Electrical Impedance Tomography of a Seafloor Volcano
R.V. Revelle shiptime proposal submitted by David Myer, Steven Constable, and Kerry Key

Abstract.

We propose to use R.V. Roger Revelle student shiptime available in May 2006 to carry out a completely novel study of an active seafloor volcano (Loihi Seamount). Electrical Resistance Tomography (or ERT), also known as electrical impedance tomography, is a medical technique used to image the human body, but is also used in geophysics to study the porosity of core samples in the laboratory, and map groundwater in borehole-to-borehole experiments. Here we propose to carry out a 3D ERT study of an active volcano, by deploying 20 or more seafloor electromagnetic recorders around the perimeter of Loihi seamount and towing an EM transmitter around the same path. Both receivers and transmitter will be at a depth of 1500 m, or 500 m below the summit of the volcano. The intersecting geometries of approximately 140 transmitter locations broadcasting to 20 receiver locations will allow us to build an electrical conductivity image of a horizontal slice through the volcano at a depth of 500–1000 m below seafloor. Since electrical conductivity is closely linked to the presence of fluids, both magmatic and hydrothermal, we will effectively be peering into the plumbing of the volcano. This experiment will exploit equipment (receivers and transmitters) developed over the last 10 years at SIO using petroleum industry funding. The data and analysis will form the thesis of a first-year graduate student, David Myer, and the cruise will provide an opportunity for many other students and postdocs to see marine electromagnetism (a rapidly emerging technique for hydrocarbon exploration as well as academic studies) in action.

Introduction.

Scheduling issues have provided an opportunity for SIO to fund a 6-day student cruise on the R.V. Roger Revelle out of Hawaii. We propose to use this ship time, along with equipment and expertise already available at SIO, to carry out a new and exciting project: the imaging of a volcanic magma system using electrical tomography. Electrical resistance, or impedance, tomography is used extensively in medicine to image the human body. It is used (less frequently) in geophysics to image rock samples in the laboratory or to study groundwater systems between two or more boreholes. Figure 1 shows the basic concepts.

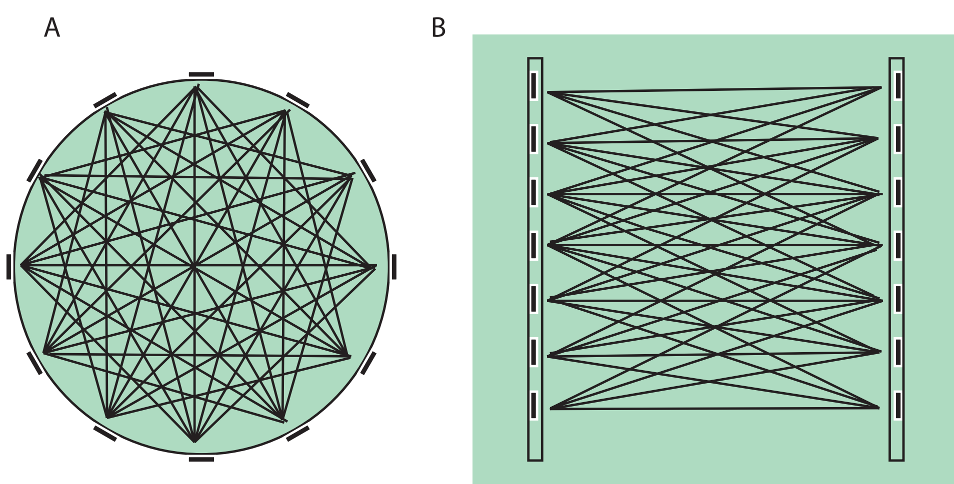

Figure 1: The basic concept behind electrical tomography is to measure the electrical impedance between every combination of electrodes surrounding a cylindrical core of rock (A) or between two boreholes (B) and to use the intersecting geometries of the paths of maximum current density to build an image of the electrical conductivity of the material. In practice for geophysical applications, pairs of electrode would be used for transmitting and receiving in order to avoid the effects of contact impedance associated with individual electrodes.

Multiple electrodes produce many different geometries of electrical current flow in the sample, from which a 2D or 3D image of the material can be constructed. In practice the point-to-point impedance paths would be replaced by a more complicated pair-to-pair pattern in order to eliminate the effects of electrode contact impedance.

The Revelle shiptime, along with an extensive and well-tested equipment pool at SIO, provides an opportunity to extend the laboratory and borehole experiments to the scale of an entire volcano. This has been attempted once on land (‘Structure of the Soufriere of Guadeloupe by Electrical Tomography: Preliminary Results’, F. Nicollin, D. Gibert, F. Beauducel, unpublished abstract presented at the Joint Earth Sciences Meeting Société Géologique de France - Geologische Vereinigung, September 2004), but using DC resistivity at a smaller scale (100’s of meters). Here we will use the marine controlled source electromagnetic (CSEM) method, a technique developed at SIO and now well established in the hydrocarbon exploration business, to extend the scale to the 5–10 km diameter of the Loihi summit (Figure 3). In Figure 2 we present first data from an experiment carried out on the East Pacific Rise, showing apparent resistivities from 22 seafloor receivers and a 12-hour transmitter tow across the axis of the ridge. We obtained good quality data to a range of 20 km, which is more than enough to illuminate the axial magma chamber. A great deal of work remains to be done on this data set, but it illustrates the scale of the experiment that we could do on Loihi. Because we will be transmitting signals though the seamount, the resolution of the proposed experiment will be greater than seafloor-to-seafloor transmission used on the EPR.

Equipment and Capability.

As a consequence of 10 years work with the petroleum industry, SIO now has a state-of-the-art equipment pool of 45 seafloor EM recorders and 2 deeptowed transmitters (Figure 4). This equipment, valued at several M$, is well developed and well tested. We can collect a large amount of high quality data in a very short period of time, illustrated by our August 2004 experiment on Hydrate Ridge to study seafloor gas hydrates. In this opportunistic use of the New Horizon during a transit to Oregon, we deployed 25 seafloor receivers, towed our transmitter along the receiver line twice and also off-line, and recovered the receivers (and 25 high-quality data sets) all in 3.5 days on station. The resulting data was extensive enough to form the backbone of Karen Weitemeyer’s thesis, and a preliminary interpretation is in press in Geophysical Research Letters.

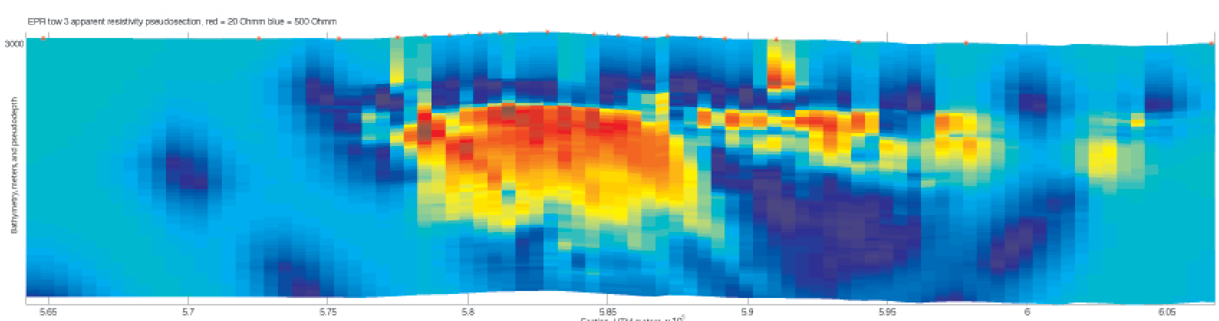

Figure 2: Preliminary apparent resistivity pseudo-section plot of the data collected over the axial magma chamber at 9 degrees north on the East Pacific Rise. Red is conductive and blue is resistive. Red dots are receiver locations.

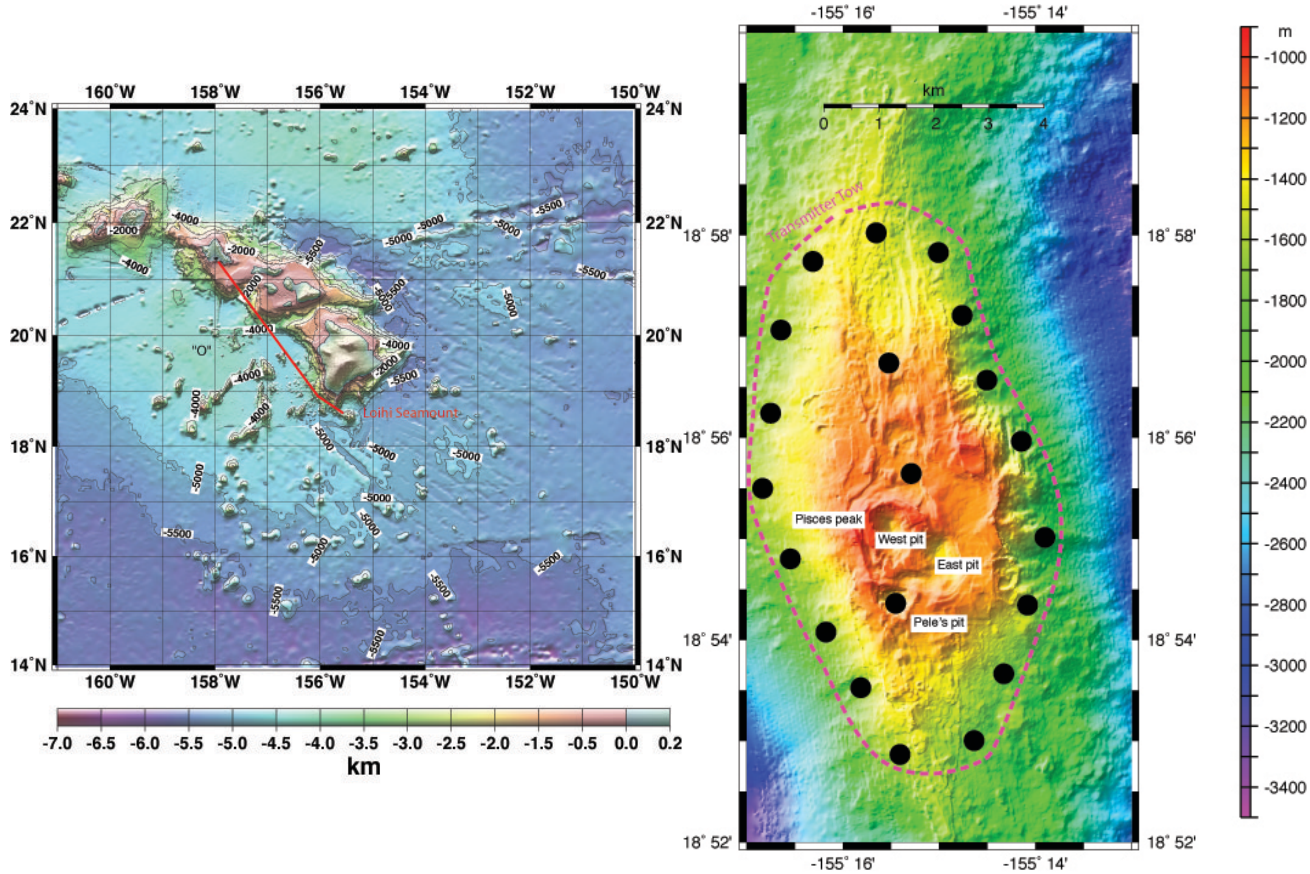

Figure 3: Left: Location of Loihi Seamount, the current focus of the Hawaiian hotspot, in relation to the Sand Island facility on Oahu, Hawaii. The transit (shown in red) is approximately 200 nm, or about 18 hours. Right: Layout of proposed experiment. Black dots represent receiver locations, and the red line the transmitter tow.

Logistics and proposed experiment.

We will send 20 receiver instruments, 20 anchors, and the transmitter system to Honolulu by 20' shipping container. For such a short deployment rechargeable batteries are adequate. We have used the Revelle for the EPR work described above, so loading should go smoothly – our receiver operation is very well honed, and on a recent cruise we were off the ship within 2 hours of docking. The only complication to the logistics is the deep-tow cable for the transmitter. At the moment, we use telemetry on a coaxial 0.680" cable. The default cable on the Revelle is a 0.680" fiber and electrical cable, which we cannot currently use. There are two solutions to getting a coaxial tow cable on the Revelle; swap out the deeptow cable (time consuming, somewhat expensive, and exposes the fiber to handling) or install the MPL Flip winch, which currently has 4 km of coax owned by a company that will certainly give us permission to use it. This would still involve the cost of shipping and time for installation, but lower than for swapping cable. (Since we intend to fly the deeptow at a constant depth, we can live with the slow speed of this winch.)

We do have plans to include a fiber optic telemetry capability for our transmitter (for exactly this reason – our gear is being designed for flexibility and ship-of-opportunity applications). Our only concern with this approach is that it may be difficult to get enough testing done before May to ensure rapid installation and reliable operation. However, we are prepared to explore this option, and we could insure against any hiccups on the cruise by providing an option to log the transmitter parameters internally and fly the transmitter without telemetry using acoustic navigation from the ship.

Figure 3 shows the work area in relation to Honolulu and the layout of the experiment. The table below shows that we have time to carry out this ambitious experiment with a few hours contingency for additional transmitter tow or instrument recovery.

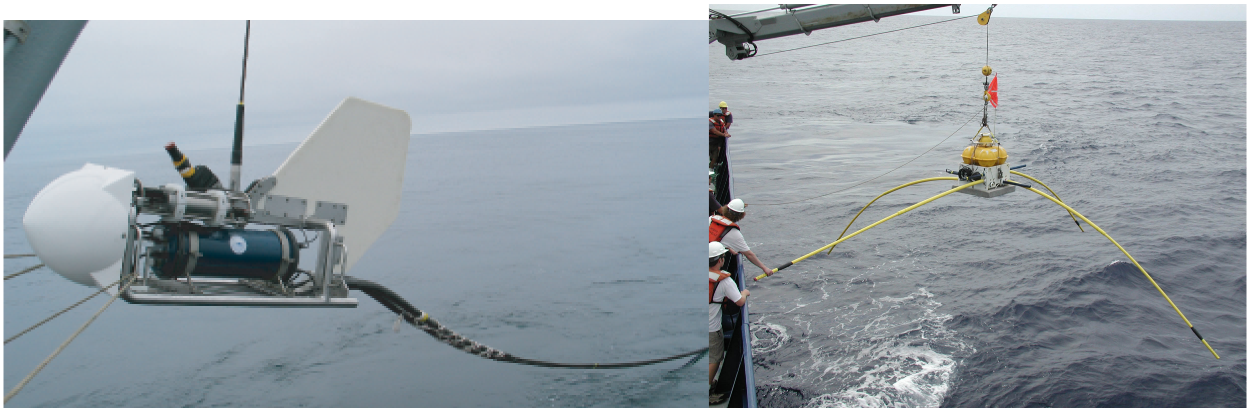

Figure 4: Left: SUESI-200, the second-generation EM transmitter being deployed. This unit has a 200 A output (a 500 A version is now available). Right: A receiver instrument being deployed. A total of 45 such receivers are currently available.

Start time	**Activity**	**Elapsed time**
12:00 May 25	Start loading equipment	28 hours
16:00 May 26	Depart Sand Island	1 hour
17:00 May 26	200 mile transit to station at 12 kts	17 hours
10:00 May 27	Deploy 20 instruments @1 hour each	20 hours
06:00 May 28	Deploy transmitter	3 hours
09:00 May 28	25 km transmitter tow	14 hours
23:00 May 28	Recover transmitter	3 hours
02:00 May 29	Recover 20 instruments @1 hour each	20 hours
22:00 May 29	Transit to Oahu	17 hours
15:00 May 29	Tie up	1 hour
16:00 May 30	End	
	Contingency	12 hours

The receiver locations are spaced sufficiently close that time between deployments is limited by the preparation time of the instruments, which is an hour or less, and that recoveries can be carried out by releasing instruments at one-hour intervals (the release and rise time in 1500 m water is about 1.5 hours, but we routinely work with two instruments in the water column in these days of GPS navigation). We will have plenty of manpower to carry out 24-hour operations; the lab has a core group of 3 receiver technicians and an engineer working on the deeptow development, the PI will be joined by 2 or 3 postdocs and 4 students. Hubert Staudigel and another student (Lynn Oschman) will join the project to lend volcanology expertise, and we will throw the opportunity open to any other postdocs and students that would like to see modern marine EM in action.

In an add-on experiment, we propose to work with Jeff Gee to tow a magnetic gradiometer behind the deeptow. Jeff is interested in the magnetic signatures of seafloor basalts, and if we can make this technology work it will also have applications in oilfield exploration. The CSEM receivers will also collect magnetotelluric data, which will be processed to provide a deeper (but lower resolution) image of conductivity within the volcano.

Should the proposal be supported, David Myer will run 3D forward model studies using a finite-difference code, in order to choose the optimum frequencies for this experiment. This same code can be used to supplement the pseudo-imaging shown in Figure 2 with a more rigorous interpretation, and we expect to have full 3D inversion capability well before David will be finishing his thesis.

Non-shiptime costs.

The lab will cover the salaries of the students and technicians involved. Deployment supplies are about $300 per instrument, but we may be able to cover this from industry related funding. The large cost (apart from the vessel) will be shipping the equipment (and possibly winch) and air travel for the participants, which may amount to 14 or more people.

Student involvement and broader context.

The data set from this cruise will form the thesis of David Myer, a first-year graduate student (but who passed his departmental exam a year early). David professed an interest in working on marine EM applied to tectonic problems, and was hoping to work on NSF projects we had pending to carry out marine magnetotelluric (MT) work over the Hawaiian Plume, and an MT study of South Pacific gravity rolls, but both these proposals were turned down (times are tough at NSF). It is true that the marine EM group is well funded, demonstrated by the equipment and personnel we can bring to this project, but most of our current funding is for applied industry work. We are still building the reputation for marine EM as a solution to tectonic problems, and a novel experiment such as the one proposed, while difficult to fund through the usual channels, will undoubtedly help in getting future NSF funding. In particular, it may help re-submissions of the Hawaiian plume MT proposal, and we may be able to get funding to do repeat surveys of Loihi to look for changes in magmatic architecture over time (time-lapse electrical tomography of a volcano), and/or to study deeper levels of the volcano (the limited shiptime constrains us to the shallower depths for the proposed project).

In conclusion, we believe we can use the available shiptime to carry out a world-class experiment and generate enough data to occupy David Myer for most, if not all, his Ph.D. studies.