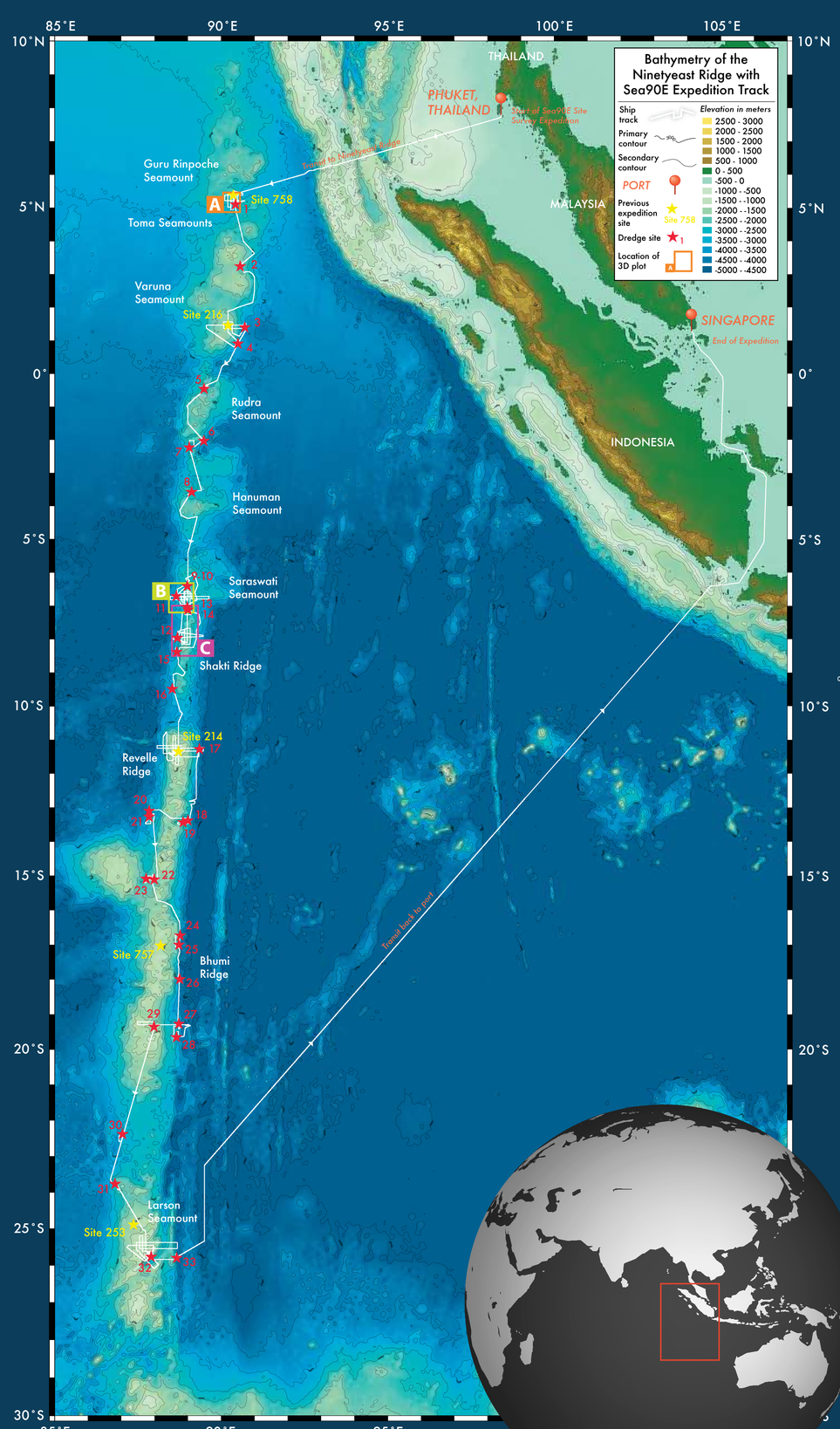
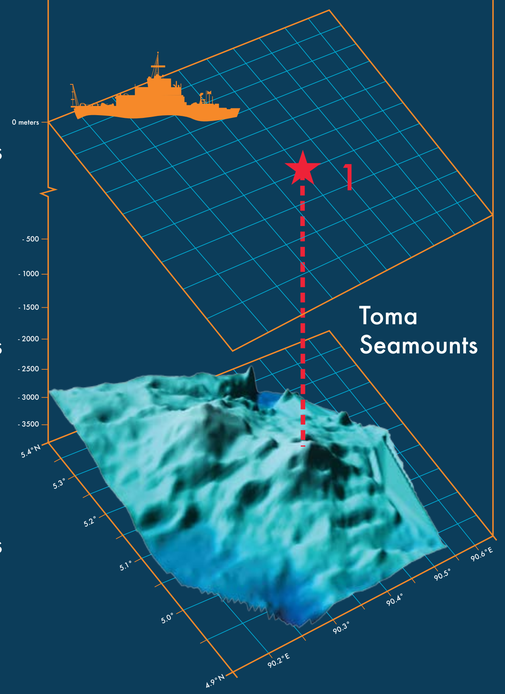


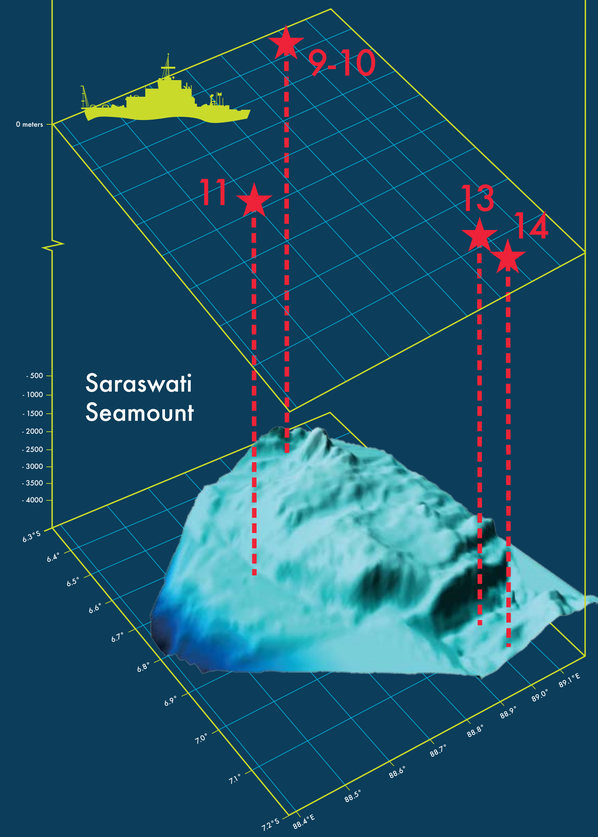
A

The Sea90E Expedition began its survey work and completed its first successful dredge here at Site 1 on the Toma Seamounts. Dredging is a technique used to collect rock samples from the seafloor. The *Revelle*'s dredge can collect over 1000 pounds of rocks at a time! The ship drops the dredge and drags it along the seafloor for as long as two miles. Then scientists bring up the dredge basket, secure it on deck and sort the rocks by type. They weigh, wash and describe each rock – to learn what each can teach us about the geology of the Ninetyeast Ridge.



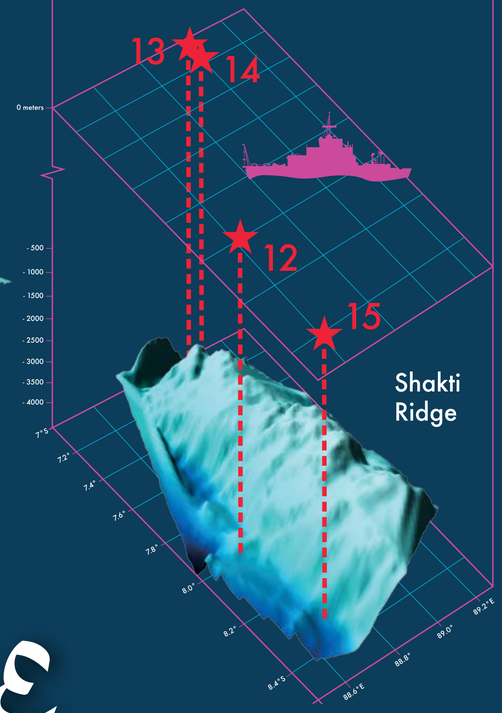
B

The Saraswati Seamount gave the team some surprises! Scientists expected this seamount to have a dome-like shape, much like others along the Ninetyeast Ridge and elsewhere. However, as the 3D plot below shows, this seamount is highly irregular and has several peaks and troughs on its summit!



C

The Ninetyeast Ridge was formed by a stationary hotspot – a place where hot rock from deep within the Earth's mantle rises and breaks through a tectonic plate – so the different parts of the ridge are different ages. These differences reflect the movement of the tectonic plate above the hotspot. As the plate moved northward, the hotspot continued to create seamounts one after the next. The four successful dredges completed at Shakti Ridge provided many more rocks to use for radioactive age-dating. This new age data will give scientists a much greater understanding of the regional tectonic plate movement over time.



SEA90E

It is difficult to imagine that there are still unexplored areas of the Earth. Yet the vast majority of Earth's deep oceans remain to be truly discovered. An oceanographic site survey is an expedition to "see what's there" and pave the way for future research expeditions to an area. Sea90E was such a survey, on board the research ship *Roger Revelle*. It explored the Ninetyeast Ridge in the Indian Ocean and investigated a large number of seamounts (underwater mountains) that had never before been mapped in detail.

The images shown here are the results of this survey. For more information about Sea90E, visit http://www.oceanleadership.org/sea90e.

a site survey expedition to the Indian Ocean

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Sea90E
Anatomy of a Seamount Survey

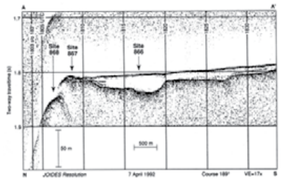
A site survey is an expedition to "see what's there" and pave the way for future potential research expeditions to an area. Sea90E was a site survey of the Ninetyeast Ridge in the Indian Ocean done on board the research ship *Roger Revelle*. It took place June 18 – August 6, 2007 and included investigations of a large number of seamounts (underwater mountains) that had never before been mapped in detail.

The R/V Roger Revelle on the dock in Phuket, Thailand.

To do a survey like this, researchers rely on a number of really cool technology tools. Oceanographers use sound waves of different frequencies to probe at different depths and resolutions. They use high frequency sound waves to get a high-resolution picture of the near surface. The short wavelengths of high frequency sounds give a lot of detail, but they quickly die out with distance. Low frequency sound waves are used to study deeper surface. They are also called seismics because they literally make the ground shake. They do not give high resolution, but last longer and penetrate deeper.

Onboard the *Revelle*, the team used a **chirp echosounder** that emits a sound pulse about once per second. In between pulses it listens for the waves returning from the ocean bottom. These sound waves bounce off the seafloor if it is made of hard sediment or penetrate about 50 meters into it if the seafloor is covered with soft sediments. This technique is called acoustic profiling because, as the ship moves along, sequential pulses are sent out and the return echoes are plotted vertically to make a picture that looks like a profile of the ocean bottom. **Acoustic profiling** works because the medium in which the sound waves travel is not uniform. When a sound wave hits a place where density changes (like the ocean floor), part of the sound passes through and part bounces back.

To do low frequency profiling, Sea90E scientists used air gun seismic sources. Each air gun is a high-pressure air chamber. It is pumped with high pressure air from compressors. Once every 10 seconds, a trigger allows air to escape. The explosive release of air causes a "pop." The team used a device called a **hydrophone array** – a plastic tube about 800 meters long filled with cables and microphone-like devices to "listen" and record the sound waves bouncing back from the seafloor and below.



Bathymetry profile from a 3.5 khz echosounder

With the help of complex computer programs, the team then used this data to create highly detailed maps of the areas they explored. They also used dredges to bring up samples of rocks from the ocean floor. Together, these two kinds of information gave scientists a much clearer picture of the seafloor along the Ninetyeast Ridge.

A cool discovery of Sea90E

The Saraswati Seamount gave the team some surprises. Scientists expected this seamount to have a dome-like shape, much like others along Ninetyeast Ridge and elsewhere. As the multibeam bathymetry map on the front shows, that is not the case at all; this seamount is highly irregular and has several peaks and troughs on its summit.

Many of the high and low points and escarpments all have trends that are nearly west-east. What does that mean? The seismic data show that the volcanic basement beneath the sediment is broken and faulted. The faults show up most on north-south lines, meaning these faults are oriented more-or-less east - west.

These discoveries indicate that the Saraswati Seamount has been chopped up by faulting. The fact that the faults are not all parallel suggests that maybe there was more than one faulting episode. The science team thinks that some of the faulting may have been original, i.e., the faults were formed at the time the seamount formed because this bit of the Ninetyeast Ridge may have been very close to the west-east spreading ridge that created the Indian and Antarctic plates 50 or 60 million years ago.

Some of the faults, however, may be more recent. Several scientists (including S. Krishna and D. Gopala Rao, who were on board this expedition) have noted that the Indian plate has been breaking up for the past 7 million years and that its faults extend right up to Ninetyeast Ridge. It looks like these faults may cut into and through the ridge here.

To get the story straight, the team will have to do some more analysis of their evidence, but this was a good start. You never know what you are going to find when you start out on a survey expedition!

Credits

Writing: Rory Wilson, Will Sager and members of the Sea90E team

Editing: Sharon Katz Cooper, Leslie Peart, and Lynne Pacunas

Design: Matt Niemitz

Scientific Review: Will Sager, Chris Paul, Fred Frey, Malcolm Pringle, Evelyn Mervine, and Masako Tominaga

All images courtesy of Rory Wilson and the Sea90E team. Special thanks to Chris Paul, Texas A&M University, for creating the bathymetric track and 3D plots.

For more information on the Sea90E expedition, see www.oceanleadership.org/sea90e.

To order copies of this poster and for related background information, classroom activities, professional development opportunities for teachers, and career profiles, please visit: www.deepearthacademy.org.

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Sea90E Profiles:
Who does it take to run a site survey expedition?

Dr. Will Sager

Dr. Sager is a **professor** at Texas A & M University teaching and doing research in oceanography, specifically marine geology and geophysics. His job is to figure out how the ocean floor formed and evolved. He does this using data collected from ships.

It turns out that scientists know less about the ocean bottom than they do about the Moon because the sea floor is hidden by ocean water. Dr. Sager has always been fascinated by the process of exploring the ocean bottom. On the Sea90E cruise, for example, he was able to visit and map places that no one had thoroughly mapped before - and his team even had the opportunity to name some of those places!

As the primary scientific investigator for the Sea90E expedition, **Dr. Sager's responsibilities** were quite broad. The planning for this expedition began a few years ago, and many tasks were involved. He looked at the amount of time he would need for the research, the costs, who needed to be involved and how the team wanted to communicate its work. He wanted students involved at all levels in this expedition. The Teacher at Sea position and the web site (www.oceanleadership.org/sea90e) were developed because he wanted young people to experience research at sea. The team also had several undergraduate and graduate students working side by side with experienced scientists.

Dr. Fred Frey

Dr. Frey is a **geochemist** and holds a BS in Chemical Engineering and a PhD in Chemistry. While doing graduate research in chemistry he developed methods for measuring the abundance of rare earth elements in rocks from land. He found that abundances of these elements differ in terrestrial rocks of different types – and this result was a surprise because these elements are quite chemically similar. He then applied this discovery to understanding geologic processes. As a result, his career evolved toward geology and a focus on using the chemical composition of igneous rocks to understand processes that form volcanoes.

As one of the primary scientific investigators for Sea90E, **Dr. Frey's responsibilities** included working carefully to establish research goals and then doing everything possible to fulfill these goals. His planning began several years ago and was based in part on a drilling expedition to the Ninetyeast Ridge on which he also participated.

Malcolm Pringle

Dr. Pringle is a **geochronologist** – a scientist who figures out the age of rocks. He has a keen interest in opening the world of inquiry-based science to budding explorers of all ages.

As one of the primary scientific investigators for this expedition, **Dr. Pringle's responsibilities** included working carefully to establish research goals and using the team's time at sea most efficiently to collect the information needed to fulfill these goals.

He likes to tell students that to become a well-rounded earth scientist today, you should explore chemistry, physics, biology, astronomy, geology and math. And that going into marine science will give you the chance to work with scientists from all over the world and to travel extensively. The earth and sea are your laboratory!

Masako Tominaga

Ms. Tominaga is a **PhD candidate** who has worked with Dr. Sager for the past five years. She was born and grew up in Japan, and came to the U.S. when she was 23. **Her role** was co-chief for the geophysics science team. In that capacity, she worked with Dr. Sager so that the team had 24-hour coverage for the scientific survey of the Ninetyeast Ridge She made sure that the team kept detailed logs for all the instrumentation and did some immediate bathymetric maps so they could identify new features and locate dredge sites. She organized teams to work on deck at all times of the day and night.

Evelyn Mervine

Ms. Mervine grew up in rural New Hampshire and had a long interest in geology. She had a rock collection as long as she can remember. In 2006, she graduated from Dartmouth College with a double major in earth science and Arabic language and literature, and is now a **PhD student** in marine geology in the joint program of Woods Hole and the Massachusetts Institute of Technology (MIT). For her graduate work, she studies the petrology and geochemistry of volcanic rocks and gases. She analyzes major elements, trace elements, and isotopes. She also uses isotopic decay to determine the ages of volcanic rocks.

As a **petrologist** on the Sea90E expedition, **her responsibilities** included helping to order and ship all the materials that the team needed at sea and planning what they would do with rock samples they collected. On the ship, she played the lead role in rock collecting and helped set up procedures for the petrology team.

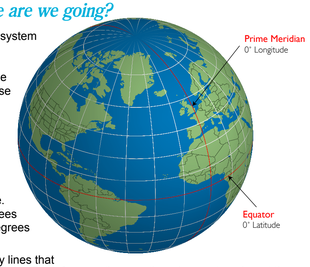
Rory Wilson

Rory Wilson was the Deep Earth Academy-sponsored Teacher at Sea on board the Revelle for the Sea90E Expedition. He teaches middle school math in Meeker, Colorado. His job on board the expedition was to find ways to share the work of the researchers and crew with students back on land. He worked with the scientists and crew on board to develop the interactive website for Sea90E and communicate regularly with students around the world about the exciting science and discoveries of this expedition.

Sea90E
Science Challenges

A research expedition presents many challenges. Questions of all kinds come up along the way. Some of them have to do with living, working and navigating on a ship, others with the science questions the expedition is attempting to answer. To get a taste of these challenges, try the activities below. For an answer guide, visit www.oceanleadership.org/sea90e/education.

Challenge 1: Where are we going?



Latitude and longitude are a system of imaginary lines crossing the Earth. Latitude lines are concentric circles that hug the Earth around its middle. These lines are called parallels because they are all parallel to each other. Around the center of the Earth is the Equator, which divides the Earth into the Northern and Southern hemispheres. Its address is 0 degrees latitude. The North Pole is at 90 degrees N; the South Pole is at 90 degrees S.

Longitude lines are imaginary lines that run up and down (think "long") the Earth from north to south and come together at the Poles (e.g., they are not parallel to each other). They are called meridians. The prime meridian is 0 degrees longitude and runs through Greenwich, England. From there, the meridians go up to 180 degrees East towards Asia and 180 degrees West towards North America. The lines of longitude meet in the Pacific Ocean, called the International Date Line. By knowing coordinates of longitude and latitude, you can find any place on Earth!

Degrees latitude and longitude are further divided into minutes of latitude or longitude, which are 1/60th of a degree. In other words, one degree = 60 minutes.

Your challenge:

The Sea90E expedition set out from Phuket, Thailand, at 7 degrees and 49 minutes North latitude, and 98 degrees and 24 minutes East longitude. Find that location on the map on the front of this poster. The ship sailed to 5 degrees, 24 minutes North latitude, and 90 degrees and 18 minutes East longitude to begin its work. Find that location on the map.

The ship traveled at about 10 knots, which is 10 nautical miles per hour. One minute of latitude or 1 minute of longitude near the equator is exactly 1 nautical mile. So at 10 knots, the ship covers 10 minutes of longitude every hour. In other words, 1 hour of travel = 10 minutes of longitude.

How long should it take the ship to reach its destination?

(Hint: There is more than one way to figure out an answer to this question.)

Challenge #3: Where to Dredge?

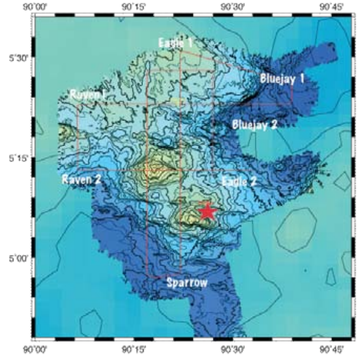
The research ship Revelle used a technique called dredging to collect rock samples from seafloor sites along the Ninetyeast Ridge. The dredge onboard Revelle is called a basket dredge because it is essentially a large "basket" consisting of a net of metal chains suspended from a metal frame. The dredge is large enough to collect over 454 kg (1000 pounds) of rock!

To collect samples, technicians suspend the dredge from a strong metal cable over a pulley and out into the water. The weight of the empty dredge is over 181 kg (400 pounds). The technicians then attach a "pinger" to communicate back to ship, and a winch operator lets out enough cable to lower the dredge 200m (656 ft) from the seafloor. Control of the winch is then handed over to a Resident Technician in the computer lab, who lets the cable out via remote control until the dredge reaches the seafloor. The captain drives the ship slowly to drag the dredge along the seafloor as it gathers rocks into the basket.

When the team brings the dredge basket back on deck, researchers take the rocks out and sort them by rock type. Scientists and technicians weigh, wash, and describe those rocks, and even cut some of them in half to see what they look like on the inside.

When looking for an interesting dredge site, the science team looks for a few important characteristics in the seafloor:

1. They look for a smooth upslope along a seamount that may have been a volcanic site.
2. If the location is very steep, it is sometimes easier to pull the dredge up the slope to "scoop up" the rocks.
3. Most of the time, they try to avoid spikes or cliff locations since it is difficult to keep the cable from becoming snagged or tangled.



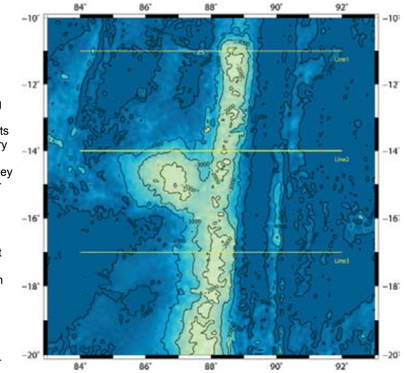
4. They also tend to avoid smooth bottom surfaces, since there is usually more sediment there than volcanic rock.

Your challenge:

Look at the map to the left. Each of the named sites is a possible dredge location for the expedition (the red star indicates where the ship was when this map was made). If you were the Resident Technician, where would you dredge? Why there? What site might you choose to skip? Write a short paragraph explaining your choices.

Challenge #2: Bathymetry

An important goal of a site survey cruise is gathering information for creating bathymetry maps. What is bathymetry? It is a word that comes from two Greek words, "bathy," meaning deep, and "metry," meaning measure. So bathymetry means taking measurements of water's depth. Bathymetry maps are like topographic maps of the ocean floor. They tell you how deep the water is at any particular location.



Your challenge:

Look at the chart to the right. This is an actual chart of a part of the Ninetyeast Ridge. Like contour lines on a topographic map, each squiggly line represents the same depth of water along that line. As the color becomes darker, the water becomes deeper. For example, the very dark blue areas are all over 5000 meters (16,404 feet) deep. There are three straight lines on the chart: Line 1, Line 2, and Line 3. Each of these lines is a path that the ship took across the ridge as it conducted its survey.

1. Look at the data set below and see if you can determine which line the data represents. Each depth is for a longitude, shown at the top and bottom of the chart.

Degrees Longitude	Depth (meters below sea level)	Feet (below sea level)	Circle your answer:
84	-4403	-14,446	
85	-4860	-15,945	Line 1
86	-3905	-12,812	
87	-2837	-9,308	
88	-3159	-10,364	Line 2
89	-4202	-13,786	
90	-4500	-14,764	
91	-5559	-18,238	Line 3
92	-5309	-17,418	

2. Create a data chart like this for each of the other two lines. You can use round (approximate) numbers.
3. Using the two data sets you created, create one line graph. When you are done, these graphs will give you a cross-section view of the underwater mountains!

Challenge #4: Rock On!

The research vessel Revelle's dredges brought up a lot of rocks! Why do we care about chunks of rock from the ocean floor? Because they can tell us a lot about what the ocean floor looks like, how it was formed, and how old it is. This information will help scientists decide if they want to do further research at this site.

Rock scientists, called petrologists, sort the rocks into groups to get a sense of how many of each kind there are at any particular location. This can give them important information about the geology of the site.

Your challenge:

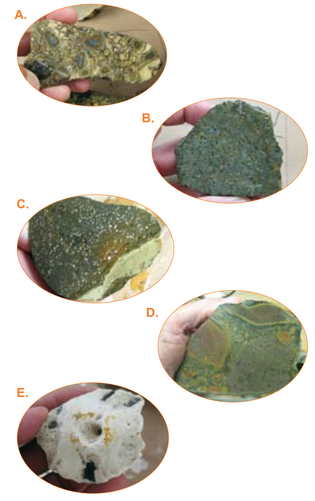
Match each Sea90E-collected rock below with one of the descriptions on the left. Then look at the rock photos on the front of this poster. Which can you identify?

Basalt

A common gray or black, fine-grained volcanic rock formed by cooling of hot lava and rich in iron, magnesium and calcium. Ocean crust is composed primarily of this rock, which was formed by upwelling of magma from the Earth's mantle at the ridges between tectonic plates. This is also the rock most useful for the science team, since they can use it to estimate the ages for areas along the ridge.

Breccias

Rocks made up of jagged fragments of rocks or minerals held together in a mineral matrix, a kind of natural cement. There are many different kinds of this rock.

Carbonates

These sedimentary rocks are commonly composed of the minerals calcite (CaCO3) and dolomite (CaMg(CO3)2). These rocks are usually softer than basalts and tend to form in layers.