Final Project Report
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The WHOI Towed Digital Camera and Multi-Rock Coring System (*TowCam*)

Daniel J. Fornari – WHOI
(dfornari@whoi.edu)

1. Introduction

The application of recent advances in digital imaging technology to deep-sea photography is necessary for conducting a wide range of disciplinary investigations in many seafloor terrains without the cumbersome and time-intensive requirements of 35mm film development, especially at sea. Because digital imaging provides the potential for immediate or near real-time analysis of the photographs, the benefits of deep-sea digital photography are significant in terms of ground-truthing interpretations made from sonar data or using the imagery to plan other deep submergence vehicle operations (e.g. night surveys prior to diving *Alvin*). The WHOI Towed Digital Camera and Multi-Rock Coring System (*TowCam*) was developed in consideration of these advantages for conducting a wide range of seafloor science using both traditional, surface-ship methods, as well as nested surveys employing deep submergence vehicle systems.

The current *TowCam* system benefited from several earlier deep-sea cameras developed at WHOI between 1993 and 2001. The project was intended to provide funds to construct one camera system with rock coring capability. Because an earlier camera system was lost during a deployment in Sept. 2001 in the Galapagos Islands, the insurance money recovered from that system was used to supplement the grant funding to build three (3) systems. All the systems share the same components and electrical - mechanical infrastructure. The three camera frames are staged as follows. The prototype frame (TowCam#1) (~1700# fully configured) is resident on R/V Atlantis for use as a nighttime survey system to complement *Alvin* diving operations (Figure 1). The second frame (TowCam#2; ~1500# fully configured) (Figure 2) is available for use by any investigator requesting it and can be deployed from most ships in the UNOLS fleet that have a CTD winch and conducing cable system. The third frame (also ~1500#), which is identical to TowCam #2, is staged at NOAA-PMEL in Seattle, WA for use as an event response camera, CTD and sampling systems for Ridge2000 science programs.

2. TowCam System Overview

The WHOI *TowCam* is an internally recording digital deep-sea camera system that also permits acquisition of volcanic glass samples using up to eight (8) rock core winches, and triggering of four (4) 1.2 liter or 5.0 liter Niskin bottles, in conjunction with CTD water properties data. The *TowCam* is towed on a standard UNOLS 0.322” coaxial CTD sea cable, thereby permitting real-time acquisition of digital depth and altitude data that can be used to help quantify objects in the digital images. The use of the conducting sea cable and CTD system permits real-time, manual triggering of any of eight rock core units and four Niskin bottles on the sled so that discrete samples of volcanic glass and seawater can be collected during a lowering from specific areas. By operating either at night in between *Alvin* dives, or during other seagoing programs, photographic information of the seafloor can be recorded for near real-time analysis and for planning subsequent *Alvin* dives or other sampling/surveying programs using other vehicle systems.

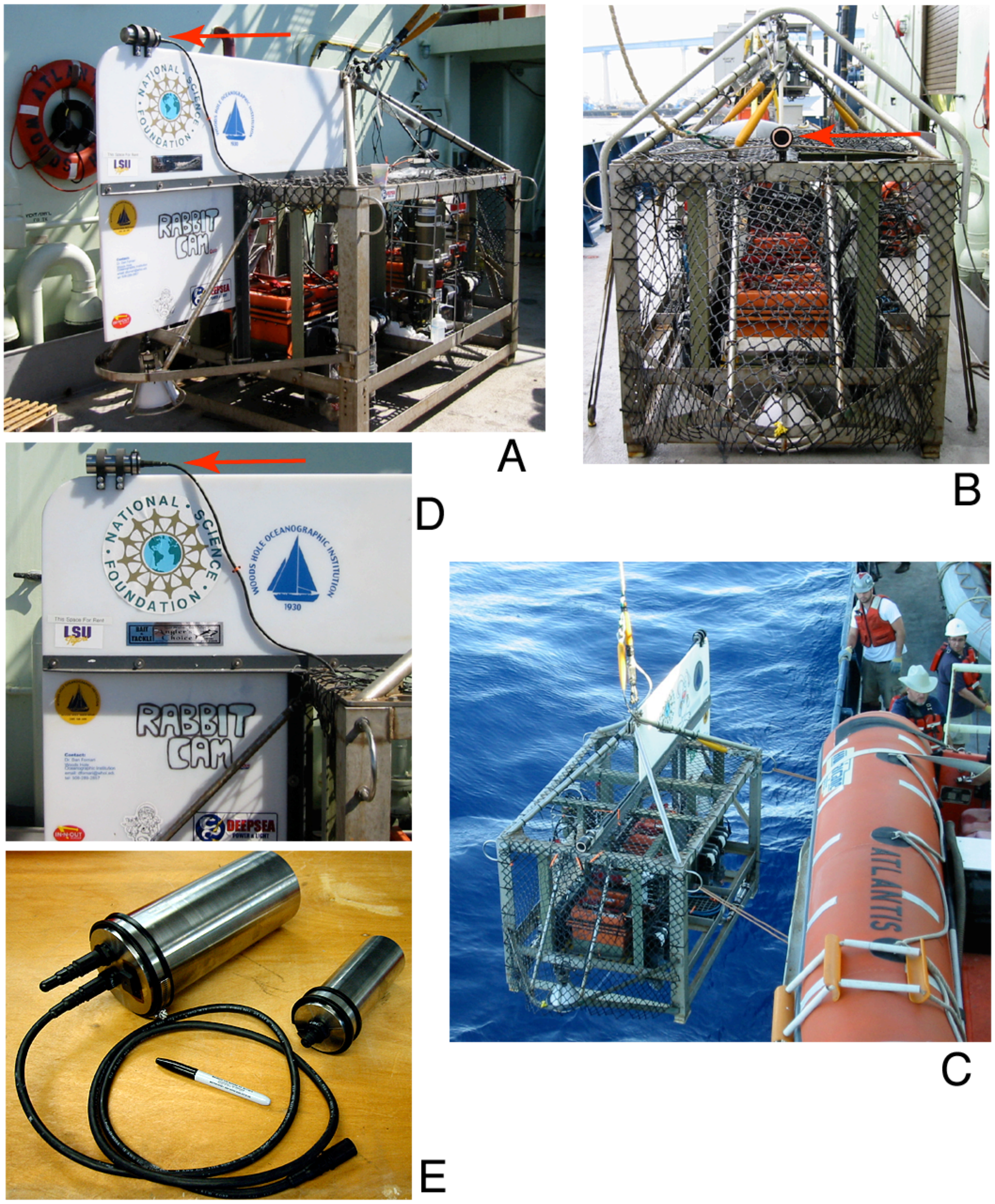

Figure 1. Photographs of TowCam#1, the system resident on R/V Atlantis. A) Photo from rear of the frame showing the self recording magnetometer (red arrow) and rear strobe head under the tail. Orange boxes are the DSPL battery boxes. Instrument in the middle of the frame along the right edge is the SeaBird SBE25 CTD. B) Photo from front of the frame showing forward-looking altimeter (red arrow) used for obstacle avoidance. Forward strobe head is protected by the frame and the black plastic mesh. Aluminum 'roof' shaped poles are supports for the tarp that is kept over the TowCam while on deck to keep the sun off the batteries and instruments. C) TowCam#1 being lowered over the starboard side of R/V Atlantis. Two tag-lines are used to steady the frame as it is deployed and recovered. D) Detailed photo of TowCam#1 tail showing self recording magnetometer (red arrow). E) Self-recording magnetometer on the bench. Larger pressure housing is the recording computer and battery pack. Data are downloaded by plugging into the second connector on this housing (shown dummied off). Smaller unit is the sensor (Sharpee marker for scale).

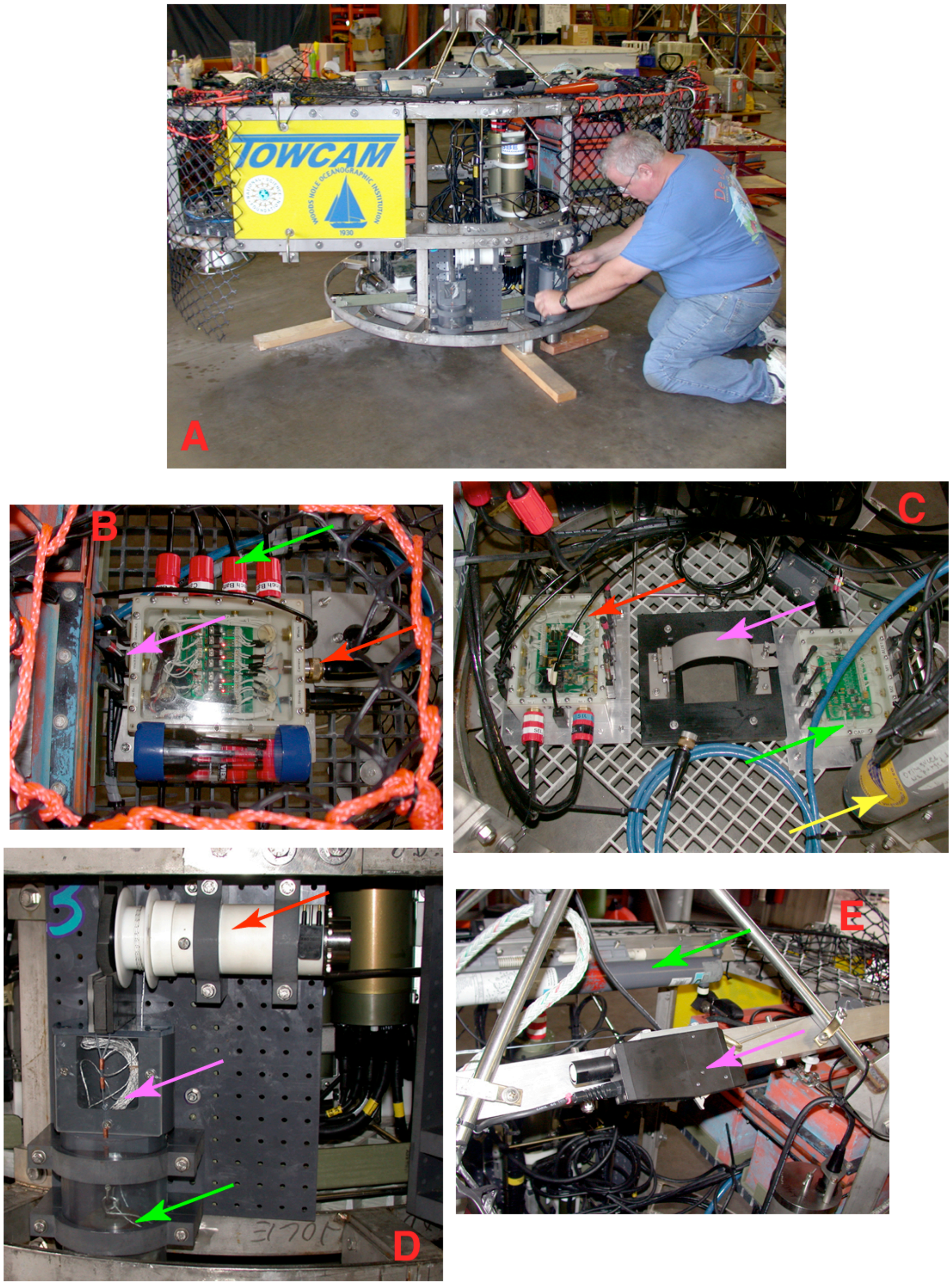

Figure 2. Photographs of TowCam#2, the system available for general use on most UNOLS ships with a hydrographic winch and .0322" CTD conducting cable. A) TowCam#2 frame being worked on by Marshall Swartz, one of the WHOI CTD engineers who has been responsible for the CTD instrument and data integration with the TowCam systems. This frame now has a tail fin to help maintain the orientation of the system as it is towed. Gray units are the winches (see D). B) Power distribution junction box (J-box) is mounted behind the aft strobe head (behind the yellow plastic sheet). Green arrow points to battery inputs, red arrow points to cable coming from camera and strobe electronics unit. Purple arrow points to connectors where the shorted plugs are inserted. The shorted plugs 'turn on' power to the camera, strobe and winch system. C)

top view showing where DSPL camera is mounted (purple arrow); water-bottle J-box is at right (green arrow), and winch system J-box is at left (red arrow). Blue cable is main DSPL camera cable – the other end of which is connected to the power distribution J-box. Yellow arrow at lower right points to the strobe electronics pressure housing. D) TowCam winch unit. Red arrow points to winch motor, green arrow points to sampling ball housed in the clear plastic cylinder, purple arrow points to 10 m of line in the storage chamber. E) Niskin water bottle triggering is done using solenoids (purple arrow) that mechanically releases the monofilament cord to trigger the sampler. Green arrow shows a 1.2 liter Niskin temporarily mounted on the frame during testing of the water bottle triggers on the R/V Sproul in Sept. 2003.

The *TowCam* height off-bottom is monitored in real-time using primarily the 100 kHz altimeter on the CTD (Figure 3B). A 12 kHz pinger is used as a contingency to provide analog altimetry information in case the CTD altimeter malfunctions during a tow. The *TowCam* altitude is controlled by hauling-in and paying out the CTD wire at the lab winch control station. The system is normally towed ~5-7 m above the seafloor at speeds of ~1/4 to 1/2 knott, hence great care must be taken to avoid hitting the bottom. In areas where bottom water clarity is reduced, the tow altitude may be reduced to 2-4 m. The *TowCam* also has a forward-looking altimeter (Figure 3D) that provides quantitative obstacle avoidance so that modest scarps (~<50 m) can be approached and imaged safely during a tow. Detailed multibeam bathymetry maps are a prerequisite for operation of the system. In general camera tows should be conducted along or oblique to bathymetry contours for best towing and safety. Camera and strobes functionality are verified during the tow using the "Flashbird"; a light sensor developed by Mr. Paul Fucile at WHOI that plugs into one of the available serial ports on the Seabird25 CTD (Figure 3C). Each flash from the strobe produces a signal in the CTD data acquisition screen (Figure 4) so that camera functionality can be constantly monitored and the time of each flash can be correlated to the camera time stamped on each image.

A *TowCam* technician, or dedicated person in the science party, must be responsible for preparing the system for each tow and for system maintenance. Operating the *TowCam* requires experienced personnel. Training and supervision of science users in safe and successful towing of the *TowCam* by a qualified technician is required. The ship's Bosun and Resident Shipboard Technicial are critical to the safe launch and recovery of the *TowCam*, and every effort should be made to follow the their instructions and to go over deployment/recovery plans. Detailed discussions with the ship's officers in regards to tow start and end points, water depths and topography are also very important. A detailed log is required for each lowering of the *TowCam*. Those logs, along with maintenance records and charging data sheets are returned to WHOI with the system after a cruise for archiving.

Since completion of its construction in mid-2002, the WHOI *TowCam* has been used successfully on seven research cruises in the Gulf of Mexico, north of Iceland, and in the eastern Pacific Ocean (Figures 4 and 5). It has collected over 150 samples of volcanic glass and recorded >150,000 deep-sea photographs. In addition, since 2002, the digital deep-sea cameras developed as part of the grant have been used on *Alvin* and ROV *Jason2* to collect both horizontal and vertical incidence seafloor photographs on numerous diving expeditions. Use of the cameras on those vehicles has resulted in the collection of an additional ~200,000 deep-sea photographs.

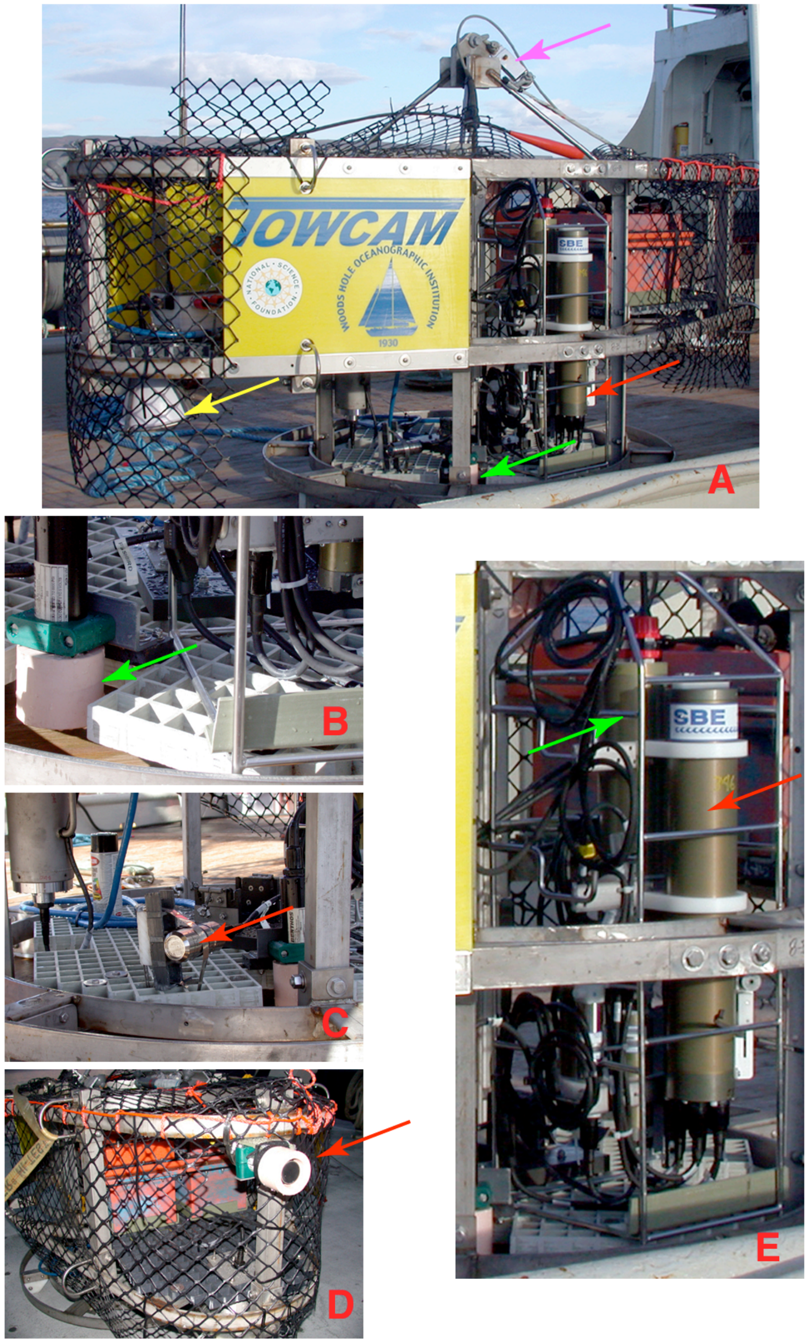

Figure 3. A) TowCam #2 showing location of strobe heads (yellow arrow), down looking altimeter (green arrow) and SeaBird SBE25 CTD (red arrow). Purple arrow points to the weak-link. B) Close-up showing down looking altimeter (green arrow) with the syntactic collar around the transducer head that improves the beam focus and reliability of the sensor. C) Red arrow points to the 'flash bird' the light sensor that monitors the strobe flashes during each tow. This provides verification on deck that the camera is functioning properly, as the camera triggers the strobe. It also confirms when the first photo is taken and when the last one fires. This serves as a check on the time stamp on each image. D) Red arrow points to forward looking altimeter mounted on the nose of the TowCam frame. E) SeaBird SBE25 CTD unit showing the main CTD unit (red arrow) and the Command Release Module (green arrow) that provides the trigger control the rock coring winch operations and Niskin water bottle firing.

2.1. TowCam Mechanical Design

The *TowCam* frame is made of stainless steel with a bridle and lift point suitable for connection to standard UNOLS CTD terminations. The frame is constructed to withstand moderate abuse in order to protect the camera components from contact with the ocean bottom or other objects such as the ship and shipboard equipment. The design and large sail area of the 'tail' provide towing stability to the sled in a nose forward attitude under normal conditions. During a recent cruise to the EPR at 9°30'-50'N, a self-recording 3-axis magnetometer was used on the TowCam (Figure 1). Data from the magnetometer show that the TowCam orientation during a traverse is within ~5° of the course over ground of the ship, and that the magnetic effect of the TowCam frame is very small (~400 T).

The *TowCam* is connected to the end of the CTD wire using either a molded termination or a 'Chinese-finger' termination. A 'weak-link' system has been designed to prevent damage to the cable and release of the frame from the seafloor if it snags on the bottom (Figure 2). A Scripps dredge weaklink with a 5000# tested bolt is attached between the termination and the frame. A ~3m length of wire rope is connected to another 'Chinese-finger' mounted above the termination and to the back of the *TowCam* frame. This arrangement should permit the frame to dislodge from the seafloor when the weak-link parts. At ~2500m depth, the total weight of the system in water ~800# plus the weight of the wire is ~1500# less than the 5000# release, and well below the yield strength of 0.322" cable.

2.2. Electrical Design and Junction Boxes

The electronic design of the system was developed to take advantage of the capabilities and requirements of the four major components of the *TowCam*: the Seabird25 CTD, the DeepSea Power & Light (DSPL) DigiSeacam digital camera (Figure 4), the Benthos 383 strobe and flash-heads, and the WHOI corer winches (Figures 1 and 2) and water bottle releases. The SeaBird25 CTD is powered through the 0.322" coaxial sea cable and data are transmitted through the sea cable to the ship for real-time monitoring of depth, altitude, forward-looking altimeter, flash confirmation (via the 'Flashbird'), and water properties. The sea cable also powers the modified pylon (Command Release Module – [CRM]) used to trigger the core winches and water bottle. The other system components (camera, winches/bottle releases and strobe) operate using the DSPL SeaBatteries (Figure 1) each having a rating of 24 VDC 42 amp/hr (see Sec. 2.3 below). Two batteries are connected in parallel via the power distribution J-box to provide power for the strobes. One battery supplies power to the digital camera and the other battery supplies power to the rock core winches and Niskin bottle releases.

The WHOI designed power distribution system (Steve Liberatore) and corer winches (Ken Doherty and Terry Hammar) were designed to interface with the SeaBird pylon that normally is used to trigger Niskin bottles. SeaBird modified their normal 24 position plyon per specifications delivered to them by Steve Liberatore and Marshall Swartz of WHOI (when used with the *TowCam* this unit has been named the Command Release Module – [CRM] and is documented within the SeaBird component inventory). The power distribution and control electronics designed and built by Liberatore consist of pressure tolerant components housed in three small junction boxes that are mounted on the *TowCam* frame. Detailed documentation and drawings of the electrical design and J-box wiring are part of the *TowCam* system documentation developed as part of the grant and available from D. Fornari at WHOI.

Junction Boxes (J-box) were designed to be modular and interchangeable between all the systems. The TowCam system comprises 3 J-boxes (Figure 2). One is used for power distribution (in from batteries and distributed to camera, strobes and winch/water bottle circuits) and input from camera and strobe. The second J-box is used to take input from the CRM and power from the power distribution J-box and deliver power and trigger signal to the rock coring winches and the water bottle trigger J-box. The third J-box delivers power and signal to specially designed Niskin bottle release solenoids such that when activated they trigger a Niskin bottle.

Figure 4. A) DSPL camera (right) and deck box (left). Inset shows CTD data acquisition screen. Green arrow points to flashbird signals, red arrow points to scrolling 1 Hz depth, altitude data and yellow arrow points to wiggle trace of 1 Hz data. B) Example of a TowCam photograph taken from 4 m altitude at the East Pacific Rise near 9° 50'N. Rectangular blocks on the seafloor are Alvin weights (yellow arrow) and have a dimension of 12" x 12" x 14". Purple arrow points to galatheid crab (squat lobster) that is ~10 cm long.

2.3. Power

The four, 24 VDC DSPL SeaBatteries (see <http://www.deepsea.com>) each provide an average capacity of 42 amp/hr of current. Each DSPL battery comprises two (2) Pb-acid gel-cell 12 VDC batteries wired in series to produce 24VDC. The batteries are pressure compensated using vegetable oil (carnation oil). Even when derated at ~40% for operation at ~2-4°C ambient bottom water, these batteries provide more than enough to provide power for the sled's components during a ~8 hour tow. Normal recharge of the DSPL batteries takes no longer than ~3 hours. A bank of 4 chargers is supplied with each *TowCam* to facilitate simultaneous charging of all the *TowCam* batteries. The chargers are manufactured by MajorPower and are 24V 8 amp 'smart' chargers consisting of three stage, constant current, constant voltage and proportionally timed systems that provide fast charging and optimal timing of charge currents. Careful monitoring and recording of voltages and currents during battery charging is required to ensure proper charging and optimum bottom time, as well as long term records of battery usage so that batteries can be replaced periodically. Battery chargers provide appropriate power to the battery at each stage of the charge cycle, including trickle charging at the end of the cycle. The bank of four chargers is housed in a covered plastic box and should be positioned indoors out of the weather if possible.

As part of the funded project, a large number (30) DSPL SeaBatteries were reconditioned so that each *TowCam* system has a full set of spare batteries (4 on each frame and 4 spares per system). An additional 6 SeaBatteries are available for other uses of the DSPL DigiSeaCam as part of a time-lapse deep-sea photography system (see below).

2.4. Digital Imaging

The DSPL DigiSeaCam (Figure 4) offers a flexible, high-resolution digital photography system that can be applied to a variety of oceanographic imaging applications. The system used on the *TowCam* provides a 6000 m depth rated, 3.3 Mpixel, digital camera (Nikon 995 Coolpix) with a 2GB CompactFlash card for internal image storage. The camera has a corrected dome port that generates crisp, wide-angle photographs exhibiting a minimum of geometric distortion (Figures 4 and 5). The DSPL camera can operate in either attended or unattended modes (for time-lapse photography) and provides the capability to operate, change time-lapse settings, and upload photographs without opening the pressure housing. For the *TowCam*, it is used in a 'simple time lapse' mode whereby the camera is programmed to have a delay that permits descent to the seafloor without taking photographs, thereby saving images for the seafloor traverse. The camera utilizes a DigiSnap controller board (currently a DigiSnap Model 2300 with firmware rev. 3.02- manufactured by Harbortronics (<http://www.harbortronics.com>).

The *TowCam* can take ~1800 digital photographs and stores them internally on the 2 Gbyte CompactFlash card installed in the Nikon 995 camera inside the DSPL DigiSeacam housing. The camera can be set for a delay interval (to permit descent to the seafloor without wasting photographs, i.e. for operations at ~2500m depth a delay of ~60 min. is normally used) via serial communication to the Digisnap board. The interval between photographs is also variable and is set via a serial terminal connection to the Digisnap board. It can be set for intervals between 10 sec to several minutes depending on the use. For normal TowCam operations the interval is set to either 10 sec (bottom time = ~5.5 hrs) or 15 sec (bottom time = ~7.5 hrs). One of DSPL DigiSeacams that is part of the WHOI TowCam systems was used a part of a time-lapse system for Ridge2000 science at the EPR Integrated Study Site (T. Shank et al.) (Figure 6). It was used to take photographs of colonization plates and in situ chemical sensors at a rate of one photograph every 6 min. for a week.

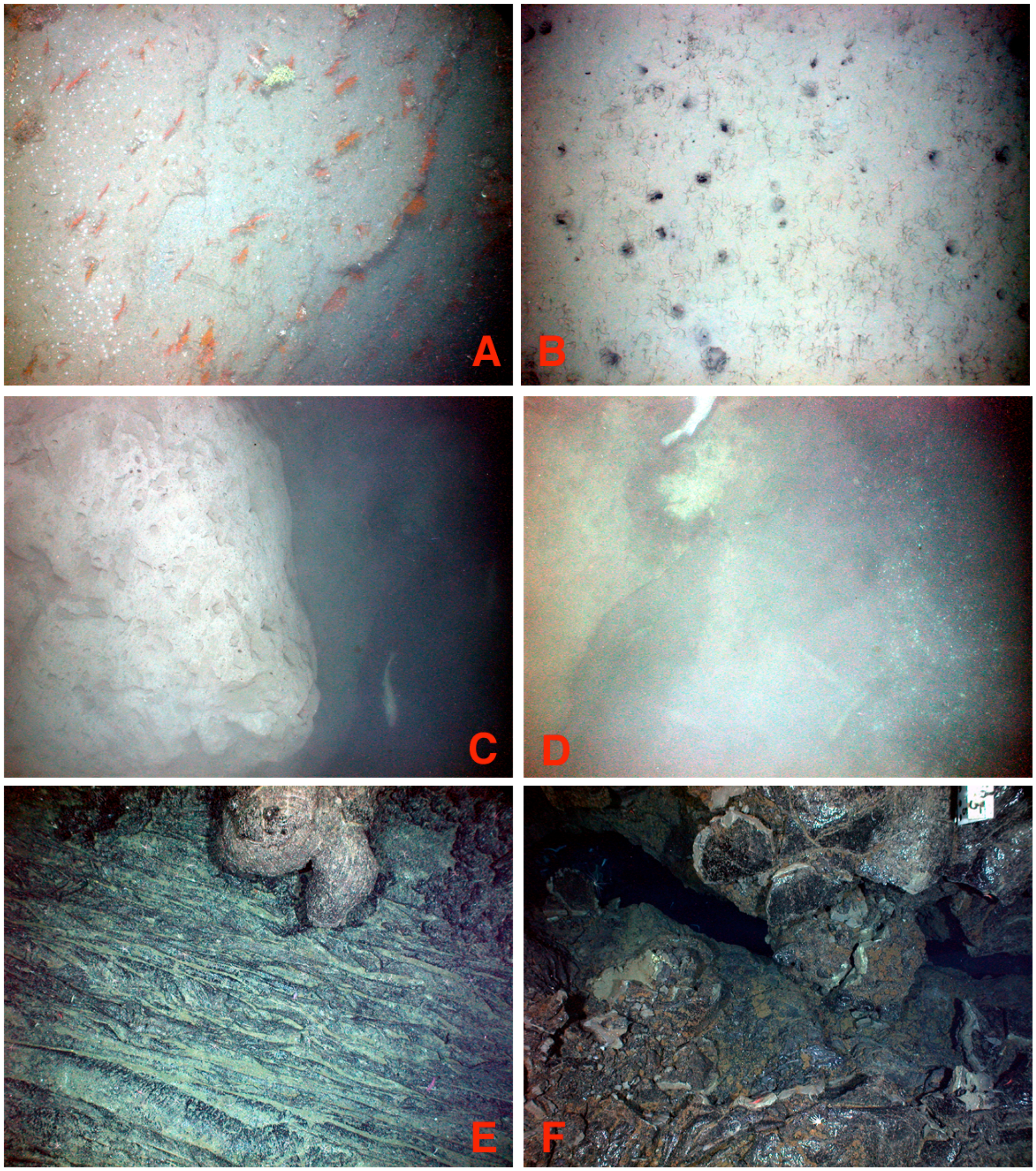

Figure 5. Examples of TowCam photographs taken in different seafloor settings. A) Sediment covered seafloor offshore La Jolla, CA adjacent to the La Jolla Submarine canyon (190 m depth) showing outcropping ledges and orange and yellow soft corals [scale across image is 3 m]. B) Sedimented covered seafloor offshore northern Iceland showing black holes created by probable gas seeps in 170 m depth [scale across image is 3 m]. C) and D) Photographs offshore northern Iceland showing swarming cod fish in areas where gas bubbles are reaching the surface in ~200 m depth [scale across image in photo C is 2 m and in photo D is 3 m]. E) Ropy sheet flow surface on the East Pacific Rise near 9° 50'N at 2550 m depth. Small curl of a lava toe at top of image shows lobate flow that overlies the sheet flow [scale across image is 4 m]. F) Close-up of a small fissure thorough ponded lava within the axial trough of the East Pacific Rise near 9° 50'N at 2510 m depth. Biomarker is at upper right [scale across image is 3 m].

Setup for the camera and downloading procedures, as well as other information on the WHOI Towcam are described in the TowCam users manual available at:

http://www.whoi.edu/marops/support_services/list_equip_towed_camera.html.

The digital images are 2048 x 1536 color, high-resolution JPEG format files, each ~900kbytes in size. Each image is date/time stamped when acquired, but the image file names are in standard Nikon format and must be converted in order for the files to be tagged with date and time as the file name. DOS and Apple Mac OSX scripts have been written and are used for converting the raw Nikon formatted files to date/time named files having the format:

"yyyy_mm_dd_hh_mm_ss.jpg".

In addition, a Perl script has been written to correct image file name times based on correlation to photographs of GMT clock time at the beginning and end of each tow in order to correct for any clock drift over the course of a cruise. In general, the camera clocks keep very good time, to within a few seconds if they are used every day.

2.4.1. DSPL DigiSeacam Specifications

Camera System:

Nikon Coolpix 995

Image sizes (user settable): 2048 X 1536 (FULL), 1600 X 1200 (UXGA), 1280 X 960 (SXGA), 1024 X 768 (XGA), 640 X 480 (VGA) 2048 X 1360 (3:2).

Optical Zoom: 4:1

Lens: Nikkor, f 2.8 – 5.1, 10 elements, 8 – 32 mm.

Viewfinder: NTSC or PAL monitor video available on test video output connector

Storage/ File System: Design rule for Camera File systems, Digital Print-Order Format (DPOF) compliant.

Storage, Compression: JPEG-based-compliant, FINE (normally used for *TowCam*), NORMAL (~1/8), BASIC (~1/16), HI (uncompressed: RGB – TIFF).

Storage, Media: 2 GB CompactFlash Card (Type 2)

Sensitivity: ISO 100 equivalent (selectable:Auto, ISO 100, 200, 400, 800)

Shutter: 8 sec to 1/2000 sec

Normal settings for *TowCam* use in deep ocean and clear bottom water are: 1/60 sec shutter speed and f2.6.

Optics

Port: 80mm diameter, hemispherical, tempered, BK-7 dome port.

Corrective optics: Multi element, pseudo-telecentric corrector, A/R coated.

Field of View:

Vertical: 46°

Horizontal: 74°

SubSea Field of View

The DSPL DigiSeacam has been calibrated in seawater using measured poles with accurate centimeter/meter markings on them. The table below provides the results of image size for three common altitudes.

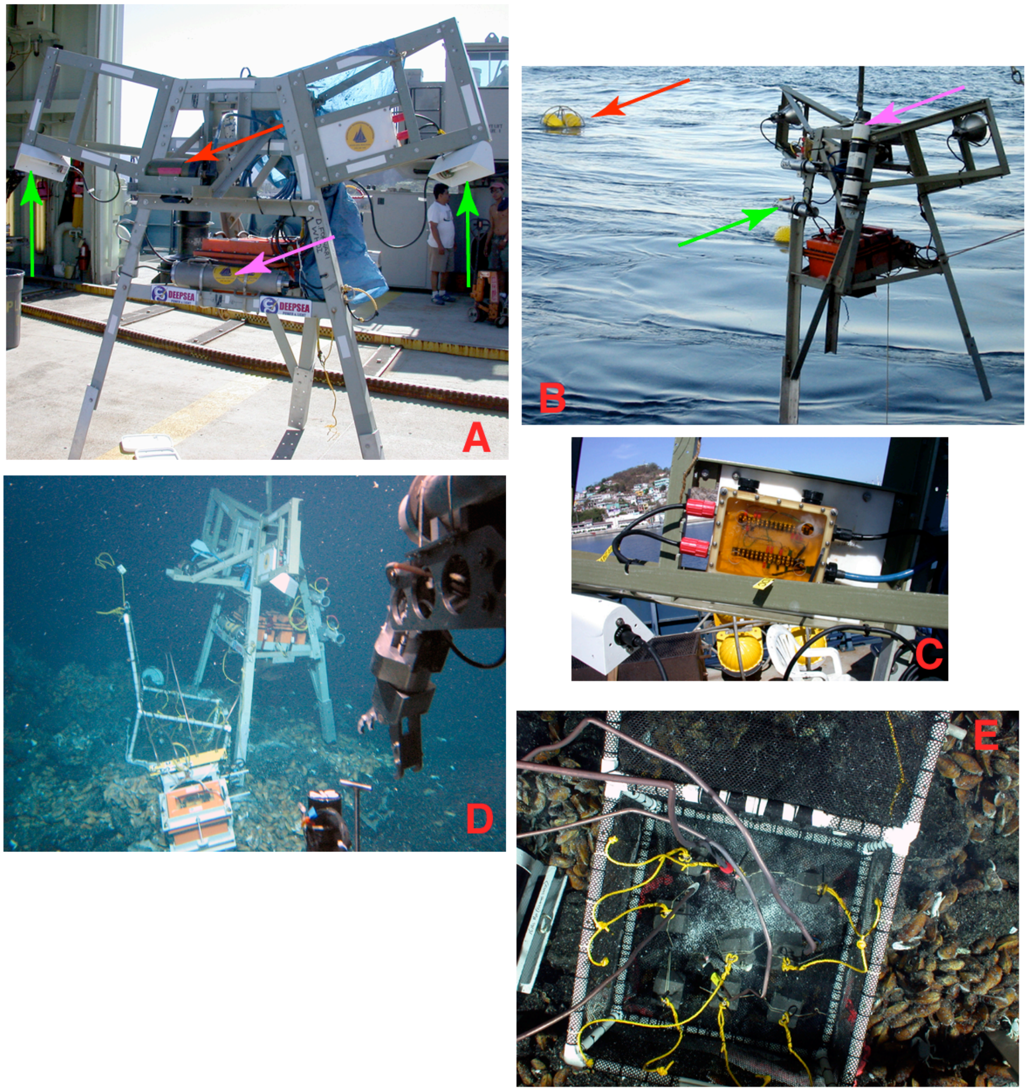

Figure 6. Photographs of the time-lapse camera system developed using the DSPL camera and J-box design used for the WHOI *TowCam*. A) Time-lapse frame on deck of R/V Atlantis showing: strobes (green arrows), strobe electronics pressure housing (purple arrow) and DSPL camera (red arrow). B) Time-lapse system being deployed. Purple arrow points to the relay transponder beacon used to acoustically locate the transponder on the seafloor. Green arrow points to deep sea 'on/off' switches used to turn the strobe and camera power on/off on the bottom. Red arrow points to floatation assembly comprising 6 - 17" glass balls. C) Junction box on the time-lapse system. D) Time lapse system on the seafloor at 2510 m depth taken from *Alvin* (courtesy of T. Shank – WHOI). E) Photograph taken with DSPL camera on time-lapse system showing basalt colonization blocks and sensor tubes for in situ chemical analyzer of G. Luther and D. Nuzzio of U. Delaware (courtesy of T. Shank – WHOI).

Table 1. Field of view in seawater for DSPL DigiSeaCam.

Altitude above Bottom	3 meters	5 meters	7 meters
Field of View in Seawater	3.49mx2.62m	6.06x4.54m	8.03x6.02
Pixels/Meter	586	338	255

<u>*Electrical and Data Downloading*</u>
Power requirement: 10 – 34VDC, 1A max (nominal ~ .1A)
Camera Control Port: EIA, RS-232 Compliant
Camera Data (image upload) Port: USB compliant, downloading of a full 2 GB card usually takes of the order of 40 minutes.
Strobe interface: X-sync
Video output: Slow scan, 15 frames/sec, NTSC or PAL compliant
Control: External switch closures may be used to: START, or STOP time-lapse, as well as snap a single photo.

2.5. Deep Sea Strobes

Illumination for the photographs is provided by a Benthos 383 strobe electronics unit and two flash heads (Figures 1 and 2). Each head provides 300 watt/sec of illumination; total illumination is 600 watt/sec. The DSPL DigiSeacam triggers the flash via an X-synch to ground. Wiring between the camera and strobe system is done in the Power Junction Box (J-box) (Figure 2). Minimum recharge time for the strobe system is 7-8 seconds to ensure full output with each flash, hence minimum photo interval has been set at 10 sec to ensure full illumination for each shot.

2.6. CTD System

The *TowCam* uses a SeaBird SBE25 CTD system as the primary real-time data sensing and control system (Figure 2). One SBE25 CTD, including all standard sensors and altimeter, and a SBE33 deck box were purchased with supplementary funding to the grant. An additional SBE25 CTD is available through the WHOI CTD pool. The CTD provides standard depth, altimetry, temperature, turbidity, and conductivity and data are parsed at 1 Hz using SeaBird software and MATLAB scripts. Data files provided to scientists include 1 Hz records for the entire tow of time, depth, altitude, temperature, turbidity, and conductivity, as well as parsed files of the data at each strobe flash and for each rock core or Niskin water bottle sample. The Command Release Module (CRM) was designed by WHOI engineers in collaboration with SeaBird engineers to provide the functionality of using the standard CTD system to trigger the sampling mechanisms. Samples are triggered either using the buttons on the SBE33 deck box or via the SeaSoft software GUI.

2.7. Rock Coring and Niskin Water Bottle Sampling System

The rock coring winches used on the TowCam were designed by: Terry Hammar, Ken Doherty, Andy Billings and Rod Catanach, (all at WHOI). The winches are unique in that they provide a remote sampling capability while the camera continues to record images. Currently, the corers have been designed to sample volcanic glass, such as commonly found at the axis of the mid-ocean ridge. In the future, it will be possible to design small teardrop sediment corers to sample the upper 10-15 cm of seafloor sediments. A prototype of a sediment corer was tested in the fall of 2003 with good success.

The wax core release and retrieval mechanism operates using a small DC motor with a high ratio gearbox in an oil filled, pressure compensated housing (Figure 2). This motor is directly connected to a small drum and has a ratchet wheel (mounted on its end. When a winch is triggered it activates both the drum and ratchet wheel, causing them to rotate. A mechanism is brought to bear on the ratchet wheel, and, during activation, this mechanism pivots on a shoulder screw, freeing the release link and dropping the wax coated core ball.

The weight of the core ball pulls 10 meters of 100#-test monofilament line out of the storage chamber (Figure 2). Simultaneously the other end of the line is spooled on to the drum attached to the motor. The motor wind-up speed is designed so that it takes approximately (4) minutes to spool up ten meters of line, allowing the core ball to drag on the basalt for about 1.5 - 2.0 min at a nominal speed of ~ 1/2 knot. This time permits the corer ball to bounce on the seafloor over a distance of ~10-30 m, depending on the speed. Once the core ball is fully retrieved it is captured in a plexiglass cylinder housing by the ratchet mechanism so that it cannot spool out inadvertently.