ~20-30 mins at 2-3 knts. After tow, redeploy magnetometer and continue to WP11. (Estimated time: 30-60 mins)
(~21)	WP12 – 2nd night-time tow. After tow, redeploy magnetometer and continue to first dredge site (D1).
28.0	Arrive at first dredge site (D1). Recover magnetometer. Conduct rock dredging at 3 or 4 sites, as time permits (D1-D4). Estimate ~4-6 hrs per dredge with a short transit between sites. Alternate with additional surface tows, minimum of 2-3 (~30 min each). (Estimated total time for dredges+tows: 24-25 hrs)
47.5	Leave last dredge site. Transit to Honolulu Harbor. (Estimated time: 8-9 hrs) Deploy magnetometer while underway.
57.0	Arrival.

Figure 10. Deploying the manta trawl for surface sampling of larval fish and microplastics.

3. Accomplishments

After an on-time departure, we proceeded towards WP1. There was some delay getting the multibeam systems online due to water leaking into the SVP casing. OTG patched the leak and brought multibeam systems online, then, after a test surface tow of the manta trawl, we deployed the magnetometer and began the full geophysical survey (acoustics, gravity, and towed-magnetics). These systems remained fully functional until the patched leak came unsealed and the SVP flooded and was no longer functional (sometime early morning on Jul 19). After that, multibeam readings began to suffer, with readings often deeper than expected. Because magnetics and gravity data were the main priorities, the inability to properly calibrate the multibeam data did not significantly impact our science goals. Because OTG had their hands full patching the SVP and handling dredge operations, we chose to skip the XBT launches since they were not essential to operations. We completed 100% of the planned survey, as well as a few additional survey lines during downtime associated with dredging operations. Multibeam data will require careful processing/QC to determine when data first began to suffer from the SVP issues, but initial gravity and magnetic maps reveal high-quality acquisition (see below).

Three dredges were conducted, two of which had successful sample recovery. The first dredge was not successful, with suspected equipment failure leading to its loss (see below for further analysis). After the first failed dredge attempt, we returned to the first site to try again with the spare dredge since the dredge track conditions and wire readings had seemed good while the dredge was on-bottom. The second attempt was successful, recovering an estimated ~200 kg of pillow basalts. We then proceeded to the second dredge site, where we had another successful haul. The two successful dredges resulted in significant rock recovery totaling an estimated ~300-400 kg, many of which were olivine-rich pillow basalts, with some relatively unaltered glassy rinds and only a thin coating of Mn-oxide. These are the first rock samples ever collected from Paʻuwela Ridge.

In addition, we conducted two tows of the manta trawl to sample surface water in search of microplastics and fish larvae. Sample return was very modest, with only a few pieces of plastic identified in the first tow, and none in the second. Additional microplastics were recovered using the underway scientific seawater system (USSP), all <<1 mm in size. Three fish larvae were collected, one during the day tow, and two during the night tow.

The final track map is shown in Figure 11, with locations of surface tows and dredge sites listed in Table 1.

Table 1. Coordinates of waypoints and dredge sites

	Latitude (deg N)	Longitude (deg W)	Description
WP1	21° 16'	156° 40.8'	Start of survey
WP2	21° 0'	156° 28'	
WP3	21° 0'	156° 24'	
WP4	21° 20'	156° 40'	
WP5	21° 20'	156° 36'	
WP6	21° 0'	156° 20'	
WP7	21° 0'	156° 16'	
WP8	21° 20'	156° 32'	
WP9	21° 20'	156° 28'	
WP10	21° 0'	156° 12'	
WP11	21° 0'	156° 8'	
WP12	21° 16'	156° 20.8'	End of initial survey
WP13	21° 15.5'	156° 12.4'	Start of return survey
WP14	21° 6'	156° 4.8'	
WP15	21° 6'	156° 8.8	
WP16	21° 20'	156° 20'	
Surface tows:			
Tow #1	21° 16.34'	157°1.38'	*start* - en route to WP1
	21° 16.54'	157°0.87'	*stop* (duration: 20 mins)
Tow #2	21° 0.12'	156° 9.82'	*start* - between WP10-11
	21° 0.15'	156° 9.39'	*stop* (duration: 20 mins)
Dredge sites:			
D1	21° 18.40'	155° 54.88'	*start*
	21° 17.33'	155° 56.96'	*stop* (on bottom: 4 hr 3 min)
D2 *(D1 repeat)*	21° 18.49'	155° 54.83'	*start*
	21° 17.74'	155° 55.52'	*stop* (on bottom: 2 hr 18 min)
D3	21° 16.30'	156° 0.83'	*start*
	21° 15.42'	155° 59.71'	*stop* (on bottom: 2 hr 18 min)

3.1. Cruise Narrative

17 Jul 2017
08:00 – Departed pier.
08:30 – Cleared harbor. Ship orientation and safety meeting, followed by fire drill and abandon ship drill.
09:30 – Multibeam system not online due to issue with sound velocity profiler (SVP) leak. OTG worked to seal leak, student watchers on standby.
10:45 – Leak patched, brought multibeam systems online (EM 122 and EM 710). Began pinging and logging of both multibeam systems ~11:00.
12:00 – Meeting to discuss dredge operations. In attendance: Captain, Chief Mate, Chief Scientist, OTG (Jeff Koch, Trevor Young, Julianna Diehl), Scott Curry, John Sinton, Robert Dunn.
13:10 – Deployed manta trawl and conducted ~20 min test surface tow at ~1 knt.
14:00 – Manta trawl on deck, deployed magnetometer. Tested magnetometer and resumed survey. Surveyed WP1-10.

18 Jul 2017
03:30 – Recovered magnetometer and deployed manta trawl for night tow.
04:25 – Manta trawl on deck, redeployed magnetometer and resumed survey (WP11-12).
08:20 – Arrived at first dredge site. Recover magnetometer and prepped for dredge #1. Dredge in water 08:35, on bottom 09:55. Conduct rock dredging (maximum tension reading at winch ~16000 lbs). On bottom for ~4 hrs, multiple bites, get hung up once, stop ship to free. Dredge off bottom at 13:50, but wire tension too low on return. No dredge on recovery at 15:10 (safety chain intact, with single shackle on end). Dredge lost (presumed due to equipment failure since measured tensions never exceeded weak link settings).
15:10 – Prepared spare dredge for deployment. Conduct short multibeam survey (10 knts) while lining spare dredge with net and double-checking all shackles, links, etc.
17:30 – Returned to dredge site #1 for second dredge deployment. Dredge on bottom at 19:10 for total of 2 hrs 20 mins. Full dredge recovered at 23:00, rock sampling successful. After desk secured, transited to second dredge site.
23:50 – Third dredge deployment (site #2).

19 Jul 2017
01:25 – Dredge #3 (continued) – on bottom for total of 2 hrs 20 mins. Stopped ship when winch began reading consistently low tensions, concern that dredge may be empty, but tension values seem normal again during recovery. Full dredge recovered at 05:00, rock sampling successful.
05:30 – Deployed magnetometer for surveying during transit home. ~11.5 hr total transit time. Multibeam logging inconsistent, with questionable depth readings due to flooded SVP.
~16:30 – Arrived at buoy; equipment testing and waiting on pilot house.
~18:00 – Arrived at dock.

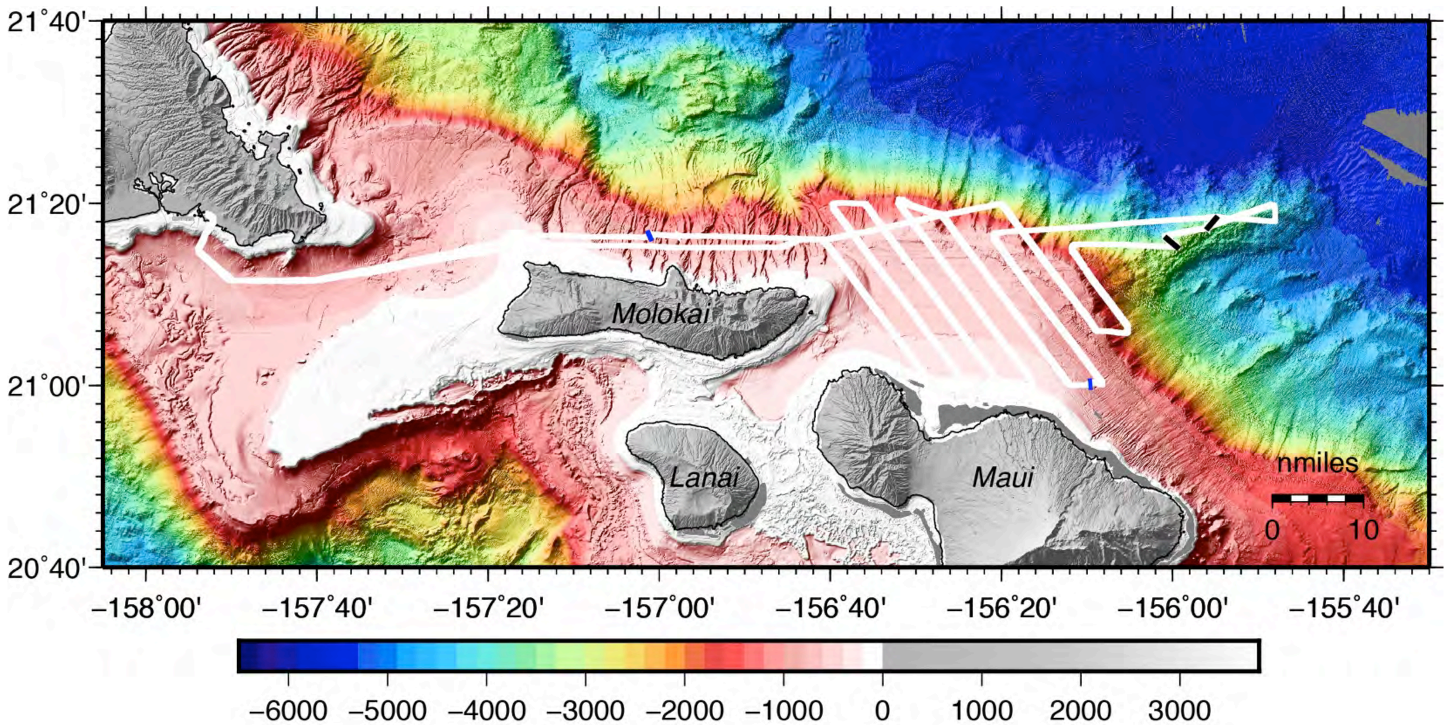


Figure 11: Map of final cruise track (white lines), net tows (blue) and dredge sites (black).

4. Preliminary Cruise and Data Assessment

Multibeam bathymetry and acoustic imagery data, gravity data, and magnetic data were the principle geophysical data recorded during this experiment. Watchstanders monitored the data streams in the Science Control Room, and logged their activity every 20-30 minutes for the duration of the cruise.

4.1. Pre-processing

Final digital files of KM17-10 data were supplied by OTG at the end of the cruise. The navigation, gravity and magnetic data were pre-processed and processed and are described here. The magnetic and gravity data have time stamps, but no location information, so the first step was to extract the raw navigation, gravity, magnetic data and merge them with bathymetry values (along the ship track). A shell script “extractRawData.csh” (see Appendix) was devised to pull the appropriate columns of data from these files, and to extract bathymetry data using the ship’s location and a processed bathymetry grid for this area (no center beam depth information was provided in the cruise files). This procedure produced three new ascii files of: navigation (with bathymetry), gravity, and magnetics. Using a MATLAB script “mergeData.m”, the navigation data was merged with the raw gravity and raw magnetic data, where the navigation data was interpolated onto the time base of the other two data streams. As part of this merge, the raw gravity data were also merged with ship speed, heading, pitch, roll, heave, and water depth information, and the raw magnetic data were also merged with ship speed, heading, and water depth information.

4.2. Gravity

The *R/V Kilo Moana* was equipped with a Bell Aerospace BGM-3 marine gravimeter attached to a gyro-stabilized platform. The gravimeter was located in a closed room on the main deck, at a location above the water line and somewhat starboard of the ship's centerline. The gravimeter records data continuously and we began logging that data stream the morning of departure. The gravimeter was zeroed-in relative to a benchmark located at the pier. The logging system converts the raw data stream to gravity units and merges the gravity data the ship's navigational clock data and saves the output to ASCII format day files.

A MATLAB program procGrav.m was used to filter the gravity data with a cosine-shaped filter and calculate and apply the Eötvös correction:

$$E = 7.5038V\sin(\alpha)\cos(\phi) + 0.004154V^2$$

where V is the ship's speed in knots, α is the ship's heading, ϕ is the ship's latitude, and E has units of mgal. The Eötvös correction was calculated after median and cosine filters were applied to the speed and heading data to remove spikes and smooth the data. No drift correction was made to the gravity data as the cruise was very short. As a test, in places where the gravity lines cross, the differences in measured values are minimal.

The free air gravity (Fig. 12) is calculated as:

$$FA = g_{obs} - \left(g_o + FAC\right)$$

where g_{obs} is the observed gravity, g_0 is gravity field of the 1980 Geodetic Reference Standard Ellipsoid and *FAC* is the Free-Air Correction. The free air gravity and corresponding latitude and longitude values were then written to an ASCII file for gridding and plotting via *GMT* (The Generic Mapping Tools). The free air map was created using the script "pl_faa.sh".

The bouguer gravity (Fig. 13) was calculated and plotted using *GMT* in the script "pl_bgrav.sh". Using *GMT*'s gravfft module the standard Bouguer gravity was calculated, which utilizes Parker's method. This was then used to calculate the Bouguer gravity anomaly using the formula,

$$BG = g_{obs} - \left(g_o + FAC + g_{boug}\right)$$

where g_{boug} is the standard Bouguer gravity correction calculated using Parker's method. The Bouguer gravity was then transformed into a grid file and plotted using *GMT* in the same way as the free air anomaly. The Bouguer correction was made assuming a density contrast between seawater and carbonate, and the dominant feature in the map may reflect the topography of the volcanic edifice beneath the carbonate platform.

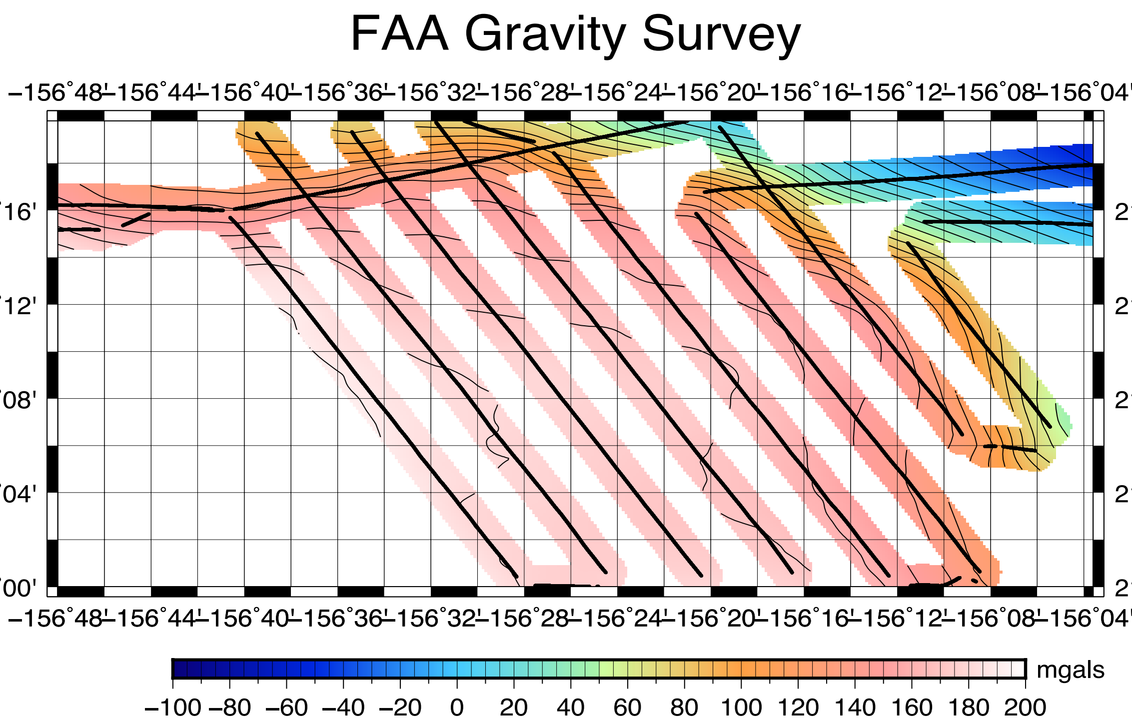


Figure 12. Preliminary free-air gravity map of the study area with ship tracks where data are included for the compilation.

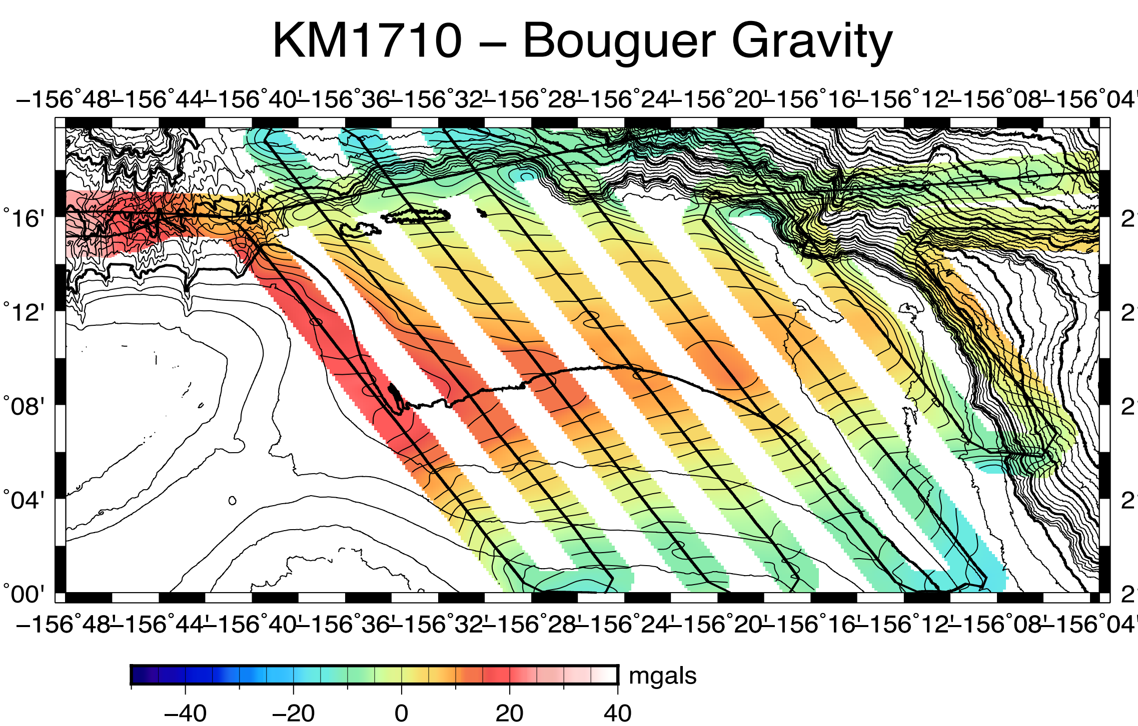


Figure 13. Preliminary Bouguer gravity map of the study area with contours of bathymetry and ship tracks superimposed.

4.3. Magnetics

Basalts preserve the magnetic signature of the geomagnetic environment in which they cooled. Magnetic anomaly maps can be used to decipher volcanic and tectonic processes, as well as age of the seafloor.

The marine magnetometer used for this study was the Geometrics G-882 Cesium magnetometer (Fig. 14). It detects variations in the resonance of self-oscillating split-beam cesium vapor with an accuracy of <3 nT over an operating range of 20,000 to 100,000 nT with a sampling rate of 10 Hz (Geometrics 2005).

When towed from a ship traveling at approximately 10-12 knots, the magnetometer glides along at a depth of approximately 8 meters. The depth sensor transducer must be periodically calibrated to compensate for temperature variations that affect its strain gauge mechanism. The specific calibration information for the magnetometer used on the KM17-10 cruise is given in Table 2.

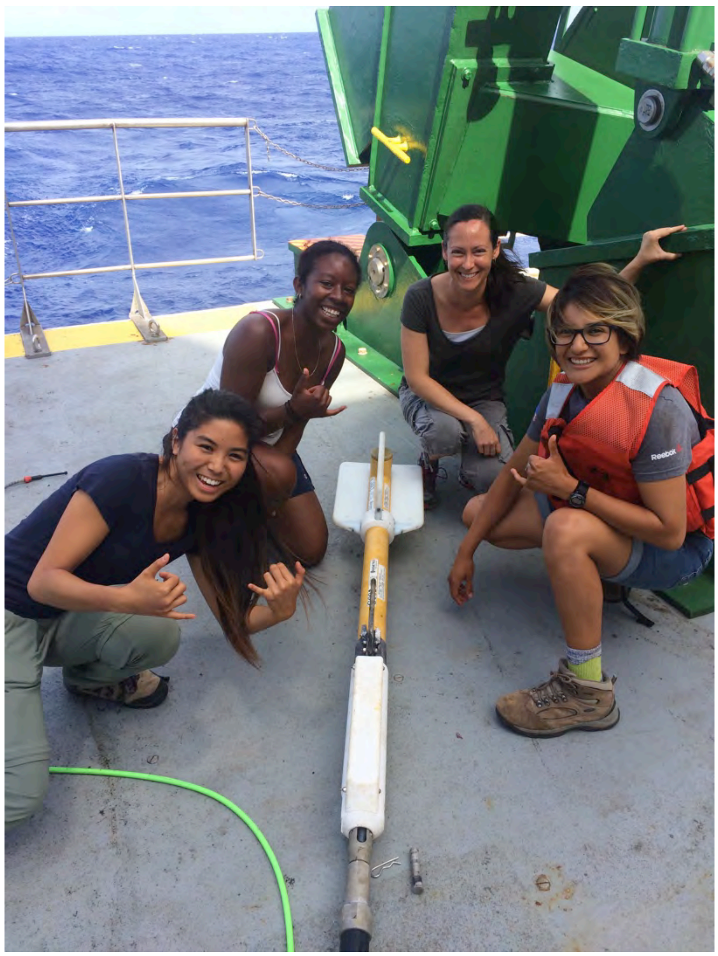


Figure 14: The Geometrics G-882 Cesium magnetometer.

Table 2: Geometrics G-882 Manufacture and Depth Calibration Certificate Information

Manufacture Date:	8 Oct 2004	Last Calibration Date:	28 Nov 2012
Magnetometer S/N:	882045	Depth Sensor S/N:	2378121
Salt Water Scale:	0.034881	Salt Water Bias:	-3.84
Fresh Water Scale:	0.035578	Fresh Water Bias:	-3.91

Deployment of the G-882 involved connecting it to its multi-conductor tow cable, lifting it off the deck by hand, and carefully lowering it into the water. The magnetometer was towed 100m behind the stern. The offset of the stern and the ship's GPS antenna was not considered for the initial data processing presented in this report.

The magnetometer was deployed near the end of the transit to the main survey site. Data collection began on day 199 at 01:06:35 GMT. Data were steamed at 0.1 s intervals and saved in raw files, but the final merged data were provided at 1 sec intervals. The magnetometer was retrieved for manta-trawl work and during dredging operations. On day 201 at 01:30 GMT, the magnetometer was disconnected and retrieved.

4.3.1. Magnetic Data Processing and Initial Results

Final raw data are stored in a single merged file with the time-stamp of the recordings. Prior to recording, raw values were scaled value by the Salt Water Scale value for the G-882 (0.034881), the Salt Water Bias value for the G-882 (-3.84) was then added. Processing of the raw data involved three main steps: (i) merging of magnetic with navigation data, (ii) applying an IGRF correction, and (iii) applying a reduction to pole correction. The raw data were merged with navigation as described above.

The International Geomagnetic Reference Field (IGRF) is a spherical harmonic numerical model of the Earth's magnetic field and its secular variation (IAGA 2010). Subtracting the IGRF value from the observed magnetic field, produces a map of magnetic anomalies largely due to local structure. The IGRF field was calculated via the GMT software command "mgd77magref" and subtracted from the total field (using shell script "proc_Magg.csh"). Using a shell scrip "pl_mag_igrf.csh", the track line (IGRF corrected) data were gridded.

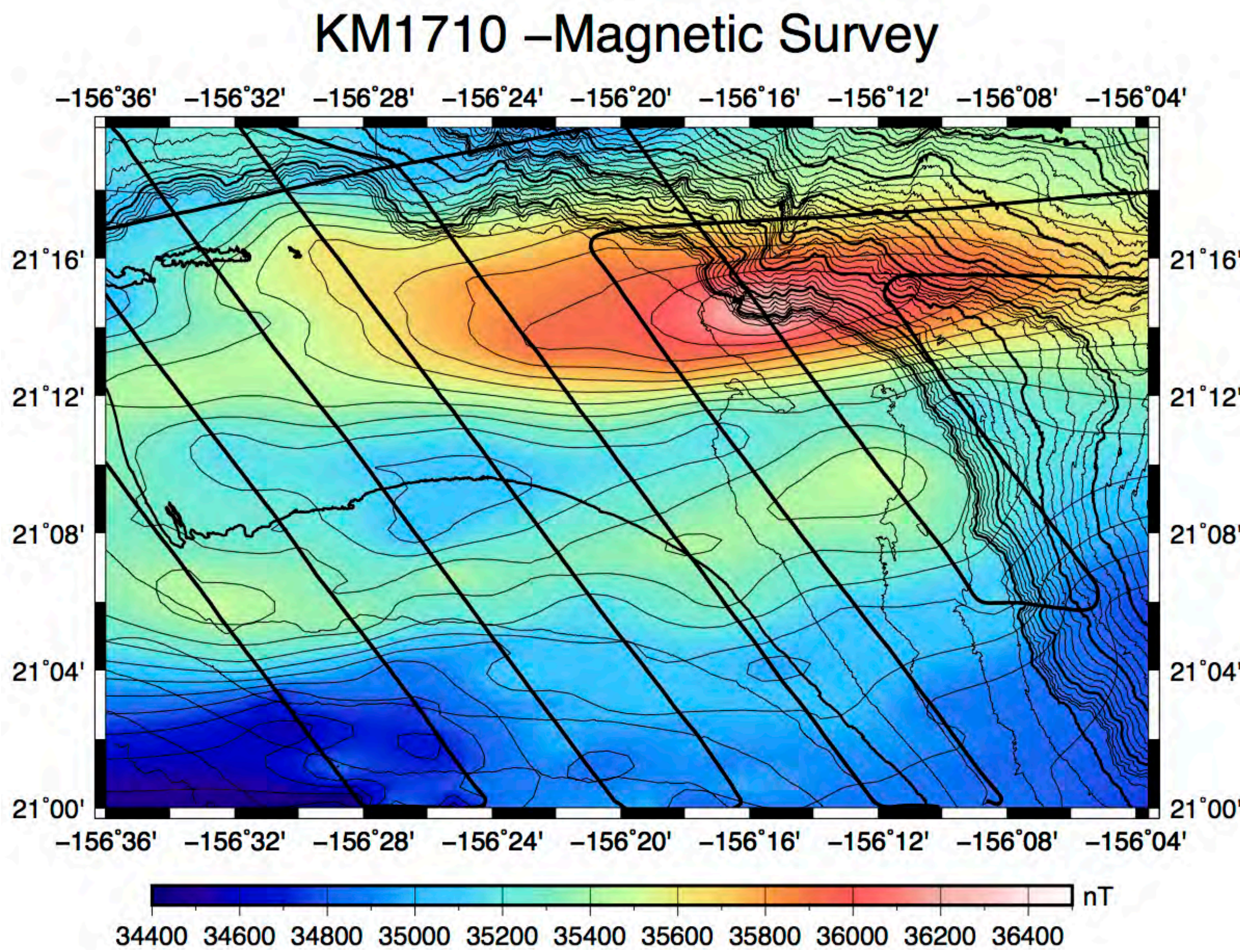


Figure 15: Filtered and gridded total-field magnetic data (nT) overlain by ship tracklines and contours of bathymetry.

The inclination of the Earth's magnetic field varies from ~90° at the magnetic poles to ~0° at the equator. The magnetization vector at any intermediate latitude can be described by its constituent inclination and declination components. Local magnetic anomalies can therefore appear skewed from their sources depending on the local inclination and declination. The Reduction to Pole (RTP) correction is a spectral domain transformation that reduces observations to what they would look like at the magnetic poles with an inclination of 90° and a declination of 0°. The latest GMT version 5 release includes a routine called `grdredpol` that computes the RTP anomaly (Wessel and Smith 1998). We applied it to the IGRF anomaly to arrive at a map of "reduced-to-pole" magnetic anomalies.

The final map (Fig. 16) has a large positive anomaly located along the northern edge of the volcanic edifice. This is likely an edge effect due to topography of a magnetized layered. There is an additional positive anomaly located along the Bouguer gravity high, which may reflect the location of a rift zone. Further processing would include calculating the source magnetization using a magnetic inversion, which would help adjust for the edge effect.

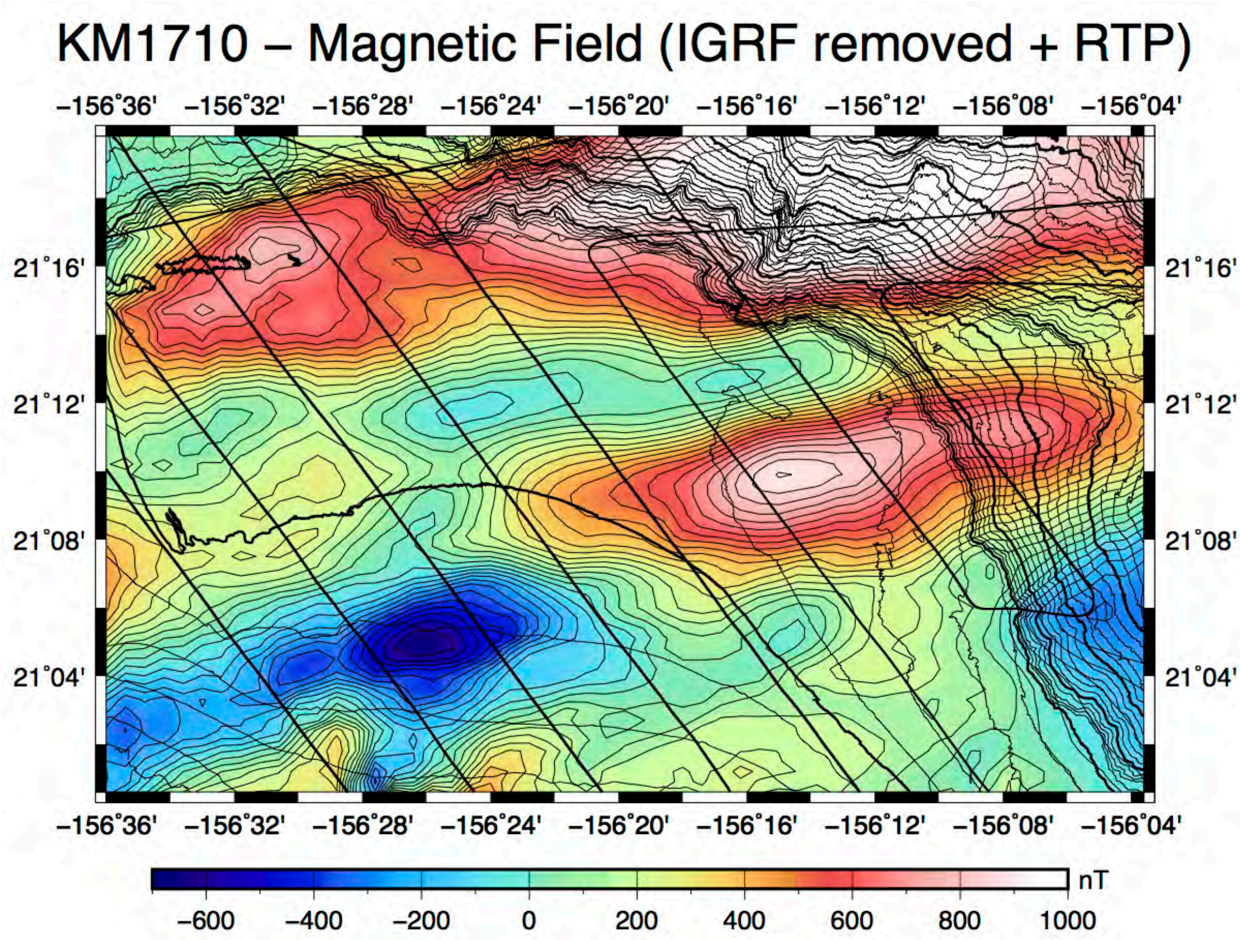


Figure 16: Preliminary magnetic anomaly map with IGRF removed and RTP correction applied (nT), with bathymetry contours and track lines overlain. The large positive anomaly in the north is likely an edge effect due to the edge of the volcanic platform. High magnetization also appears along a line trending from the Pa'uwela Ridge westward beneath the carbonate platform towards East Molokaʻi.

4.4. Multibeam Acoustics

Two hull-mounted multibeam echo sounders were employed aboard the R/V Kilo Moana; type Kongsberg Maritime EM122 and EM710. The EM122 is designed to emit 12 kHz frequencies, with a depth range of 20-11,000m. Swath width is roughly a multiple of 6 times water depth. The EM710 is designed to emit 400-100 kHz frequencies and has a depth range of 3 m below transducer to 2800m. Swath width is roughly a multiple of 5.5 water depth. These systems rely on a measure of surface sound speed in the water for accuracy, but due to technical issues the sound speed profiler was shut off late in the cruise and the bathymetry data collected after that point suffered greatly in quality. Data collection was undertaken at a speed of ~12 knots. Preliminary versions of the resulting multibeam bathymetry map (Fig. 17) and sonar amplitude image (Fig. 18) are shown below.

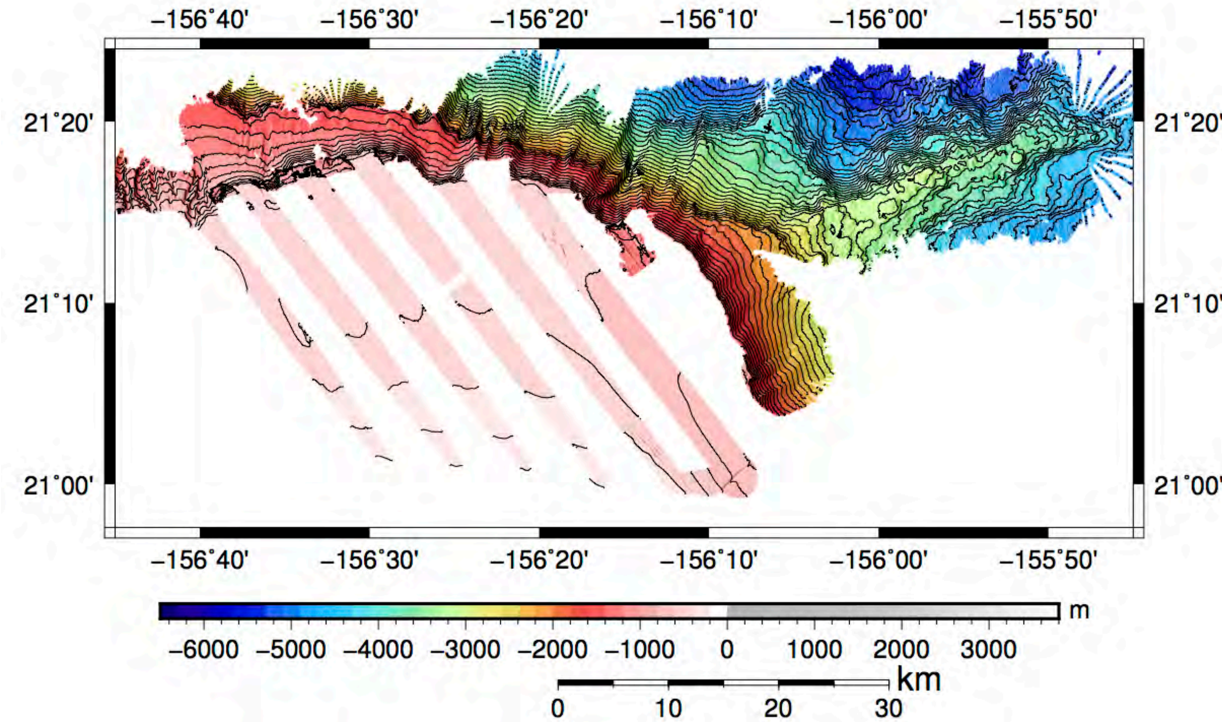


Figure 17. Multibeam bathymetry map of data collected during KM1710.

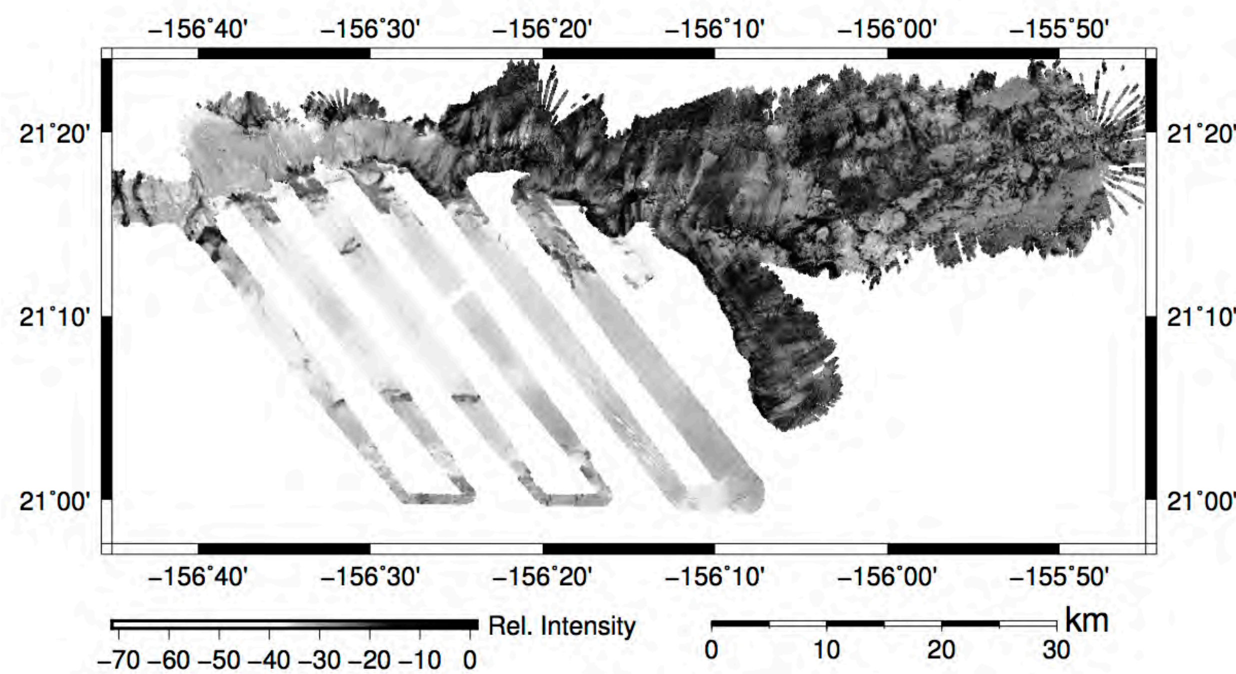


Figure 18. EM122 multibeam sonar amplitude image of the seafloor.

4.5. Rock Dredges

We conducted three dredge deployments, two of which successfully recovered rock samples. Locations and durations of dredges are shown in Table 3. Dredges were conducted from the computer lab where we had easy access to wire tension data, ship position and speed information, and a winch console set up so to drive the winch remotely from the lab. During the first dredge, we discovered that the remote console had a dead zone at low wire speeds (~0-15 m/min), which made it impossible to pay the wire in as slowly as desired. Although wire tensions never exceeded the safe operating limit, and the tension readings were fairly typical the entire time the dredge was on bottom, the wire tensions dropped significantly at the start of recovery, and the wire returned with the dredge missing but the safety chain still attached.

After the first failed dredge, we returned to the first dredge site and tried again with the remaining dredge, which was newer and appeared to be in better condition. We double-checked the equipment and weak link settings, and switched the winch console for one that allowed for better control at low wire speeds. The new console solved the dead zone issue, and the second attempt was more efficient and successful, recovering an estimated ~200 kg of rock samples. We conducted a third and final dredge in a different location with another successful sample recovery.

Table 3. Summary of rock dredges

Dredge	Date	Total time	Dredge on bottom	Dredge off bottom	Recovery
1	7/18/17	4 hrs	21° 18.364 N, 155° 54.880 W	21° 17.334 N, 155° 55.966 W	--
2	7/18/17	2 hrs 18 min	21° 18.489 N, 155° 54.828 W	21° 17.739 N, 155° 55.522 W	~200 kg ol-phyric pillow basalts
3	7/19/17	2 hrs 18 min	21° 16.298 N, 156° 0.827 W	21° 15.424 N, 155° 59.707 W	~150-200 ol+pl pillow basalts

Rock samples are dominated by olivine-rich pillow basalts with a thin (1-3 mm) manganese rind. Some of the pillow basalts have a thin glass rind with variable amounts of devitrification and alteration. Representative samples were selected and numbered for each dredge (9 from dredge 2 and 8 from dredge 3), and will be sub-sectioned and prepared for geochemical analyses of glass (EPMA) and whole rock (XRF and ICP-MS) material.

4.6. Surface Water Sampling

We conducted two deployments of the manta trawl for plastic sampling and larval fish sampling (Table 4), during which three plastic pieces and three larval fish were recovered.

We also conducted underway water sampling using the underway seawater pump, which was connected to a 100-µm filtration system. Three additional micro-plastic pieces were recovered during the underway sampling.

Table 4. Surface water sampling

Manta trawl	Date	Local time	Total time	Flowmeter			Lat (°N)	Long (°W)	# plastics
				start	end	difference			
1	7/17/17	12:45	26 min	633063	674704	41641	21 16.339 N	157 1.378 W	3
2	7/18/17	03:30	23 min 55 sec	674704	826579	151875	21 0.060 N	156 9.981 W	0
Underway system	7/18/17	15:30	12 hrs	0.5 l/min	0.5 l/min	360 liters	21 0.060 N	156 9.981 W	3

5. The REU Experience

This cruise provided a 3-day seagoing research experience for 11 undergraduate students (including 10 students participating in the Department of Geology and Geophysics' NSF/REU program and 1 student from an NIST summer research program) and 3 graduate students. Two high school students from Kamehameha Schools also participated. All students were actively engaged in research activities, serving as watch standers, keeping data logs and activity logs, and assisting with deck operations (including rock dredging and net tows) and sample processing. Students learned about ship operations, the technology we use for geophysical data collection (including sonar, magnetics and gravity) and how those data inform us about the Earth. They also got a taste for life at sea, and got to experience first-hand the challenges of working on a moving platform in a dynamic environment, and the adjustments and problem solving that occurs when dealing with the unexpected. In addition to the hands-on introduction to marine geology and geophysics, students emphasized the greater understanding they gained of what it means to be part of a team, with scientists across a range of disciplines and career stages all contributing their skills towards a common goal.

Two of the students will use samples collected during the cruise in their current thesis projects, and we anticipate additional student projects will be conducted on the data and samples in the future.

About the REU program

This is the first summer of the Department of Geology and Geophysics' NSF/REU site program (the program is expected to run at least 3 years). The first objective of the REU is to provide cutting-edge STEM research opportunities for traditionally underrepresented groups, in particular Native Hawaiians and Pacific Islanders, as well as other minorities presently enrolled at undergraduate institutions that provide few opportunities to participate in cutting-edge research. In short, find excellent students from this population who will benefit the most from our program. The second objective is to improve students' writing and presentation skills and to encourage all students to submit an abstract and present their work at the Fall AGU Meeting or the Annual GSA Meeting. The third objective is to remain connected with our REU students long after they leave our campus and to follow their progress in graduate school and beyond. This year the program hosted 10 undergraduates. Among them, there are six sophomores, three juniors and one freshmen, with three Pacific Islanders, three Caucasians, two African-Americans, one Asian, and one Hispanic student. Each student was engaged in a 9-week intense research project with individual mentors. This research cruise was a major component of programmatic objective one: to provide cutting-edge STEM research opportunities for students who would otherwise not have available to them such a unique and challenging opportunity.

6. Personnel

Table 5. Ship's Officers and Crew

Name	Position
Greg Steele	Captain
Brian Wehmeyer	Chief Mate
Luke Barker	Second Mate
Brian Ziehl	Third Mate
Thomas Perry	Able Seafarer
Roger Rios	Able Seafarer
Drew Steiger	Able Seafarer
Guy Butler	Able Seafarer
Ryan Williams	Able Seafarer
Chris Altieri	Able Seafarer
Ted Kane	Chief Engineer
Dimitri Exintadekas	First Ass't Engineer
Arron Gavin	Second Ass't Engineer
Dan Jensen	Third Ass't Engineer
Nanea Baird	QMED
Dan Hinshaw	QMED
Richie Velasquez	QMED
Tim Webb	Chief Steward
Manny Camacho	Cook
Robert Alvarez	Steward's Ass't

Table 6. Science Party

Name	Position	Duties
Deborah Eason	Chief Scientist	
Robert Dunn	Co-Chief Scientist	Geophysical survey
John Sinton	Scientist	Dredging, sample processing
Steve Martel	REU mentor	Student mentoring and oversight
Sarah-Jeanne Royer	Postdoc (CMORE)	Net tows, microplastics
Emily First	Graduate student (GG)	Watch stander

Cassie Ka'apu-Lyons	Graduate student (MBIO)	Net tows, larval fish
Michael Mathiodakis	Graduate student (GG)	Watch stander
Kayla Brignac	NIST student (GES)	Net tows, microplastics
Jacob Burstein	REU student	Watch stander/Sci. Ops.
Joshua Burstein	REU student	Watch stander/Sci. Ops.
Jennet Chang	REU student	Watch stander/Sci. Ops.
Imani Guest	REU student	Watch stander/Sci. Ops.
Christina Kitamikado	REU student	Watch stander/Sci. Ops.
Marcelina Kubica	REU student	Watch stander/Sci. Ops.
Daniel Litchmore	REU student	Watch stander/Sci. Ops.
Holly Pettus	REU student	Watch stander/Sci. Ops.
Paul Regensburger	REU student	Watch stander/Sci. Ops.
Leann Zuniga	REU student	Watch stander/Sci. Ops.
Alex Aarona	Kamehameha student	Watch stander/Sci. Ops.
Kalia Finau	Kamehameha student	Watch stander/Sci. Ops.
OTG		
Jeffrey Koch	Marine tech	
Trevor Young	Marine tech	
Scott Curry	Marine tech	
Julianna Diehl	Marine tech	

Table 7. Science Watch Schedule

Standard watch:

watch leaders (8 hrs)	0800-1600	1600-2400	0000-0800
	Robert Dunn	Steve Martel	Emily First

(4 on 8 off)	0800-1200	1200-1600	1600-2000	2000-2400	0000-0400	0400-0800
1	Jacob B.	Alex A.	Joshua B.	Jacob B.	Alex A.	Joshua B.
2	Jennet C.	Imani G.	Christina K.	Jennet C.	Imani G.	Christina K.
3	Kalia F.	Daniel L.	Paul R.	Kalia F.	Daniel L.	Paul R.
4	Marcelina K.	Holly P.	Leann Z.	Marcelina K.	Holly P.	Leann Z.
5	Michael M.	--	--	Michael M.	--	--

Flex watch:

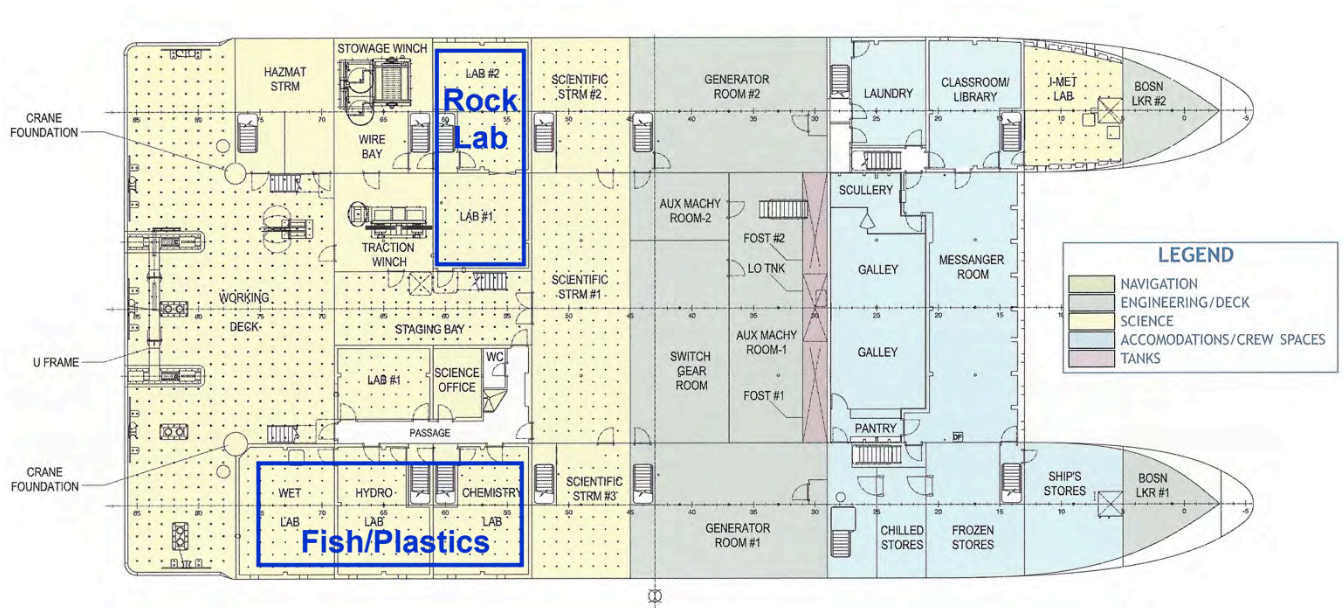
net watch (~8 hrs, and/or as needed)	*(as needed)*	2000-0600
		Sarah-Jeanne R. Kayla B. Cassie K.-L.
dredge watch	*(on call as needed)*	
	John Sinton, Deborah Eason	

Watch Stander Activities
All watch standers report to computer lab 15 mins before start of watch.
Monitor all science equipment and data feeds.
Keep a running log of all science activities and ship motion.
Keep running logs of the acoustics, gravimeter, and magnetometer data collection systems.
Log all net tows and seafloor dredges, and assist with sample processing.

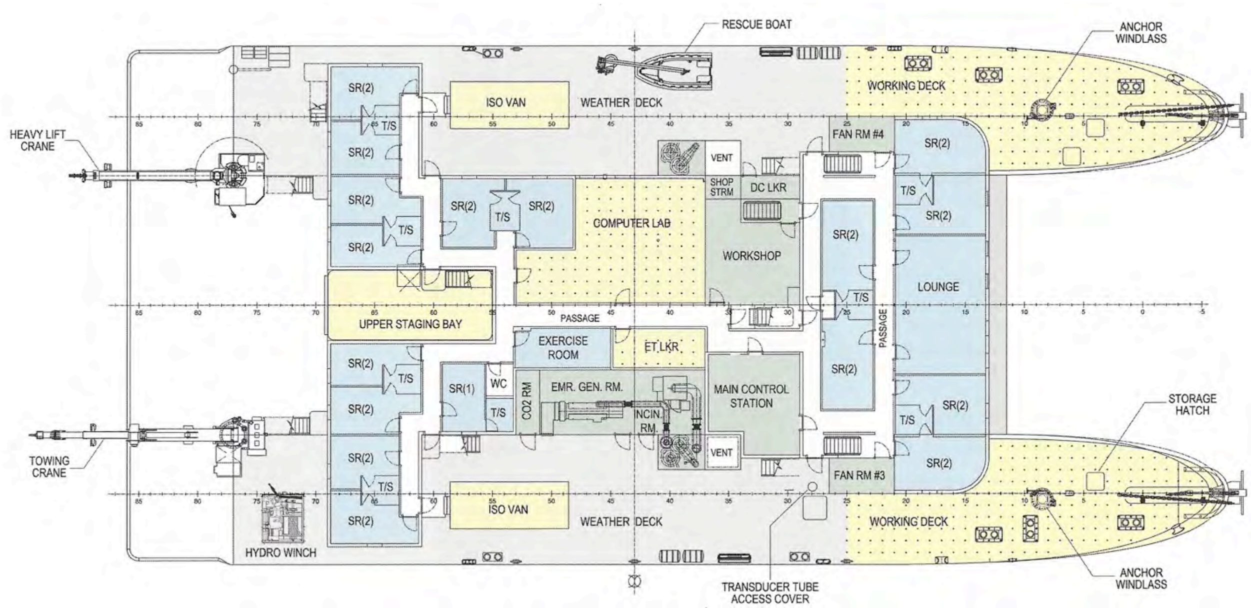
7. Ship Layout

Figure 19. Ship layout, showing location of sample processing labs.

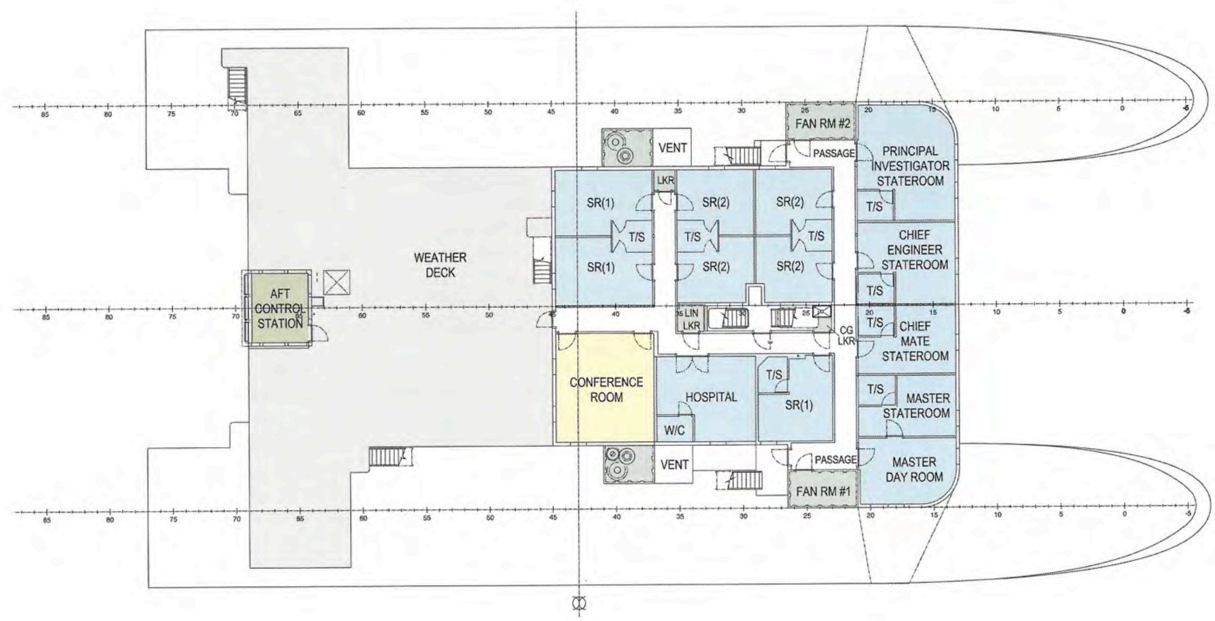
Main deck



Level 01



Level 02



8. Acknowledgments

The science party would like to thank Paul Wessel for his hard work that led the creation of the Department of Geology and Geophysics REU program and who arranged the ship time for this research experience. Thanks to Scott Curry and John Sinton for lending critical knowledge and assistance to the dredging operations. We would also like to thank the Captain, officers, and crew of the R/V *Kilo Moana* for their hospitality and expertise, as well as the OTG group, who consistently went above and beyond to lend a hand, and helped ensure smooth operations despite a grueling schedule. We are indebted to all for their patient and enthusiastic reception of our students. Funding was provided by the National Science Foundation as part of a Research Experience for Undergraduates program awarded to the Dept. of Geology and Geophysics (PI: Wessel), with additional ship time provided by SOEST, University of Hawaii at Mānoa.

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Appendix

Gravity and Magnetics Processing Codes

```
#extractRawData.csh
#!/bin/csh
##############################################################
#        Extract the raw gravity, magnetic, and the navigation data
#        for merging and processing
#       Extract bathymetry values from a grid file to merge with data
#       since rdepth file is empty.
#
#       Use a set of lat/lon values to window down the data to main survey
#
##############################################################
# dummy files
set TMP1 = ../TMP/tmp1.txt
set TMP2 = ../TMP/tmp2.txt
set TMP3 = ../TMP/tmp3.txt
#############################################################
#
# Extract the GRAVITY data
#
set IDIR = ../../KM1710/km1710-Finaldata/
set ODIR = ../TMP/
set IFN = km1710_bgm3grav
set OFN = grav_cut.txt
# Extract main columns of data (time and raw gravity)
awk '{print $1, $2, $3, $4, $5, $6, $10}' $IDIR/$IFN >! $ODIR/$OFN
##############################################################
# Extract the MAGNETIC data
#
set IDIR = ../../KM1710/km1710-Finaldata/
set ODIR = ../TMP/
set IFN = km1710_rmagy
set OFN = magy_cut.txt
# Extract main columns of data (time and raw gravity)
awk '{print $1, $2, $3, $4, $5, $6, $8}' $IDIR/$IFN >! $ODIR/$OFN
#############################################################
# Extract the navigation data
#
set IDIR = ../../KM1710/km1710-Finaldata/
set ODIR = ../TMP/
set IFN = km1710_pos-mv
set OFN = pos-mv_cut.txt
# Extract main columns of data (time and raw gravity)
awk '{print $8, $9, $1, $2, $3, $4, $5, $6, $11, $12, $15, $16, $17, $18}' $IDIR/$IFN >! $ODIR/$OFN
#awk '($8 >= -156.75)' $TMP2 >! $TMP1
#awk '($8 <= -156.05)' $TMP1 >! $NAV
#############################################################
# Extract the bathymetry from a grid file using gmt (grdtrack)
#grdtrack reads a grid file (or a Sandwell/Smith IMG file) and a table (from file or
#       standard  input) with (x,y) positions in the first two columns (more columns may be
#       present). It interpolates the grid at the positions in the table and writes out the
#       table  with  the  interpolated  values added as a new column.
set BGRD = ../GRD/himbsyn.bathytopo.v19.grd
set XYZFILE = $ODIR/pos-mv_cut.txt
set ODIR = ../TMP/
set OFN = pos-mv_cut.txt
grdtrack $XYZFILE -G$BGRD -: >! $TMP1
#Re-order columns so time comes first like other files (convert neg depths to pos. depths)
awk '{print  $3, $4, $5, $6, $7, $8, $1, $2, $9, $10, $11, $12, $13, $14, $15*-1}' $TMP1 >! $ODIR/$OFN
exit
##############################################################

% MergeData.m
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Load raw navigation, gravity, maggie and merge the navigation with the
% grav/mag data
%
clear all
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
make_vectors = 0;
merge_data   = 1;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Nav data
if(make_vectors)
    disp('Setting up matlab vectors of time and data')
    load ../TMP/pos-mv_cut.txt
%Create time and data vectors
```

```
    nav = pos_mv_cut;
    nav_time = nav(:,2)*24 + nav(:,3) + nav(:,4)/60 + (nav(:,5)+nav(:,6)/1000)/3600;
    nav_lat     = nav(:,7);
    nav_lon     = nav(:,8);
    nav_speed   = nav(:,9);
    nav_cog     = nav(:,10);
    nav_heading = nav(:,11);
    nav_roll    = nav(:,12);
    nav_pitch   = nav(:,13);
    nav_heave   = nav(:,14);
    nav_depth   = nav(:,15);
    save ../TMP/KM1710_nav_raw.mat nav_time nav_lat nav_lon nav_speed nav_cog nav_heading nav_roll nav_pitch
nav_heave nav_depth
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % Magy data
    load ../TMP/magy_cut.txt
    mag = magy_cut;
    mag_time = mag(:,2)*24 + mag(:,3) + mag(:,4)/60 + (mag(:,5)+mag(:,6)/1000)/3600;
    mag = mag(:,7);
    save ../TMP/KM1710_mag_raw.mat mag_time mag
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % Gravity data
    load ../TMP/grav_cut.txt

    grv = grav_cut;
    grav_time = grv(:,2)*24 + grv(:,3) + grv(:,4)/60 + (grv(:,5)+grv(:,6)/1000)/3600;
    grav = grv(:,7);

    save ../TMP/KM1710_grav_raw.mat grav_time grav
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Merge lat/lon with data
if(merge_data)
    clear all
    disp('Merging navigation data with mag and grav data')
    load ../TMP/KM1710_nav_raw.mat
    load ../TMP/KM1710_mag_raw.mat
mag_lat     = interp1(nav_time,nav_lat,mag_time,'linear');
    mag_lon     = interp1(nav_time,nav_lon,mag_time,'linear');
    mag_speed = interp1(nav_time,nav_speed,mag_time,'linear');
    mag_heading = interp1(nav_time,nav_heading,mag_time,'linear');
    mag_depth = interp1(nav_time,nav_depth,mag_time,'linear');
figure(1); clf reset
    plot(mag_lon,mag_lat,'.')
    drawnow

    save ../PROC/KM1710_mag_raw_merged.mat mag_time mag_lat mag_lon mag
    fid = fopen('../PROC/KM1710_mag_raw_merged.txt','w');
    fprintf(fid,'%12.7f %12.7f %12.7f %12.7f %12.7f %12.7f %12.7f\n',[mag_lat(:) mag_lon(:) mag(:) mag_time(:)
mag_speed(:) mag_heading(:) mag_depth(:)]');
    fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % question: include ship's gyroscope? is it much different from
    % pos-mv heading? A gyroscope is usually more reliable, but with
    % less accurate data than pos-mv.
    clear all
     load ../TMP/KM1710_nav_raw.mat
    load ../TMP/KM1710_grav_raw.mat
%cut gravity time base to be within bounds of nav timebase
    i1 = find(grav_time>nav_time(1),1,'first');
    i2 = find(grav_time<nav_time(end),1,'last');
    grav_time = grav_time(i1:i2);
    grav = grav(i1:i2);
    grav_lat = interp1(nav_time,nav_lat,grav_time,'linear');
    grav_lon = interp1(nav_time,nav_lon,grav_time,'linear');
    grav_speed = interp1(nav_time,nav_speed,grav_time,'linear');
    grav_heading = interp1(nav_time,nav_heading,grav_time,'linear');
    grav_roll = interp1(nav_time,nav_roll,grav_time,'linear');
    grav_pitch = interp1(nav_time,nav_pitch,grav_time,'linear');
    grav_heave = interp1(nav_time,nav_heave,grav_time,'linear');
    grav_depth = interp1(nav_time,nav_depth,grav_time,'linear');
figure(1); clf reset
    plot(grav_lon,grav_lat,'.')
save ../PROC/KM1710_grav_raw_merged.mat grav_lat grav_lon grav grav_time grav_speed grav_heading grav_roll
grav_pitch grav_heave grav_depth
fid = fopen('../PROC/KM1710_grav_raw_merged.txt','w');
fprintf(fid,'%12.7f %12.7f %12.7f %12.7f %12.7f %12.7f %12.7f %12.7f %12.7f %12.7f\n',[grav_lat(:) grav_lon(:)
grav(:) grav_time(:) grav_speed(:) grav_heading(:) grav_roll(:) grav_pitch(:) grav_heave(:) grav_depth(:)]');
    fclose(fid);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%gravityProc.m
% Process the raw (merged with nav) gravity data
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear all
clf reset
% Load file: [time, lat, lon, raw_grav, speed, depth, heading]
data = '../PROC/KM1710_grav_raw_merged.mat';
load(data);
n = numel(grav);
%Re-zero time vector, convert to decimal seconds, and make it regularly
%spaced (remove time jitter) and any steps (interpolate across steps
% grav_time is in decimal hours
grav_time = 3600*(grav_time-grav_time(1));
%#####kluge: gravity is sampled at 1 sec intervals
dt = 1;
time = 0:dt:grav_time(end);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Interpolate all variables to uniform time vector
grav = interp1(grav_time,grav,time);
grav0=grav;
grav_depth = interp1(grav_time,grav_depth,time);
grav_heading = interp1(grav_time,grav_heading,time);
grav_heave = interp1(grav_time,grav_heave,time);
grav_lat = interp1(grav_time,grav_lat,time);
grav_lon = interp1(grav_time,grav_lon,time);
grav_pitch = interp1(grav_time,grav_pitch,time);
grav_roll = interp1(grav_time,grav_roll,time);
grav_speed = interp1(grav_time,grav_speed,time);
% Unwrap heading values
grav_heading = unwrap(grav_heading*pi/180)*180/pi;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Filter heading and speed with a median filter
% Filter width = 4-6 min
 fwidth = floor((10)/dt);
 heading = medfilt1(grav_heading,fwidth);
 speed  = medfilt1(grav_speed,fwidth);
% FM: Use a cosine filter (use filter1d) 5-6 minutes
%) smooth the heading and speed values: nwh must be even
% Window width in seconds
nwh = (6*60)/dt;
window = hanning(nwh);
window =window./sum(window);
%remove the median before filtering to reduce the edge effect at ends of
%time series.
ml = median(heading);
headings = conv(heading-ml,window,'same')+ml;
ml = median(speed);
speeds  = conv(speed-ml,window,'same')+ml;
% nwh = (4*60)/dt;
% window = hanning(nwh);
% window =window./sum(window);
% ml = median(grav_lat);
% lat = conv(grav_lat-ml,window,'same')+ml;
% ml = median(grav_lon);
% lon = conv(grav_lon-ml,window,'same')+ml;
%[numel(heading) numel(headings)]
%Filter raw gravity
nwh = (6*60)/dt;
window = hanning(nwh);
window =window./sum(window);
ml = median(grav);
gravs = conv(grav-ml,window,'same')+ml;

figure(1); clf
subplot(311)
plot(time,grav_heading,'-k')
hold on
plot(time,heading,'r')
plot(time,headings,'g')
xlabel('relative time, sec')
ylabel('Heading Angle')
subplot(312)
plot(time,grav_speed,'-k')
hold on
plot(time,speed,'r')
plot(time,speeds,'g')
xlabel('relative time, sec')
ylabel('Ship speed, knots')
subplot(313)
plot(time,grav,'-k')
hold on
```

```
plot(time,gravs,'r')
xlabel('relative time, sec')
ylabel('Ship speed, knots')
figure(2)
subplot(311)
plot(time/60/60,gravs,'k')
xlim([35000 80000]./3600)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Calculate Eotvos
eotvos = 7.5038*speeds.*sind(headings).*cosd(grav_lat) + 0.004154*speeds.^2;
% Calculating normal gravity using 1980 geodetic reference standard
g0 = 978032.68*(1+0.00193185138639*(sind(grav_lat)).^2)./((1- 0.00669437999013*(sind(grav_lat)).^2).^0.5);
% As ship is at sea level FAC is not applied as the ship sails along % the refernce ellipsoid so h=0
% Calculate Eotvos
% Calculate Eotvos0
% Calculate the free air anomaly
faa = gravs - g0;
faa_e = faa + eotvos;
figure(2); clf
subplot(311)
plot(time,eotvos,'k')
subplot(312)
plot(time,faa,'r')
subplot(313)
plot(time,faa_e,'r')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Mad filtering
if(1)
  cutoff = 5;
  dh = gradient(headings,dt);
  mad = 1.4826*median(abs(dh-median(dh)));
  ii = find(abs(dh) < cutoff*mad);
  clf
  plot(time,dh,'-k'); hold on
  plot(time(ii),dh(ii),'.r');
  B = [grav_lat(ii)',grav_lon(ii)',faa_e(ii)'];
  C = [grav_lat(ii),grav_lon(ii),grav_depth(ii)];
else
  B = [grav_lat(:),grav_lon(:),faa_e(:)];
  C = [grav_lat(:),grav_lon(:),grav_depth(:)];
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fid=fopen('../PROC/faa_grav.txt','w+');
for i=1:size(B,1)
  fprintf(fid,'%12.8f %12.8f %12.4f\n', B(i,:));
end
fclose(fid);
% Create bathymetric file to use in GMT
fid=fopen('../PROC/bathy.txt','w+');
for i=1:size(C,1)
  fprintf(fid,'%10.8f %10.8f %4.3f\n', C(i,:)); end
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

#pl_faa.csh
#!/bin/csh
# GRID MAGGI DATA and OPTIONALLY MAP the DATA
#########################################################################
#########################################################################
set VERSION = 0.1
echo " "
echo Script $0 version $VERSION at `date`
echo " "
#########################################################################
#########################################################################
set DIRIN  = '../PROC/'
set DIROUT = '../GRD/'
set RANGE  = "-156.8/-156.06/21:00/21:19.8"
set INCX = 0.002
set INCY = 0.001
set GRID_DATA       = 1
set GRID_MODE_SURFACE = 1
set MAP_DATA        = 1
set IFN = $DIRIN/faa_grav.txt
set GFN = $DIROUT/faa_grav_v1.grd
set OFN = ../FIG/faa_grav_survey_map_v1.ps
set BGRD = /Users/MAIN/Dropbox/0.LAB_GROUP/Eason/2017_KM_REU_Cruise/code/bathym/himbsyn.bathytopo.v19.grd
set CNT_LABEL_FILE = molokai_contours.txt
set CPT_FILE_M = molokai_map.cpt
set CPT_FILE = ../TMP/dum.cpt
set TMP1 = ../TMP/tmp1.xy
```

```
set TMP2 = ../TMP/tmp2
if (-e $TMP1) /bin/rm $TMP1
#######################################################################
echo 'Setup Complete'
#######################################################################
#######################################################################
#######################################################################
if ($GRID_DATA) then
    if (-e $TMP1) /bin/rm $TMP1
    if (-e $TMP2) /bin/rm $TMP2
    if (-e $GFN) /bin/rm $GFN
if ($GRID_MODE_SURFACE == '1') then
       echo 'Gridding Data using "Surface" routine'
       #blockmedian -F uses pixel node registration
       echo $IFN
       blockmedian $IFN -I$INCX/$INCY -R$RANGE  -V  -: >! $TMP1
       surface $TMP1 -G$GFN -I$INCX/$INCY -R$RANGE -T.2B -T.2I -V  -:
#Create a mask
       grdmask $TMP1 -G$TMP2 -I$INCX/$INCY -R$RANGE -NNaN/1/1 -S0.015 -V  -:
       grdmath $GFN $TMP2 MUL = $GFN
else
       echo 'Gridding Data using "Surface" routine'
       blockmedian $IFN -I$INCX/$INCY -R$RANGE  -V  -: >! $TMP1
       nearneighbor $TMP1 -G$GFN -I$INCX/$INCY -R$RANGE -N3 -S0.015 -V  -:
endif
endif
#######################################################################
#######################################################################
if ($MAP_DATA) then
   if (-e $OFN) /bin/rm $OFN
#Make the figure
   gmtset PAPER_MEDIA letter
set SCALE = 17
   set TIC   = a4mf2mg2mWESN
   set OPT = "-R -V -O -K -P"
   gmtset PLOT_DEGREE_FORMAT -ddd:mm:ss
   gmtset ANOT_FONT_SIZE  8p
   gmtset HEADER_FONT_SIZE 10p
makecpt -Chaxby -T-100/200/50 -M  -D  -V -Z >! $CPT_FILE
gmt psbasemap -JM$SCALE -R$RANGE -Yc -Xc -B$TIC/:."FAA Gravity Survey": -V -K -P >! $OFN
   gmt grdimage $GFN -JM $OPT -V  -Q -C$CPT_FILE -fg  -B$TIC                >> $OFN
   gmt grdcontour $GFN -J $OPT -C10  -W0.5p  -A-   >> $OFN
#gmt grdcontour $BGRD -J $OPT -C$CPT_FILE_M  -W0.5p  -A- -S4 -Q200  >> $OFN
   #gmt grdcontour $BGRD -J $OPT -C$CNT_LABEL_FILE  -W1.2p -A+r1 -S4 -Q200  >> $OFN
cat $IFN | awk '{print $2, $1}' > $TMP1
#   gmt psxy dum.xy  -J $OPT -W1p >> $OFN
   gmt psxy $TMP1  -J $OPT -W1p -Sc.02  >> $OFN
gmt psscale -C$CPT_FILE -D3.5i/-0.5i/14/0.125ih -Ba20f10g5/:"mgals": -V -O  >> $OFN
open $OFN
endif
exit
#######################################################################
#pl_bgrav.csh
#!/bin/csh
# shell script used to calculate and plot the bouguer gravity anomaly in GMT
#######################################################################
#######################################################################
set VERSION = 0.1
echo " "
echo Script $0 version $VERSION at `date`
echo " "
#######################################################################
#######################################################################
set BOUG_CORR       = 1
set MBOUG_CORR      = 0
set MAP_DATA        = 1
#######################################################################
#######################################################################
set DIR = ../
set DIRIN  = $DIR/GRD/
set DIROUT = $DIR/GRD/
set OFN      = $DIR/FIG/Bouguer_grav_v3.ps
set STDBOUG  = $DIROUT/standard_bouger_correction_v3.grd
set BGA      = $DIROUT/standard_bouguer_anomaly_v3.grd
set MBGA     = $DIROUT/mantle_bouguer_anomaly_v3.grd
set MOHOG    = $DIROUT/moho_grav_v3.grd
set GRAVFILE = $DIRIN/faa_grav_v1.grd
set IFN      = $DIR/PROC/faa_grav.txt
set CUTBATH = $DIR/TMP/junk.grd
# Compute fft on larger grid than final cut (final cut is same soze as faa grid)
set RANGE0  = "-157/-155.3/20.7/21.5"
set RANGE  = "-156.8/-156.06/21:00/21:19.8"
set INCX = 0.002
```

```
set INCY = 0.001
set DENSITY_CONTRAST = 1500
#set DENSITY_CONTRAST = 1200
set BGRD = /Users/MAIN/Dropbox/0.LAB_GROUP/Eason/2017_KM_REU_Cruise/code/bathym/himbsyn.bathytopo.v19.grd
set CNT_LABEL_FILE = molokai_contours.txt
set CPT_FILE_M     = molokai_map.cpt
set CPT_FILE = $DIR/TMP/dum.cpt
set TMP1 = $DIR/TMP/tmp1.xy
set TMP2 = $DIR/TMP/tmp2.xy
if (-e $TMP1) /bin/rm $TMP1
if (-e $TMP2) /bin/rm $TMP2
if (-e $CUTBATH) /bin/rm $CUTBATH
if (-e $OFN) /bin/rm $OFN
#########################################################################
set GRD = $BGA
if ($BOUG_CORR) then
   if (-e $TMP1) /bin/rm $TMP1
   if (-e $TMP2) /bin/rm $TMP2
   if (-e $CUTBATH) /bin/rm $CUTBATH
   if (-e $STDBOUG) /bin/rm $STDBOUG
   if (-e $BGA) /bin/rm $BGA
# cut out a piece of the topo grid
   gmt grdcut $BGRD -G$TMP1 -R$RANGE0 -fg
# This grid has holes! So write out the data and re-grid with surface
   gmt grd2xyz $TMP1    >! $TMP2
   if (-e $TMP1) /bin/rm $TMP1
   grep "NaN" -v $TMP2  >! $TMP1
#blockmedian -F uses pixel regiatration
   if (-e $TMP2) /bin/rm $TMP2
   gmt blockmedian $TMP1 -R$RANGE0 -I$INCX/$INCY -V  >! $TMP2
if (-e $CUTBATH) /bin/rm $CUTBATH
   if (-e $TMP2) /bin/rm $TMP2
gmt surface $TMP1 -G$CUTBATH -I$INCX/$INCY -R$RANGE0 -T0.375B -T0.375I -V
# Calculate bouguer correction assuming seawater density 1035kg/m^3 and crustal density 2700kg/m^3 = 1665 kg/m3
   if (-e $TMP1) /bin/rm $TMP1
   gmt gravfft $CUTBATH -D$DENSITY_CONTRAST -G$TMP1 -fg -E4 -V
gmt grdcut $TMP1 -G$STDBOUG  -R$RANGE -fg
gmt grdmath $GRAVFILE $STDBOUG SUB = $BGA
set GRD = $BGA
endif
if ($MBOUG_CORR) then
   gmt gravfft $CUTBATH=nf/1/-12000 -D600 -G$MOHOG
   gmt grdmath $BGA $MOHOG SUB = $MBGA
   set GRD = $MBGA
endif

# De-mean the grid
gmt grdmath $GRD MEDIAN = $TMP1
gmt grdmath $GRD $TMP1 SUB = $GRD

#########################################################################
if ($MAP_DATA) then
gmt grdgradient $GRD -A270 -Nt1 -G$GRD.grad
   #Make the figure
   gmtset PAPER_MEDIA letter
   set SCALE = 17
   set TIC   = a4mf2mWESN
   set OPT = "-R -V -O -K -P"
   gmtset PLOT_DEGREE_FORMAT -ddd:mm:ss
   gmtset ANOT_FONT_SIZE  8p
   gmtset HEADER_FONT_SIZE 12p
   gmt makecpt -Chaxby -T-50/40/2 -M  -D   -V -Z >! $CPT_FILE
   gmt psbasemap -JM$SCALE -R$RANGE -Yc -Xc -B$TIC/:."KM1710 - Bouguer Gravity": -V -K -P >! $OFN
   gmt grdimage $GRD -JM $OPT -V  -Q -C$CPT_FILE -fg  -B$TIC             >> $OFN
   gmt grdcontour $GRD -J $OPT -C2 -W0.5p  -A-  >> $OFN
   gmt grdcontour $BGRD -J $OPT -C$CPT_FILE_M  -W0.5p  -A- -S4 -Q200  >> $OFN
   gmt grdcontour $BGRD -J $OPT -C$CNT_LABEL_FILE  -W1.2p -A+r1 -S4 -Q200  >> $OFN
   cat $IFN | awk '{print $2, $1}' >! $TMP1
   gmt psxy $TMP1  -J $OPT -W1p >> $OFN
   #gmt psxy $TMP1  -J $OPT -W1p -Sc.02  >> $OFN
   gmt  psscale -C$CPT_FILE -D2i/-0.5i/8/0.125ih -Ba20f10g5/:"mgals": -V -O  >> $OFN
   open $OFN
endif
exit
##################################################
```

Magnetic Processing Codes:

```
!ExtractMagnetcRawData.csh
#!/bin/csh
##########################################################################
#        Extract the raw gravity, magnetic, and the navigation data
#        for merging and processing
```

```
#       Extract bathymetry values from a grid file to merge with data
#       since rdepth file is empty.
#       Use a set of lat/lon values to window down the data to main survey
########################################################################
########################################################################
# dummy files
set TMP1 = ../TMP/tmp1.txt
set TMP2 = ../TMP/tmp2.txt
set TMP3 = ../TMP/tmp3.txt
########################################################################
# Extract the MAGNETIC data
set IDIR = ../../KM1710/km1710-Finaldata/
set ODIR = ../TMP/
set IFN = km1710_rmagy
set OFN = magy_cut.txt
# Extract main columns of data (time and raw gravity)
awk '{print $1, $2, $3, $4, $5, $6, $8}' $IDIR/$IFN >! $ODIR/$OFN
########################################################################
# Extract the navigation data
set IDIR = ../../KM1710/km1710-Finaldata/
set ODIR = ../TMP/
set IFN = km1710_pos-mv
set OFN = pos-mv_cut.txt
# Extract main columns of data (time and raw gravity)
awk '{print $8, $9, $1, $2, $3, $4, $5, $6, $11, $12, $15, $16, $17, $18}' $IDIR/$IFN >! $ODIR/$OFN
########################################################################
# Extract the bathymetry from a grid file using gmt (grdtrack)
#grdtrack reads a grid file (or a Sandwell/Smith IMG file) and a table (from file or
#       standard  input) with (x,y) positions in the first two columns (more columns may be
#       present). It interpolates the grid at the positions in the table and writes out the
#       table  with  the  interpolated  values added as a new column.
set BGRD = ../GRD/himbsyn.bathytopo.v19.grd
set XYZFILE = $ODIR/pos-mv_cut.txt
set ODIR = ../TMP/
set OFN = pos-mv_cut.txt
grdtrack $XYZFILE -G$BGRD -: >! $TMP1
#Re-order columns so time comes first like other files (convert neg depths to pos. depths)
awk '{print  $3, $4, $5, $6, $7, $8, $1, $2, $9, $10, $11, $12, $13, $14, $15*-1}' $TMP1 >! $ODIR/$OFN
exit
#######################################################################
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%mergeMagnData.m
% Load raw navigation, and maggie and merge the navigation with the
% mag data
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear all
make_vectors = 1;
merge_data  = 1;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Nav data
if(make_vectors)
  disp('Setting up matlab vectors of time and data')
  load ../TMP/pos-mv_cut.txt
%Create time and data vectors
  nav = pos_mv_cut;
  nav_time = nav(:,2)*24 + nav(:,3) + nav(:,4)/60 + (nav(:,5)+nav(:,6)/1000)/3600;
  nav_lat   = nav(:,7);
  nav_lon   = nav(:,8);
  nav_speed  = nav(:,9);
  nav_cog   = nav(:,10);
  nav_heading = nav(:,11);
  nav_roll  = nav(:,12);
  nav_pitch  = nav(:,13);
  nav_heave  = nav(:,14);
  nav_depth  = nav(:,15);
save ../TMP/KM1710_nav_raw.mat nav_time nav_lat nav_lon nav_speed nav_cog nav_heading nav_roll nav_pitch
nav_heave nav_depth
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Magy data
  load ../TMP/magy_cut.txt
  mag = magy_cut;
  mag_day_one = mag(1,2);
  mag_time = mag(:,2)*24 + mag(:,3) + mag(:,4)/60 + (mag(:,5)+mag(:,6)/1000)/3600;
  mag = mag(:,7);
  save ../TMP/KM1710_mag_raw.mat mag_time mag mag_day_one
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Merge lat/lon with data
if(merge_data)
  clear all
  disp('Merging navigation data with mag data')
  load ../TMP/KM1710_nav_raw.mat
  load ../TMP/KM1710_mag_raw.mat
```

```
  mag_lat   = interp1(nav_time,nav_lat,mag_time,'linear');
  mag_lon   = interp1(nav_time,nav_lon,mag_time,'linear');
  mag_speed  = interp1(nav_time,nav_speed,mag_time,'linear');
  mag_heading = interp1(nav_time,nav_heading,mag_time,'linear');
  mag_depth  = interp1(nav_time,nav_depth,mag_time,'linear');
  figure(1); clf reset
  plot(mag_lon,mag_lat,'.')
  drawnow
save ../PROC/KM1710_mag_raw_merged.mat mag_time mag_lat mag_lon mag mag_speed mag_heading mag_depth mag_day_one
  fid = fopen('../PROC/KM1710_mag_raw_merged.txt','w');
  fprintf(fid,'%12.7f %12.7f %12.7f %12.7f %12.7f %12.7f %12.7f\n',[mag_lat(:) mag_lon(:) mag(:) mag_time(:)
mag_speed(:) mag_heading(:) mag_depth(:)]');
  fclose(fid);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% ProcMagg.m
% Process the raw (merged with nav) magnetics data
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear all
clf reset
% Load file: [time, lat, lon, raw_grav, speed, depth, heading]
data = '../PROC/KM1710_mag_raw_merged.mat';
load(data);
n = numel(mag);
%Re-zero time vector, convert to decimal seconds, and make it regularly
%spaced (remove time jitter) and any steps (interpolate across steps
% mag_time is in decimal hours
% Set start day in hour from start of year = mag_day_one
% Remove the first part of year (up to start day) from the time vector
mtime = mag_time - mag_day_one*24;
% Save start time on day 1 of survey in decimal hours
mag_time_start = mtime(1);
% Zero the start time on day "mag_day_one" and convert to seconds
mtime = 3600*(mtime-mag_time_start);
%#####kluge: majority of magnetic data is sampled at 1 sec intervals
dt = 1;
time = 0:dt:mtime(end);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Interpolate all variables to uniform time vector
mag = interp1(mtime,mag,time);
mag0=mag;
mag_depth = interp1(mtime,mag_depth,time);
mag_heading = interp1(mtime,mag_heading,time);
mag_lat = interp1(mtime,mag_lat,time);
mag_lon = interp1(mtime,mag_lon,time);
mag_speed = interp1(mtime,mag_speed,time);
% Unwrap heading values
mag_heading = unwrap(mag_heading*pi/180)*180/pi;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Filter heading and speed with a median filter
% Filter width = 10 s
 fwidth = floor((10)/dt);
 heading = medfilt1(mag_heading,fwidth);
 speed  = medfilt1(mag_speed,fwidth);
% FM: Use a cosine filter (use filter1d) 5-6 minutes
%) smooth the heading and speed values: nwh must be even
% Window width in seconds
nwh = (6*60)/dt;
window = hanning(nwh);
window =window./sum(window);
%remove the median before filtering to reduce the edge effect at ends of
%time series.
ml = median(heading);
headings = conv(heading-ml,window,'same')+ml;
ml = median(speed);
speeds  = conv(speed-ml,window,'same')+ml;
%Filter raw maggie data wi median filter
fwidth = floor((10)/dt);
magm = medfilt1(mag,fwidth);
magm = mag;
%Filter raw maggie data wi cosine filter
nwh = (3*60)/dt;
window = hanning(nwh);
window =window./sum(window);
ml = median(magm);
magms = conv(magm-ml,window,'same')+ml;
figure(1); clf
subplot(311)
plot(time,mag_heading,'-k')
hold on
plot(time,heading,'r')
```

```
plot(time,headings,'g')
xlabel('relative time, sec')
ylabel('Heading Angle')
subplot(312)
plot(time,mag_speed,'-k')
hold on
plot(time,speed,'-r')
plot(time,speeds,'-g')
xlabel('relative time, sec')
ylabel('Ship speed, knots')
subplot(313)
plot(time,mag,'-k')
hold on
plot(time,magm,'-r')
plot(time,magms,'-g')
xlabel('relative time, sec')
ylabel('mag value, mT')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Cut out maggie survey periods (remove non-data)
%
%START LINE 0 110.00 07/18/17 00:07:31.238
%STOP LINE 0 110.00 07/18/17 13:37:26.300
%START LINE 1 110.00 07/18/17 14:30:36.387
%STOP LINE 1 110.00 07/18/17 18:23:48.767
%START LINE 2 110.00 07/19/17 15:36:13.976
%STOP LINE 2 110.00 07/20/17 01:28:42.643
%
% July 18 is day 199
% tcut is in decimal hours
tcut = [00*24 + 00 + 07/60 + 31.238/3600 00*24 + 13 + 37/60 + 26.300/3600;
    00*24 + 14 + 30/60 + 36.387/3600 00*24 + 18 + 22/60 + 00.000/3600;
    01*24 + 15 + 36/60 + 13.976/3600 02*24 + 01 + 28/60 + 42.643/3600];
% set cut times to relative times (to start of data vector)
[mag_day_one mag_time_start]
% Time in decimal hours starting at start of original trace on day 199
time = time/3600+mag_time_start;
figure(2)
subplot(311)
plot(time,magms,'-k')
hold on
icut = [];
for i=1:3
  plot([tcut(i,1) tcut(i,1)],[0 6e4],'-g')
  plot([tcut(i,2) tcut(i,2)],[0 6e4],'-r')
  i1 = find(time>=tcut(i,1),1,'first');
  i2 = find(time<=tcut(i,2),1,'last');
  icut = [icut,(i1:i2)];
end
magms  = magms(icut);
headings = headings(icut);
speeds  = speeds(icut);
depth  = mag_depth(icut);
lat   = mag_lat(icut);
lon   = mag_lon(icut);
time   = time(icut);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Calculate IGRF
figure(2); clf
subplot(311)
plot(time,magms,'.k')
subplot(312)
plot(time,headings,'.k')
subplot(313)
plot(time,speeds,'.k')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
B = [lat(:),lon(:),magms(:)];
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fid=fopen('../PROC/mag.txt','w+');
for i=1:size(B,1)
  fprintf(fid,'%12.8f %12.8f %12.4f\n', B(i,:));
end
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

proc_Magg.csh:

```
#!/bin/csh
##########################################################################
#       Add the IGRF correction to Maggie data
##########################################################################
# dummy files
```

```
set TMP1 = ../TMP/tmp1.txt
set TMP2 = ../TMP/tmp2.txt
##########################################################################
if (-e $TMP1) /bin/rm $TMP1
if (-e $TMP2) /bin/rm $TMP2
##########################################################################
# Extract the MAGNETIC data
set IDIR = ../PROC/
set ODIR = ../PROC/
set IFN = $IDIR/mag.txt
set OFN = $ODIR/mag_igrf.txt
# Extract main columns of data (time and raw gravity)Add altitude
# and time to the columns of the data
echo 'Setting up input file. Adding altitude and year'
awk '{print $2, $1, 0, 2017.5, $3}' $IFN >! $TMP1
##########################################################################
# Add the IGRF value
echo 'Computing IGRF field'
gmt mgd77magref $TMP1 -A+y -Frt/0 -V >! $TMP2
##########################################################################
echo 'Removing IGRF field'
awk '{print $1, $2, $3, $4, $5, $6, $5-$6}' $TMP2 >! $OFN
#########################################################################
exit
#########################################################################

#pl_mag_igrf.csh
#!/bin/csh
# GRID MAGGI DATA and OPTIONALLY MAP the DATA
set VERSION = 0.1
#########################################################################
set DIRIN  = '../PROC/'
set DIROUT = '../GRD/'
set RANGE  = "-156.6/-156.06/21.01/21:19.8"
set INCX = 0.010
set INCY = 0.005
set GRID_DATA       = 1
set MAP_DATA        = 1
set IFN = $DIRIN/mag_igrf.txt
set GFN = $DIROUT/mag_igrf.grd
set OFN = ../FIG/mag_igrf_survey_map.ps
set BGRD = /Users/MAIN/Dropbox/0.LAB_GROUP/Eason/2017_KM_REU_Cruise/code/bathym/himbsyn.bathytopo.v19.grd
set CNT_LABEL_FILE = molokai_contours.txt
set CPT_FILE_M = molokai_map.cpt
set CPT_FILE = ../TMP/dum.cpt
set TMP1 = ../TMP/tmp1.xy
set TMP2 = ../TMP/tmp2.xy
if (-e $TMP1) /bin/rm $TMP1
if (-e $TMP2) /bin/rm $TMP2
#########################################################################
echo " "
echo Script $0 version $VERSION at `date`
echo " "
#########################################################################
if ($GRID_DATA) then
    if (-e $TMP1) /bin/rm $TMP1
    if (-e $GFN) /bin/rm $GFN
    #blockmedian -F uses pixel node registration
    echo $IFN
    cat $IFN | awk '{print $1, $2, $7}' | blockmedian -I$INCX/$INCY -R$RANGE  -V   >! $TMP1
    surface $TMP1 -G$GFN -I$INCX/$INCY -R$RANGE -T.15B -T.15I -V
endif
gmt grdredpol $GFN  -G$GFN.rtp.grd -W.1 -F45/45 -T2017.5 -V
set GFN = $GFN.rtp.grd
#########################################################################
if ($MAP_DATA) then
   if (-e $OFN) /bin/rm $OFN
   #Make the figure
   gmtset PAPER_MEDIA letter
   set SCALE = 17
   set TIC   = a4mf2mWESN
   set OPT = "-R -V -O -K -P"
   gmtset PLOT_DEGREE_FORMAT -ddd:mm:ss
   gmtset ANOT_FONT_SIZE  8p
   gmtset HEADER_FONT_SIZE 12p
   makecpt -Chaxby -T-700/1000/50 -M  -D  -V -Z >! $CPT_FILE
   gmt psbasemap -JM$SCALE -R$RANGE -Yc -Xc -B$TIC/:."KM1710 - Magnetic Field (IGRF removed + RTP)": -V -K -P
>! $OFN
   gmt grdimage $GFN -JM $OPT -V  -Q -C$CPT_FILE -fg  -B$TIC                >> $OFN
   gmt grdcontour $GFN -J $OPT -C50  -W0.5p  -A-   >> $OFN
   gmt grdcontour $BGRD -J $OPT -C$CPT_FILE_M  -W0.5p  -A- -S4 -Q200  >> $OFN
   gmt grdcontour $BGRD -J $OPT -C$CNT_LABEL_FILE  -W1.2p -A+r1 -S4 -Q200  >> $OFN
#   cat $IFN | awk '{print $2, $1}' > $TMP1
```

```
#    gmt psxy dum.xy  -J $OPT -W1p >> $OFN
    cat $IFN | awk '{print $1, $2}' | gmt psxy -J $OPT -W1p -gd1k  >> $OFN
   gmt psscale -C$CPT_FILE -D3.25i/-0.5i/15/0.125ih -Ba200f100g200/:"nT": -V -O  >> $OFN
   open $OFN
endif
exit
########################################################################
```